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"Exploring the Institutionalization of Nanotechnology in Germany and the U.S."

How Structures, Culture, and Self-understandings Impede the Rise of an Academic Community and a Profession in Nanotechnology

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List of Abbreviations

ACS	American Chemical Society
APS	American Physical Society
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
CeNTech	Center for Nanotechnology
CFN	DFG Center for Functional Nanostructures
CINSaT	Center for Interdisciplinary Nanostructure Science and Technology
CME	Coordinated Market Economy
CMU	Carnegie Mellon University
DECHEMA	Gesellschaft für Chemische Technik und Biotechnologie (Society for Chemical Engineering and Biotechnology)
DFG	Deutsche Forschungsgemeinschaft (German Research Association)
DPG	Deutsche Physikalische Gesellschaft (German Physical Society)
e.g.	for example
etc.	et cetera
ENNaB	Excellence Network NanoBioTechnology
GDCH	Gesellschaft Deutscher Chemiker (German Chemical Society)
GTRI	Georgia Tech Research Institute
IEEE	Institute of Electrical and Electronics Engineers
LME	Liberal Market Economy
MRS	Materials Research Society
MIT	Massachusetts Institute of Technology
Nano-S&T	Nano-science and -technology
n/a	not available
NIH	National Institutes of Health
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NNUN	National Nanofabrication Users Network
NSF	National Science Foundation
ORU	Organized Research Units
PI	Principal Investigator
PSU	Penn State University
R&D	Research and Development
SCI	Science Citation Index
SPIE	Society of Photographic Instrumentation Engineers (International Society for Optics and Photonics)
STM	Scanning Tunneling Microscope
USPTO	U.S. Patent and Trademark Office
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
VoC	Varieties of Capitalism

1. Introduction[1]

While nanotechnology itself is not new, the field of nanotechnology is new and its constitution needs to be explored. Its institutionalization and visibility in research, politics, and society has been increasing over the last two decades (Roco, 2001a). The growth of this field asks for a genuine analysis of the characteristics of the nanotechnology field. Germany and the United States are used as two relevant and comparable examples because they have been leading nanotechnology in terms of patents and start-up companies (Roco, 2005, p. 711), each with different institutional contexts (Hall & Soskice, 2001a; Streeck & Thelen, 2001). The academic sector has been omitted in previous analyses of the nanotechnology field. Therefore, this study focuses on nanotechnology as an organizational field and its characteristics concentrating on the academic sector, which has not been done before to the knowledge of the author. Organizations are institutions which include both "structure and culture," (Djelic, 2010, p. 29) i.e., not only formal and informal rules but also norms and beliefs that guide social actions (for an overview see Djelic, 2010, p. 26). From a sociological neoinstitutionalism perspective, institutions, such as higher education, "diffuse the organizational world" (Djelic, 2010, p. 25) and represent rational "powerful myths," whereby structures are decoupled from activities (J. W. Meyer & Rowan, 1977, p. 340). In this study, structural and cultural elements are investigated with a focus on rules, as well as beliefs, that guide the central actors of the analysis, university nanoresearchers.

Using Germany and the United States as examples, this study addresses differences and, not to be ignored, similarities between the two countries to explore the development of the nanotechnology field. Germany and the U.S. are leading both in patents and start-up companies (Roco, 2005, p. 711), while the focus here is on government funding. In 2007, the gross domestic expenditure on research and development (R&D) by the U.S. government was 29.3% while the German government spent 28.4%. However, the German government performed slightly more of the research at 13.8% versus 11.1% in the case of the U.S. government showing that the German government has more involvement in the public sector of R&D. (OECD, 2008) Both countries highly invest in nanotechnology: The German Federal Ministry of Education and Research invested 4.3% of its budget in nanotechnology in 2009 (VDI Technologiezentrum e.V., 2009, p. 78); the U.S. government through the National Nanotechnology Initiative 1.2% (Agencies' Submission to Office of Management and Budget, 2008; National Nanotechnology Coordination Office, 2010). Naturally, the overall sum of investments in nanotechnology is larger for the U.S. but it shows that German government has a strong emphasis on nanotechnology.

While both the U.S. and Germany are investing heavily in nanotechnology, similarities and differences are to be expected due to the different dynamics of innovation and (institutional) contexts between the two countries. Various, theory-based, reasons speak to this assumption, including the institutional advantages of a liberal market economy (LME), such as that of the U.S., as elaborated in the Varieties-of-Capitalism (VoC) approach (Hall & Soskice, 2001b; Hancké, Rhodes, & Thatcher, 2007). The VoC approach categorizes political economies by their regulatory regimes. The approach uses two types of countries: coordinated and liberal market economies (Hancké et al., 2007, p. 5). Coordinated market economies (CMEs) have a corporatist state which focuses on collaboration and long-term employment strategies (Hancké et al., 2007, p. 5). The dominant factor in LMEs is the contract-based market (Hancké et al., 2007, p. 5). The fact that Germany is a paradigm for a CME and the U.S. a paradigm for an LME is another reason for choosing these two countries. A primary question of

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[1] This chapter is based on Hoser, N. (2010). Nanotechnology and its Institutionalization as an Innovative Technology: Professional Associations and the Market as Two Mechanisms of Intervention in the Field of Nanotechnology. *Nanotechnology Law & Business* 7(2), 180-197.

interest is: "to what extent does 'corporatist' Germany differ from the 'liberal' U.S. in the areas of research and higher education teaching; which differences and similarities can be observed?" Areas of research and higher education teaching are central institutional subsystems in the VoC approach and have yet to be analyzed in the context of nanotechnology, which is endeavored in the present study.

Innovations always entail further research, study and new job opportunities. The development of new technologies generally goes through several phases (Heinze, 2006a, p. 130). The first phase is the development of the technology itself (Heinze, 2006a, p. 130). The second phase is the expansion and spillover of (nanotechnological) innovations and research results into university teaching and research (Heinze, 2006a, p. 130). Finally, the last phase is expansion into the employment system, including firms, research institutes, and start-ups (which are of greater relevance in the U.S. than they are in Germany) (Heinze, 2006a, p. 130). Research breakthroughs and the introduction of new study programs and/or courses in nanoscience and nanotechnology (nano-S&T) shape these phases. The focus in the present study is on the second phase, i.e., the spillover of innovations and research results into university teaching and research.

Goal and Central Finding of Study

The aim of this explorative study is to look at the circumstances when a high-technology fostered by politics as a Mode 2 technology (see Wald, 2007 for a study on Germany) meets academe. Hereby, a mixed approach is used, which means that several different methodical and theoretical perspectives are adopted to throw light on the academic field of nanotechnology in new and plural ways. Agent-based modeling and interview techniques are the methods used to gather data for a case study comparison. The theoretical approaches of VoC, organizational fields, sociological neoinstitutionalism including networks and social structure, Mode 2, and theories on professions provide the analytical framework for the study. An explorative analysis of the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) between political funding and nanotechnology in academe, i.e., between the interdependent institutional spheres of politics and science, is delivered. The focus lies on university researchers who are most affected by public nanotechnology funding. These researchers exhibit multiple perspectives on and strategies for the handling of a politically pushed nanotechnology within the working culture they live in.

The main result of the explorative analysis is that the political push for nanotechnology creates tension in the organizational field of academe, a tension that turns out to be favorable for the functioning of nanotechnology research, despite or even because of the diverse motivations and logics of the political and university actors involved. This result is investigated on the individual level by looking at identities and on the institutional level by analyzing institutional structures and processes. Different national institutional structures provide answers that channel nanotechnology in country-specific paths when it comes to institutional change. Two processes of institutionalization are also examined: the construction of identities that are necessary for the development of a scientific community and professionalization.

In addition to the institutionally visible structures and their differences, the interviews demonstrate that there is a remarkable overlap between Germany and the U.S. in the evaluations and concepts of nanotechnology that university researchers expressed. The overlap can be noticed in the form of ambiguity and reluctance toward nanotechnology as a discipline or professional identity. This reluctance might be expected to run counter to the success of nanotechnology in academe. Still, nanotechnology, per se, is seen as a valuable tool for basic research. In the end, it is the aforementioned tension that produces the distinct identity of nanotechnology within the scientific community at the micro-level. This tension gives nanotechnology at the same time a firm institutional place at universities, a place which is contentious but institutionally relevant and fixed. The latter is due to, among other things, the financial dependency of research on public funding and the manifold promises that are attached to nanotechnology as an advanced technology both in politics and in academe. In the context

of professionalization in nanotechnology, there is an interesting result, too. Professionalization has begun in both countries while Germany has a more explicit focus on creating nanotechnologists via academic career tracks. Professionalization as a form of institutionalization, however, takes place predominantly in the market, not in academe where traditional disciplines, such as physics or chemistry, remain the structuring principle.

The observable institutional facticity of nanotechnology leads to further questions within the context of the development of nanotechnology that ask for the future of nanotechnology as a discipline and profession. Here, the reluctance and ambiguity that nanotechnology raises come into play and seem to limit a further development of nanotechnology in these directions. So, nanotechnology, for the time being, remains a specialty and technological instrument for basic scientific research. As a profession, nanotechnology has potential to become an independent career path, although this potential is primarily politically motivated. The creation of study programs in Germany after the Bologna reform has enhanced opportunities to establish nano-related programs. At least formally, these programs provide career paths for nanotechnologists despite the reluctance one encounters among scientists who are involved in nanotechnology. Further, the political economy of Germany with its focus on education and training, as elaborated in the theory of VoC, promises to be helpful for the emergence of nanotechnology as a profession (see chapter 5 and section 7.5). This does not mean that the U.S. does not offer study programs in nanotechnology. However, as this study shows, Germany has a stronger focus on these programs.

In the following, the terms nanoscience and nanotechnology are used interchangeably. The former is used less often and only in the context of academia, referring to what occurs in universities. The latter is used regularly and more often in order to direct attention to how nanotechnology is conceived as a high-technology in academia. Academia exhibits features which do not always go hand in hand with high-technology criteria, for instance applicability and competitiveness of products.

Main Research Interests

It is assumed that on a macro-level the 'corporatist,' i.e., more regulated, political economy of Germany differs from the 'liberal' U.S. in the areas of research and higher education teaching manifesting similarities and differences between these two countries. To address this issue, several innovative approaches are applied. The institutional constitution of the field of nanotechnology in the U.S. and in Germany is explored by simulating the emergence of nanotechnology by way of agent-based modeling bridging the micro- and macro-level (chapter 6). The simulation chapter outlines how this research field emerges under the influence of public funding as the independent variable. In addition, it is simulated how the impetus from public funding agencies affects science through the production of nanoresearchers, being the dependent variable, and thus inciting the diffusion of nanotechnology in universities. Second, by using sociological neoinstitutionalism and the theory of organizational fields, including their concepts of "decoupling" (J. W. Meyer & Rowan, 1977, p. 356), "formal structures" (J. W. Meyer & Rowan, 1977, p. 341), "work activities" (J. W. Meyer & Rowan, 1977, p. 342), and "collective actors" (Fligstein, 2001, p. 15), this study analyzes nanotechnology as an organizational field and carves out its characteristics while concentrating on the academic sector. This kind of analysis has not been done before to the knowledge of the author. Furthermore, organizational fields, the assumption in this study goes, are socially constructed and, consequently, characterized through the interaction of interests pursued by actors. In the present case study, these are public funding agencies and scientists. Due to the micro-approach that is part of both the simulation model and the interviews, individuals form central actors that are analyzed here. Yet these actors must be always seen in the institutional context they act in and which influences their meanings, and vice versa.

Interviews give insight into nanotechnology as an organizational field with specific characteristics when looking at the field from the perspective of scientists. These characteristics are the constant negotiation of its borders in discussions among scientists about the meanings of nanotechnology and the temporary, but recurring participation of scientists in the field of nanotechnology by performing several roles. These roles allow the entering of the field but also the 'opting out' of the field. The meanings concerning nanotechnology are elements that researchers act upon. Thus, researchers who were interviewed were not only nanoscientists, but also physicists, chemists, or materials scientists, speakers, coordinators, or principal investigators (PIs) heading university research groups, and managers.

Also, for the first time, this study looks at nanotechnology in the academic sector and integrates the organizational field and neoinstitutionalist approach into the Mode 2 concept to provide a theoretical tool for organizational analysis. Neoinstitutionalist concepts are used as a promising theoretical resource for the analysis of the empirical data gathered for this study next to the mode of knowledge production in nanotechnology. This combination of sociological neoinstitutionalism and Mode 2 does not represent a mode of theoretical eclecticism but a way of increasing the understanding of the observed inner organizational life of nanotechnology in academe by tapping into the available theoretical repertoire. The study challenges the Mode 2 argument that universities have become application oriented, interdisciplinary, context driven and socially accountable universities that must manage new sources of funding (Gibbons et al., 1994). The nanotechnology field exhibits some features of Mode 2 (Jansen, von Görtz, & Heidler, 2010). However, this is only one side of the coin. Nanotechnology has been imposed on academia as a Mode 2 field under political conceptions. These conceptions regard nanotechnology as promising for future applicability and economic growth (J. W. Meyer & Ramirez, 2009, p. 216; Schaper-Rinkel, 2006, p. 484, 2010b; Wald, 2007) and thus as a high-technology worthwhile for funding. Demands for interdisciplinarity and academic/industry cooperation have, therefore, become central features of federal grant policies in Germany and the U.S..

Mode 1, as Mode 2's predecessor, embraces categories, such as disciplinarity and disinterested basic research orientation. What happens when Mode 2 nanotechnology meets Mode 1 nanotechnology? The case of nanotechnology shows that tension has emerged, firstly, between problem-oriented and basic research. This tension turns out to be favorable for institutional change in academe: professors who still anchor themselves in academic disciplines adopt the nanotechnology label by and continue doing (still necessary) basic research at the same time. They legitimize their research by referring to the future applicability of nanotechnology (see in particular Selin, 2007). The manifold meanings concerning the definition of nanotechnology but also of Mode 2 criteria, secondly, also lead to a tension that arises due to the lack of clarity of these concepts. As Mode 2 does not account for a theoretical tool to analyze organizational fields, this approach is extended by neoinstitutionalist theory to ask what a field nanotechnology is. Neoinstitutionalist theory is applied to delineate what a field nanotechnology constitutes in academe and how this Mode 2 field is successfully integrated into universities, allowing for the coexistence of Mode 1 and Mode 2 knowledge production.

With regards to politics, political actors, and not only "popular movements" as studied by Nina Granqvist and Juha Laurila (2011), have been responsible for the demarcation of the field of nanotechnology whose boundaries are based on a nanotechnology definition of size (Schaper-Rinkel, 2010b). In federal policies, there is broad consensus with regards to the necessity of funding nanotechnology as a high-technology because it holds great potential for economic growth. Little attention, however, has been paid so far on the institutional establishment of nanotechnology in academia and how this development is evaluated from the perspective of researchers themselves. The assumption is that the picture is different when asking scientists on a micro-level about their attitudes, definitions, and views on the nanolabel. Thus, public funding of nanotechnology is used as a unit of analysis that is separate from academic research and individual opinions prevailing in the scientific community. It is unquestioned that public funding is a motor in the delineation of the nanofield, an independent variable, and quasi puts researchers on the spot (Kerr, 2005, p. 4). It can be further assumed that public funding leads to changes in the nature of academic work, including its institutionalization.

In sum, the tension between politics and academe is explored. The focus lies on how academic researchers, who are embedded in scientific communities, evaluate national academic research systems with regards to the demarcation of nanotechnology under the influence of public funding: "what does the 'academic base' think about nanotechnology?" When evaluating scientists' perceptions it becomes clear that public funding, which still makes up the largest portion of nanotechnology funding at universities, plays a pivotal, but no singular role and shapes nanoscientists' actions and thinking. Governmental policies do not only include U.S. and German grant policies but also higher education reforms, such as the Bologna process in Europe, which created opportunities for institutional change. Further issues that arise in the explorative analysis in the context of the institutionalization of nanotechnology in academia are: "will nanotechnology develop as a discipline and be aligned next to or integrated into the natural sciences? Do researchers, professors and doctoral students alike, internalize 'nano' as a source of identification or is it a mere descriptor for their research, but not for their identity within the scientific community? What are the occupational identities of those scientists who actually do nanoscience and nanotechnology?" In terms of professionalization, this tension is resolved by transferring professionalization of nanotechnology into the labor market outside of academe.

Composition of Study

This study is composed as follows: after delivering an overview of the development of nanotechnology in Germany and the U.S. (chapter 2) and of the applied theories and methods (chapters 3 and 4), the German and U.S. higher education systems are compared institutionally (chapter 5). Chapter 2 provides a historical analysis on nanotechnology and gives a political perspective by outlining the political interests in nanotechnology. Chapter 3 provides the theoretical framework for the macro-, meso- and micro-level of this study. The next chapter, chapter 4, delineates the methods that are used in a complementary way and that stress the importance of the micro-level for the data of the present case study. Chapter 5 remains on the macro-level and discusses the incorporation of nanotechnology from the VoC perspective. It includes an analysis of the institutional development of nanotechnology with a focus on institutional diversity, departmental structures, professorial autonomy, the European Bologna process, and university education as well as its relation to practice. Thereafter, the nanotechnology research network is modeled in a dynamical computer simulation and represents one way of analyzing the field of nanotechnology (chapter 6). Both chapters 5 and 6 raise more detailed questions about the actual inner life and identity of nanotechnology in academe that are addressed by the interview data. Thus, the interviews are discussed from different theoretical viewpoints (organizational fields, sociological neoinstitutionalism, and Mode 2 in sections 7.1 and 7.2), contextualized in a country comparison (section 7.3), juxtaposed to the biotechnology sector (section 7.3.3), and used as a data source for the cultural production of identities (section 7.4).

Section 7.1 discusses what happens when Mode 2 meets Mode 1 in the case of nanotechnology, and section 7.2 outlines the associations nanoresearchers have with Mode 2 criteria. The ambiguity and vagueness that these Mode 2 terms evoke are addressed. These evocations resemble the associations of the term nanotechnology and its identity in the scientific community that are manifold and contentious as well. Section 7.3.1 delivers a comparison of the institutional structures of the German and the U.S. tertiary systems by looking at departmental and personnel structures as well as the role of PIs. Section 7.3.2 turns to the individual level. It looks at the interview sample, the funding and publication patterns, the status of nanotechnology as a specialty or disciplines, the importance of applicability for the informants, individual outlooks of informants for their future career paths, and, lastly, the issues of identity change, doctoral students' interests, and PI–student relationships. In the excursus 7.3.3, the findings about nanotechnology at universities are juxtaposed to biotechnology. The excursus asks what the differences are that made nanotechnology a highly institutionally visible academic specialty. Therein, it is suggested that patterns arise both in the U.S. and in Germany similar to the pattern of hybridization in biotechnology. This pattern marked the successful realizability of biotechnology in the CME of Germany, which was as unexpected for biotechnology as it was for nanotechnology from the view of VoC. In contrast to the abundance of biotechnology studies that apply a firm-centered or market-oriented perspective, this study does not focus on the market or the relationship of science to firms. It merely gives an estimation of the future development of nanotechnology in that respect. As a consequence, the present doctoral thesis cannot be compared one-to-one to firm-centered biotechnology studies. Yet, under different aspects, market relations and industry funding play a role for the informants of this study, which is addressed in sections 7.2.6, 7.3.2, and 7.3.3. The noticeable reluctance of interviewees to use nanotechnology as a professional identity marker finally leads to section 7.5. There, nanotechnology as a profession is debated.

In sum, chapter 7 addresses the discrepancy between politics and science that leads to the production of an identity of nanotechnology which is characterized by ambiguity and reluctance. Yet, this finding is not detrimental to the institutional incorporation of nanotechnology into academe. In the end, the discussion and conclusion chapters 8 and 9 include an overview of the hypothetical findings and policy implications and wrap up the explorative analysis. Chapter 8 sums up the study's results under different perspectives.

1.1 Model of Intervening Mechanisms

1.1.1 Structural Level of Model

To illustrate the institutional context of the field under study, the static 'Model of Intervening Mechanisms' outlines the structure of the educational system and the labor market that can be applied to the nanotechnology field. To further develop the model, it is fruitful for analysis to look at professions (especially at engineering, physics, chemistry, and materials sciences) and the market (focusing on the commercialization of nanotechnological innovations). The model interprets professional organizations and the market as intervening mechanisms. As structural societal entities, these mechanisms assist individuals with the transition from the educational sector to the labor market.

Thus, on a structural level, two mechanisms of intervention are in focus: professions versus market-led relationships. Unlike the U.S., professions in Germany are rather 'closed' because they are characterized by concrete academic and job tracks with little flexibility in choosing a job after graduating from university. Unlike Germany, market relationships are 'open' in the U.S. because they are contract-based relationships which are marked by more flexibility. In the labor market, e.g., the type of study program completed is generally less connected to the actual job position (see Figure 1).

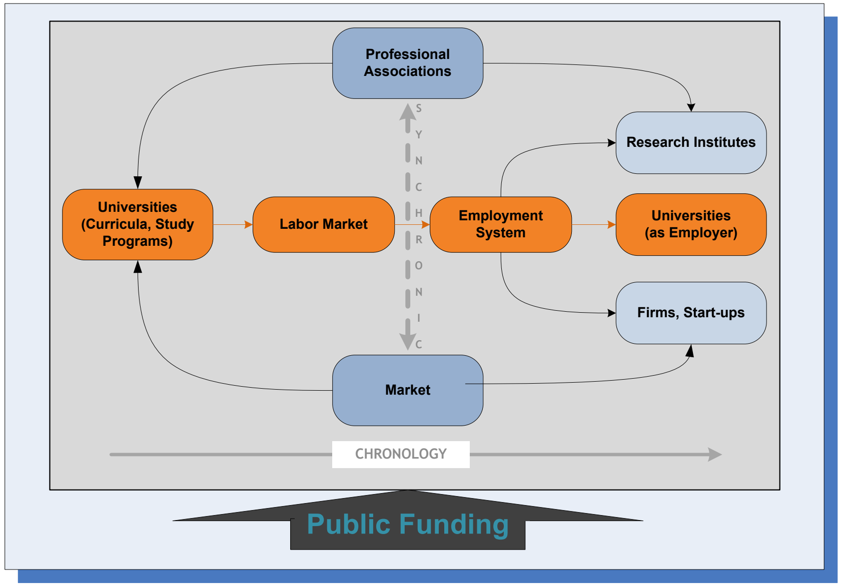


Figure 1: 'Model of Intervening Mechanisms' in Nanotechnology; Own Source

In their career path, individuals generally go from the education system to the labor market (although they may go back to education for further training). This career trajectory is dubbed here as the 'chronologic level.' These two mechanisms of professional associations and market-led relationships fall on the chronologic level between education, training and research on the one hand and the employment system and the labor market on the other. The labor market includes the employment system which combines research institutes, firms, start-ups, and universities as employer where educational careers in nanotechnology predominantly lead to after graduation. Both mechanisms, professions and the market, must position themselves between the education and employment systems (i.e., find equilibrium and social order).

The market is also an important element because it is interested in innovations. This desire for innovation leads to collaboration between industry and research. In the U.S., basic and applied research generally takes place at universities that have a strong connection to the market. Given that the market in the U.S. is contract-based (Hall & Soskice, 2001a, p. 15), venture capitalists, industry partners, government departments, such as the Department of Defense, the Department of Energy or the Department of Commerce, establish such contracts (Newton, 2002; Ratner & Ratner, 2003). Conversely, in Germany, long-term relationships shape the market (Hall & Soskice, 2001a).

In addition to the market, professional associations also play an important role. Professional associations must be seen as an organizational unit separate from the market. In Germany, professional associations are politically strong and they exert great influence over both universities and the employment system. German associations, such as the VDI (the Association of German Engineers), are involved in establishing academic programs due to their historic development (McClelland, 1991, p. 117). They exert direct influence on university curricula and on-the-job trainings at companies. German professional associations include the Society for Chemical Engineering and Biotechnology (Gesellschaft für Chemische Technik und Biotechnologie e.V.) that focuses on, among other things, nanorelated research (DECHEMA (Society for Chemical Engineering and Biotechnology)).

In the U.S., professional associations have less political influence than they do in Germany. U.S. professional associations include the American Chemical Society, the American Physical Society (APS), the American Society of Mechanical Engineers, the Institute of Electrical and Electronics Engineers, and the Materials Research Society. These associations nevertheless provide a platform for information and research exchange; thus, guarding the autonomy of researchers and universities.

Associations form an indispensable, formal and non-mandatory platform for nanoresearchers. This platform allows them to keep up with the latest developments and research findings of their colleagues. This is particularly important for a young field like nanotechnology where scientific discoveries depend on each other and, above all, on incremental (i.e., endogenous) innovations (Yusuf, 2008). Professional associations with specific subgroups for nanotechnology are also important because they provide an opportunity for connecting researchers who are not always embedded in nanotechnology centers, such as the National Nanotechnology Infrastructure Network (in the U.S.) or the Karlsruhe Institute of Technology (in Germany). Additionally, professional associations facilitate science-industry interaction, which is necessary in core technologies, to stimulate technological and innovative activities (Debackere & Veugelers, 2005; Yusuf, 2008).

Finally, market-led relationships or market dominance and professional associations must be balanced, which aim at preserving their social status that is being threatened by change in times of globalization and reforms, such as the Bologna process (Serrano-Velarde, 2009). The Bologna process is threatening the dominance of professional associations because it seeks to create the European Higher Education Area (Federal Ministry of Education and Research (German)). As part of this program, the Bologna process will make academic degree standards and quality assurance standards more comparable across Europe (Federal Ministry of Education and Research (German)). The respective national stakeholders including professional associations and the market attempt to exert their influence and power in the field of nanotechnology, thus, leading to tension. In particular, in Germany, professional organizations have long been an important social group because German professors used to be "leading members" in these organizations (McClelland, 1991, p. 117). Due to the different historical developments of associations in the U.S. and Germany, it is considered highly instructive how these associations exert influence in nanotechnology. If, and how, a balance can be reached remains unclear for the time being because nanotechnology is a new and rapidly developing technology whose institutionalization is still advancing.

The Bologna process is, on the other hand, a facilitator for German universities to establish graduate programs (and even Bachelor programs) in nanotechnology as a consequence of this educational reform. As pointed out by Patricia J. Gumport (2005), universities are put under pressure by decreasing state fund allocations which leads to the increasing commercialization of research output and the recruitment of students in the natural sciences. Therefore, the Bologna process, with its restructuring of study programs into the two-staged bachelor and master system, provided an opportunity to establish interdisciplinary and/or international programs to attract students (VDI Technologiezentrum e.V., 2008a). Unlike in other disciplines, however, those involved in nanotechnology are heavily funded by the state both in Germany and the U.S. (see Figure 1). This shows that governmental reforms and funding programs, through initiatives, such as Nano-Initiative–Action Plan 2010 and the National Nanotechnology Initiative, function as facilitators (not originators (W. W. Powell & Owen-Smith, 2005, p. 116)) in the emergence of a new research area by guiding university decisions and research projects in times of economic change.

Thus, the role people's professions (e.g., chemical engineer, nanomaterials researcher, etc.) play is also an important factor to consider. In Germany, people's professions are strongly influenced by traditional job profiles and are structured in a rigid way (i.e., workers are directly assigned to rigid job responsibilities). In the U.S., however, professions are characterized by more general profiles and are rather loosely coupled (Weick, 1976).

The attitude and definition (or lack thereof) of job roles is also reflected in the higher education system of both countries. The U.S., for example, offers a general education system (Clark, 1995; Lenhardt, 2005) where students have the opportunity to choose courses based on their own abilities and desires. Germany, conversely, offers an education system that is oriented toward specific skills and concrete job profiles based on the demand for qualifications by the labor market.

The difference in attitude toward education between the U.S. and Germany offers another issue for analysis regarding having a career in nanotechnology. Specifically, to what extent do concrete study and job profiles prevail in preparing individuals for a career in nanotechnology?

In summary, one can see that the market systems and professional associations in both countries must be considered in the institutional examination of nanotechnology due to their functioning as different mechanisms which influence the transition of individuals from the education system to the labor market. With Germany being a CME and having a more prominent role of the state and the U.S. being an LME, the market and professional associations exert influence of a different character depending on the country. Whereas in the U.S. the market system is dominant, in Germany, professional associations have a more important social role when it comes to curriculum and academic development due to their historical development and the social status that comes with associations. With fixed career profiles, study decisions are crucial for later career options in Germany. German professional organizations have a say in which skills and competencies are required for specific career tracks. In the U.S., it is solely the market that determines which skills are required.

The analysis of nanotechnology as an organizational field (chapter 7.1) and the simulation model (chapter 6) developed to trace the emergence of nanotechnology address the structural level. The independent variables on the simulation model are four different funding strategies that differently fund researchers in nanotechnology or other topics and disciplines. The dependent variable is the number of researchers engaged in nanotechnology. This number is used as an indicator for the 'success' of funding nanotechnology: The more nanotechnologists emerge, the more successfully this specialty has been funded. The question behind this approach is: "Can public funding 'steer' the development of an academic field?"

1.1.2 Process-Level of Model

The aforementioned model conveys the structural level that must be considered in the analysis of nanotechnology as a field and in the simulation model. In addition, there is a process level that plays into the structural level. On a process-related level, forms of institutionalization and the mode of knowledge production and production of innovations as influential factors are relevant. Which role do trans- and interdisciplinarity play for instance? To examine the mode of knowledge production, the concept of Mode 1 and Mode 2 knowledge production is applied. To further grasp the ongoing processes in nanotechnology research at universities, 'work activities,' as elaborated by the neoinstitutionalist approach, promise to be a fruitful way of analysis. In addition, two processes of institutionalization are studied: identity construction in scientific communities and professionalization.

As Mode 1 and Mode 2 knowledge production and neoinstitutionalism concentrate on the meso-level, theories on professions are an adequate perspective on the micro-level: Social structures, as revealed by everyday activities, individual careers, research networks, and social relations in the workplace environment, represent an important, but often neglected aspect of professions. Here, the professions include academic professions of chemists, bio- and electrical engineers, materials scientists, and physicists. Social interaction must be integrated in a study of nanotechnology as a field where the market and professional organizations interact with the education and academic employment system. Social interaction is also indispensable for the construction of identities in scientific communities. Since social interaction is based on meanings, on a micro-level, these meanings must be explored. This exploration is done by looking not only at the meanings concerning nanotechnology (see chapter 7.1) but also concerning criteria of Mode 2 knowledge production (see chapter 7.2). Interview methods are used to address the process-level of the static model presented above.

1.2 The Case of Nanotechnology: Levels of Analysis

Science and economy are interconnected because new developments drive economic growth (Heinze, 2006a). Publications and patents are relevant indicators for regional research productivity (Zucker, Darby, Furner, Liu, & Ma, 2007). Publications are an indicator of scientific performance while patents are an indicator of technological performance (rather than innovations) (Hullmann & Meyer, 2003, p. 509; M. Meyer, 2006, p. 1658). Nanotechnology demonstrates this interconnectedness as both patents in the market and publications from academic researchers continue to increase steadily. Nanotechnology patent filings began increasing in the 1980s but the increase became much more noticeable in the 1990s (Heinze, 2006a, p. 116). Similarly, a review of the Science Citation Index (SCI) reflects that publications discussing nanotechnology have risen from about 0 in 1981 to about 12,000 in 1998 (Hullmann & Meyer, 2003, p. 510). Most notably, these nanotechnology discoveries are coming from both universities and corporations. Experts generally assumed that the interaction between universities and industry followed a linear model where scientific discoveries diffuse from universities ("science-push") to the technological sector ("technology-pull") to the market ("market-pull") (Hullmann & Meyer, 2003, p. 509). Now, however, the interaction between universities and industry is increasingly interpreted as a dynamic and reciprocal one (Etzkowitz & Leydesdorff, 2000; Schmoch, 2007).

Instead of looking merely at patents and publications to find out about the interconnectedness between science and industry/labor market, the author considers the following theories in this study: the VoC approach, the neoinstitutionalist perspective, and professionalization concepts. Whereas patents and publications provide a macro-perspective, considering these other approaches allows for the analysis of the macro-level (VoC), meso-level (sociological neoinstitutionalism including social networks and structures, Mode 1 and Mode 2 knowledge production), and micro-level (professions). In the simulation model (chapter 6), two levels are predominant: the micro-level in the form of agents, i.e., researchers, and their individual behavior as well as the macro-level, which is marked by the output of the model in the form of network links and the state of diffusion of nanotechnology measured by the number of nanoresearchers. All these approaches allow for further illustrative research to gain insight into the processes and national institutional features that characterize the field of nanotechnology. Table 1 gives an overview of the theories applied in this study:

Level of Analysis	**Applied Theoretical Approach**
Macro-Level	VoC Approach
Meso-Level	Organizational Fields; Sociological Neoinstitutionalism
	Mode 1 and Mode 2 Knowledge Production
Micro-Level	Theories of Professions

Table 1: Correspondence of Level of Analysis to Applied Theoretical Approach; Own Source

2. Nanotechnology: A Literature Overview

"The greatest constant of modern times is change. Accelerating changes in technology, population, and economic activity are transforming our world, from the prosaic─the effect of information technology on the way we use the telephone─to the profound─the effect of greenhouse gases on the global climate." (Sterman, 2000, p. 3)

In this chapter, a historical analysis of nanotechnology is provided, including a political perspective and the national innovation policies of Germany and the U.S., in order to understand where nanotechnology comes from and how it could become the field that it is at the moment. Nanotechnology pertains to the most recent, innovative, and rapidly developing core technologies of the world. Despite some sporadic voices of pessimism, many are confident by now in the promising potentials of this technology on the nanometer scale (Hullmann, 2007; Jopp, 2006; Wong, Ho, & Chan, 2007). The beginning of research and science on the nano-scale is traced back to Richard P. Feynman's (1959) speech from 1959 "There's Plenty of Room at the Bottom" (Heinze, 2006a, p. 105). However, as Drexler's biography (Regis, 1995) shows, it took some decades in the U.S. until nanotechnology was accepted in the political and scientific community, since visions and stories circulated addressing nanotechnology science fiction. Drexler himself did not hear about Feynman's speech until some years later after he had come up with his idea of molecular engineering and molecular assemblers. Drexler's 'problem' was he did not do hands-on research but rather theorized about what could be possible in the world of molecules. By the 1990s, nanotechnology was established as an interdisciplinary science– a factor that attributed to Drexler's difficulty of writing his interdisciplinary dissertation at Massachusetts Institute of Technology (MIT), the first doctoral thesis in molecular nanotechnology–, whereas Drexler despite the founding of his and his wife's Foresight institute never could manage it being seen as a 'serious' scientist. This circumstance could be explained by Kuhn's theory that a new generation of scientists replacing the old one is needed in order to promote new revolutionary ideas. And nanotechnology is certainly one revolutionary idea. The irony is that there are scientists who are skeptic toward Drexler's futuristic elaborations but who themselves contribute through their research indirectly to the development of molecular nanotechnology. Examples are Whitesides or Smalley who won the 1997 Nobel Prize in Chemistry for the discovery of the 60-atom carbon isotope (also known as buckminsterfullerene). (Newton, 2002, pp. 13, 89, 105)

Thus, one must distinguish between scientists who work in their field as they did ever before and explore the nano-scale world and visionaries like Drexler who see nanotechnology already in their human application to enhance (or destroy) human lives. Not all of Drexler's ideas will be realizable. This is shown for example by Xavier Guchet and Bernadette Bensaude-Vincent (2008) who discovered the inconsistent use of the term machine in Drexler's works, hampering the feasibility of the assemblers and replicators Drexler developed. Cynthia Selin (2007) brings it to the point when she links the emergence of nanotechnology to the concepts of future and temporality:

> "Drexler's vision was longer term; it frustrated the scientists to no end, for their tools for creating authenticity cannot enter the contemptuous terrain of the future. When speaking with each other, the far future is avoided in favor of more immediate concerns and deliverables. The future, despite the productive uses that it maintains, is illegal territory for most scientists most of the time. Drexler's ruin can be read as a cautionary tale about those scientists and engineers who trespass into the future." (p. 214)

So much can be told for the beginnings in the U.S.. Nevertheless, the beginning in terms of scientific breakthroughs and a rise in publications in patents is attributed to the invention of the Scanning Tunneling Microscope (STM) by Gerd Binnig and Heinrich Rohrer in 1981 at the IBM research center in Zürich as well as the discovery of fullerenes in 1985 resulting from the study of carbon molecules (for a study on fullerenes and nanotubes see e.g. Lucio-Arias & Leydesdorff, 2007, p. 604). In 1989, Don Eigler and Erhard K. Schweizer succeeded in moving xenon atoms with the STM to "write" the word

IBM (Eigler, 1999). Carbon nanotubes which are cylindrical one-dimensional fullerenes were subsequently discovered in 1991 (Lucio-Arias & Leydesdorff, 2007, p. 604). Thus, the U.S. was not the only country where nanotechnology began to thrive. European countries started to follow and to catch up, with Germany being one of them.

In the following, Germany and the U.S. are compared to see what the present state of nanotechnology is in both countries. Both countries are successfully promoting nanotechnology. The different national institutional structures including the financial and research structures indicate that there are varying dynamics in the implementation and support of nanoscience and nanotechnology. The major aspects of comparison are research (patents, publications, expenditures, etc.), education, and the labor market. Germany at times must be set in context with the European framework of nanotechnology, when the national level alone does not explain all processes related to high-technologies. The comparison shows that institutionally, nanotechnology is strongly anchored in the technology sector in both countries and important in higher education and, increasingly, in the labor market. Differences come about the way processes are regulated and executed, for instance capitalist structures or the role of patents. They demonstrate the existence of national institutional settings that exhibit different dynamics.

The definition(s) of nanotechnology

There are abundant definitions of nanotechnology. For Drexler, nanotechnology, or more concisely molecular nanotechnology, refers in general to "building machines from bottom-up [as opposed to top-down] with atomic precision" (Newton, 2002, p. 183). A very general and technical one is the following: Nanotechnology is a technology based on elements ranging from 1 to 100nm (National Science Foundation (NSF), 2000). Thomas Heinze (2006a, pp. 104-105, see also CEDEFOP 2006) defines nanoscience and nanotechnology as "phenomena on the nanoscale, i.e., material, structures, and processes having the size of a billionth meter and whose properties and behavior of this size." Another general, but rather categorizing and delineating one is the following:

> "[N]anotechnology is a collection of different technologies and approaches, which all use the physical properties of dimensions on the nanometre scale, which differ from those observed in the micro and macro world. In order to draw a correct and comprehensive picture of the technology and to achieve a fair assessment of its status, potentials and drawbacks, it is necessary – where possible – to look at nanotechnology subareas such as nanomaterials and nanoelectronics, nanobiotechnology and nanomedicine, or nanotools, nanoinstruments and nanodevices." (Hullmann, 2007, p. 740)

What makes definitions challenging is that nanotechnology is interdisciplinary (Abicht, Freikamp, & Schumann, 2006, pp. 39-40; Hullmann & Meyer, 2003, p. 508; Newton, 2002, p. 111; Vogel & Campbell, 2002, p. 498) or cross-disciplinary (Hullmann & Meyer, 2003, pp. 507-508; Jopp, 2006, pp. 40-41; Rieland, Bachmann, Sicking, Holz, & Müller, 2009, p. 7). A group of researchers contests that nanotechnology is interdisciplinary and categorize it by the terms cross-disciplinary because of the lack of communicative structures between participating disciplines (Heinze, 2006a, p. 111) or multi-disciplinary because of the domination of classical disciplines within unconnected mono-disciplinary fields of chemistry, physics, materials science or electrical engineering (Schummer, 2004, p. 461). Joachim Schummer (2004, p. 462) differs between two forms of interdisciplinarity: One where several disciplines collaborate with each other at equal rank and having strong symmetrical connections, the other where one discipline dominates the others to which it has strong asymmetrical connections. In nanocenters or nanolaboratories the first form has been implemented by the collaboration of nanoscientists. Yet, Schummer refers to this interdisciplinary cooperation as a temporary activity because of "strong cognitive barriers" (Schummer, 2004, p. 463) and the emergence of new disciplines which integrate nanodisciplines (hybridization). He concludes further that individual scientists in materials science or engineering are rather disinclined toward interdisciplinary research cooperation so that the

process of interdisciplinarization is impeded at the lowest level of organizations (Schummer, 2004, p. 463). Additionally, also the present disciplinary institutional structure at universities represents an impediment to interdisciplinary, flexible and innovate research teams as well as students' research involvement (Roco, Williams, & Alivisatos, 1999, p. 266). The use of the terms transdisciplinarity and interdisciplinarity in publications is often unclear, unspecific or the terms are used to mean the same (see e.g. Roco et al., 1999). This is why in this study, the term interdisciplinarity is used to refer to the widely observed non-interdisciplinary research structures in nanotechnology and nanoscience.

As Angela Hullmann (2007, p. 740) and Klaus Jopp (2006, p. 40) point out that nanotechnology subsumes several technologies applying to different fields. Nanotechnology represents most often an integral, not an isolated component within a structural element or process. Additionally, nanotechnology often cannot be applied unless it is combined with other technologies, such as biotechnology. Thus, it is hardly possible to confine or outline nanotechnology very precisely. (Jopp, 2006, p. 40)

Furthermore, nanotechnology is to be separated from nanoscience. Researchers even distance themselves from the word nanotechnology as it implies applications. To them, the state of nanoscience at present, however, does not allow speaking of nanotechnology yet. Commercial nanoapplications are not as widespread as they should be to be able to speak of nanotechnology. Whereas nanoscience implies the "fundamental understanding of structures and processes at the atomic and molecular scale," nanotechnology refers to the "utilization and control of nanoscale phenomena for specific purposes" (Heinze, 2004, p. 427). One definition of nanotechnology combines nanoscience and technology saying that nanotechnology involves "nano-meterscale science and technology" (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 1).

National Innovation Policies on Nanotechnology

Looking at the history of national policies and paradigms, the turn from technology to more comprising innovation policies occurred in the 1990s for political concerns, in particular in European countries, such as Denmark, Finland, and the Netherlands, about national and European competitiveness. This was also fostered through the OECD. Since the mid-1980s, the whole European Union became involved in RTD policy (i.e., research and technological development policy) when technology development became increasingly linked to European integration issues, an underlying rationale of political leaders at the time. As the U.S. had also turned to technology and innovation policies for reasons of economic growth and competitiveness, the U.S. by now screens the European Union more intensely than decades ago. (Biegelbauer & Borrás, 2003, pp. 300-301, 310) Economic growth, national competitiveness, and general wealth over time have become rationales and legitimations for the formation of technology and innovation policies and their respective discourses (see e.g. Edler, 2003, p. 253; Schaper-Rinkel, 2006, p. 474, 2010a, p. 320, 2010c, p. 18).

In U.S. policy, with ATP, the Advanced Technology Program, the development of technology in industry in collaboration with academia was promoted. This integration of academia was motivated mainly for ideological reasons: The U.S. government is not supposed to fund industry directly as it would be considered a subsidization of technology industries. Still, public venture capital is available through a range of programs, such as SBIR, ATP, SBA, etc. (Etzkowitz, 2003, pp. 46, 48). Henry Etzkowitz (2003, p. 58) concludes that the U.S. government is still a less influential actor for change in the technological landscape than European governments are because of the use of neutral parties, such as universities, to hide ideological incompatibilities. This conclusion is contrary to the simulation findings on academia in the next chapter. In the European Union, a first statement on innovation was made in 1980 to instruct further unification of the EU market. Research and technological development policy became increasingly relevant for the EU integration process as a 'matter of survival'. With the program BRITE from 1985 that was directed at all industries interdisciplinary cooperation across borders was mandated between companies as well as between industry and research institutes. (Edler, 2003, pp. 255-256, 268-269)

Turning to U.S. and German policies, what is most striking when comparing U.S. policy to German policy is that in the U.S., *universities* must be on board as actors of developing technology and innovations for the government must stay neutral because it cannot 'subsidize' industry directly (Etzkowitz, 2003, p. 58). In Germany, but also within the 7th EU Framework, by contrast, *industry* must be participating, mostly as a coordinator, in government-funded projects on technology and innovation. This was mentioned by R1 who deplored the fact that industry cooperation with universities as coordinators have been less and less funded. Instead, big research projects with industry as the coordinator are more and more publicly funded and therefore application-oriented.

In the U.S., the adoption of nanotechnology on the political science and technology agenda occurred in 1992 under the Clinton administration. Al Gore had talks with Eric Drexler and Merckle who were committed to convincing politics to fund nanotechnology. To the U.S. government, the (risky) promises of nanotechnology for economic growth were convincing in the end. The NNUN (National Nanofabrication Users Network) from 1994 (Roco, 2001b, p. 358) starting with five universities then became one of the first initiatives to institutionalize nanotechnology in a broader way. It was not before 2000, however, that strategy papers were formulated, also in Germany (Schaper-Rinkel, 2010b, p. 38). In 2000, finally, the National Nanotechnology Initiative (NNI) was launched to fund nanotechnology publicly and durably.

Within the frame of economic growth and competitiveness, it is a short step to how nanotechnology could become part of the German political discourse from the beginning of the 1990s (Schaper-Rinkel, 2010b, p. 36). With an increasing emphasis on technological early detection as a requirement to stay competitive internationally, nanotechnology became, unsurprisingly, an item on the political agenda (Schaper-Rinkel, 2006, p. 476). From the interviews, public funding of nanotechnology was often interpreted as a necessary development from top-down: research was reaching smaller and smaller sizes so that, being on the micro-level first, reaching the nano-level was merely a matter of time. In Hamburg, for instance, microcenters were established first and served somehow as incumbents for the upcoming of nanotechnology as delineated by R1. Microtechnology, in particular in semiconductor industry, became a loophole for nanotechnology then. Looking at politics, projects in nanotechnology had been funded from the end of the 1980s but it was not before 1998 that the German government funded competence centers in nanotechnology that served the federal integration of nanotechnology and academic-industry alliances (Schaper-Rinkel, 2005). This shows that, through political discourse and agendas, nanotechnology was formed as a field that became more and more attractive to scientists because of the available public funding. As the NNI from 2001, Germany has launched several government initiatives on nanotechnology that have involved an increase in funding nanotechnology projects since 1998 (Schaper-Rinkel, 2006, p. 477). With political actors becoming central in the field of nanotechnology, concept and vision that are usually at the beginning of technology narratives soon were replaced by a focus on industrial applications of nanotechnology (Schaper-Rinkel, 2006, pp. 475-476). Entering (product) markets became more important for the allocation of public funding than societal relevance (Schaper-Rinkel, 2006, p. 484). Nanotechnology and, in a broader sense, production and process innovations were concretized in technology policy. With the development of actual mass-producible nanoproducts, the political economy had both a low- risk core of innovative products and could afford at the same time to maintain long-term visions that promised technological breakthroughs. Both sides are needed in political economies: riskless products and long-term visions. (Schaper-Rinkel, 2006, p. 492)

These national developments show that the nanotechnology discourse fits perfectly into the techno-socio-economic project of innovation. The innovation discourse in turn is reinforced by nanotechnology. (Wullweber, 2010, p. 232) With the outline of the political arena of nanotechnology innovation and technology policies in the U.S. and Germany, a context was created for the interests of scientists who are, next to political actors, of central relevance in the science-based field of nanotechnology. As assumed by the constructivist perspective, actors have interests and underlying rationales

that often are in conflict with other actors' interests and must be negotiated socially. In the last paragraphs, political interests were outlined. When it comes to scientists' interests it can be stated from the interviews with nanoresearchers that central interests are knowledge production, cutting-edge and internationally leading research (R1), publishing research results and with that, gaining reputation as a researcher within a scientific community that is usually disciplinary based, such as in physics or chemistry, and not least funding one's own research. Especially the latter point is important, as B3 and O2 revealed. Scientists are constantly in search of, in particular new, funding channels. Scientists must learn to redirect their research and be sensitive to political interests so that one's own research can be made attractive for public funding agencies. As B3 stated, public funding is always available. The 'art' is to emphasize those aspects in research that are compatible with the current political funding agenda. O2 explained when asked if she and her group deliberately mentioned 'nano' when applying for third-party funds that nanotechnology was deemed already outdated for the attraction of large sums of funding. Personal interests must also not be neglected when talking about scientists' interests. K1 emphasized strongly that, in his projects, he follows personal and basic research interests. K1 only cooperates with industry if his and their interests overlap. This is contrary to U.S. scientists who pointed to the importance of screening industry for valuable ideas for research.

The need for scientists to obtain third-party funding and the interest of political actors in innovative technologies are what combines both actors. Scientists doing such boundary work as nano-S&T make nanoresearchers and their work part of the public funding program. Nanoscientists are privileged because of a favorable technology policy and because of the trust of funding agencies in the promises of nanotechnology. As nanoreserach is privileged by public funding agencies, universities that are dependent on third-party funds gain more reputation. (Schaper-Rinkel, 2006, p. 481) This is why universities, per se, are interested in implementing nanotechnology. The negative side of it is that boundaries become more and more blurred with the differentiation of nanotechnology discourses in politics, in science, and in public (Schaper-Rinkel, 2010b, pp. 43-44). Another consequence is that by embracing nanotechnology in academia and, with that, the 'popular stories' that are told in its context, the field becomes "vulnerable to external interventions" (Granqvist & Laurila, 2011, p. 275) since these 'stories' continue to exist. The scientific community distances itself from the nanotechnology term that is too comprising and imprecise. What counts in political and public discourses is not congruent with what counts in academe where reputation is gained via publications, the production of 'new' knowledge, and disciplinary membership (Czada, 2002; Kehrt & Schüßler, 2010). This is where the political and the scientific arena diverge that must be constantly balanced in science-based technologies.

To sum up, it is to be noticed first that the orchestration of a scientific field is influenced by several actors. At the beginning, the field of nanotechnology was created by politics and the launch of government initiatives that aimed at nano-S&T. Although single researchers were highly engaged in making nanotechnology a cause, researchers did not establish nanotechnology just by themselves or because they became professors and could follow their own research interests that happened to be nanotechnology. The opportunity to do nanotechnology was there due to the political discourse that favored nanotechnology as a cutting-edge technology that promised to be decisive for innovations and related economic success on an international level. Due to that longing for competitiveness and economic success that were linked to human wealth and progress, nanotechnology was met with open arms by politics.

Second, on an organizational level, the U.S. organization of graduate research is more team-based than in Germany because of the attachment of professors to more broadly set-up chairs in Germany, the less balanced number of graduate students and post-doc positions, and the greater proportion of university-funded budget positions. However, there is a tendency to be noticed with professors who see their students as team members and project workers. This is certainly not very pervasive as doctoral students still saw their professor as the ‘boss’ in Germany (L1, O2, S2) and because the competencies of a professor who decided which lines of research to follow and how the group was financed were still sustaining a hierarchical relationship between PI and student.

One can further conclude that the often appraised greater flexibility in the U.S. departmental structure does not apply in a strict sense in the case of nanotechnology. First of all, nanoscale research does not take place in departments but in research groups, the so-called Organized Research Units, short ORUs, Roger L. Geiger (1990) writes about. These units create tension but also synergy effects when juxtaposed to departments since ORUs account for greater decentralization at universities but also greater competition among research institutes for research grants. As these units strive for independence and, thus, create tension because hierarchically, they belong to departments and thus enjoy flexibility to some degree.

Finally, one can observe that Bologna and the ‘Excellence Initiative’ have increased the potential of change. And indeed, structurally, there has been some institutional change due to the creation of new, often multidisciplinary programs, graduate programs and graduate colleges funded by the DFG (German Research Association). Yet, one must add that the early specialization in Germany, which usually does not take place in the U.S. before entering a graduate or Ph.D. program, is continued by offering bachelor and master programs that are specialized and built on each other. The reasons why nano-degree programs are created by professors and universities are pragmatic because the programs are seen as a recruiting instrument for natural science students on the one hand and as a way of producing nanotechnologists on the other. The latter is desired above all by politics indicating a functional view of higher education that is supposed to produce a workforce for industry.

2.1 Research on Nanotechnology

In this section, the clusters and leading countries in nanotechnology are outlined and described in terms of patents, publications, expenditures, markets, and market potentials. In nanotechnology, Germany belongs to the top three leading nations after the U.S. and Japan (Hullmann & Meyer, 2003, p. 511; Wong et al., 2007, pp. 724, 726 e.g.). The European Union is also very active in fostering nanotechnology. Nanotechnology is considered to be central in “achieving the Lisbon strategy of making the EU ‘the most competitive and dynamic knowledge-based economy by 2010’” (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 1).

‘The global institutionalization of nanotechnology’

To Stine Grodal (2007, p. 97), institutionalization from a socio-political perspective is the last of three phases of field emergence in the case of nanotechnology when scientists and entrepreneurs participate in the meaning creation of nanotechnology and shift the focus toward individuals. Schummer (2007) provides a compelling and recent overview of the institutionalization of nanotechnology worldwide by measuring the institutionalization strength of countries and, thus, providing a realistic point of view. As in the present dissertation, the U.S. and Germany are studied, in the following, only these two nations are considered. He examines the institutionalization strength of regions and countries, i.e., the “number of papers by all nanoinstitutions at a certain time; the relative institutionalization strength, i.e., the “share of papers by different geographical regions, countries, research sectors, or disciplines; and the institutionalization dynamics defined as the growth rate (Schummer, 2007, p. 673).

The following graphs demonstrate first, the institutionalization strength of nanotechnology compared to the institutionalization strength of major participating disciplines showing that physics and materials science show the highest strength of institutionalization whereas nanotechnology has caught up rapidly in terms of institutionalization strength since 1988 (Figure 2); second, the relative nanoinstitutionalization strengths in geographical regions shows that the U.S. lags behind Europe in terms of institutionalization (Figure 3). In the present study, it will be demonstrated accordingly that both Germany and the U.S. fostered the institutionalization of nanotechnology but Germany provides

a relatively higher strength of institutionalization in particular with regards to study programs. Further, it will be shown that nanotechnology has become a major specialty and technology in higher education but not reached yet the status of a discipline, such as physics or materials science as depicted in Figure 2.

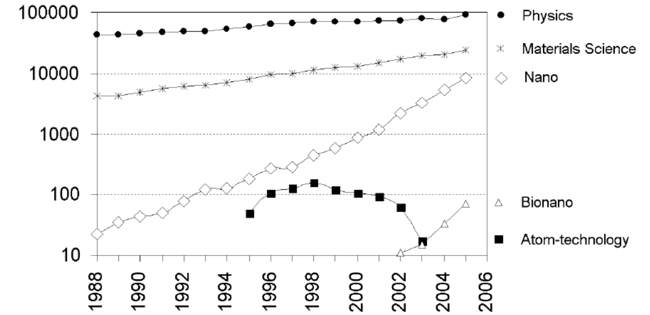


Figure 2: Institutionalization Strength of Nanotechnology Compared to Major Participating Disciplines; Source: Schummer 2007

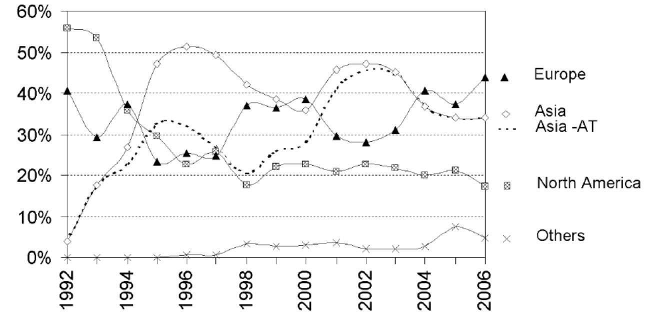


Figure 3: Relative Nanoinstitutionalization Strengths in Geographical Regions; Source: Schummer 2007

Nano-research started in the U.S. with papers published in 1984 by Nanometr Inc, a Californian company, and, then, by renaming the National Research and Resource Facility for Submicron Structures at Cornell University, funded by the U.S. National Science Foundation, into the National Nanofabrication Facility in 1987. These events followed the foundations of many nanoinstitutions in the 1990s (both in the U.S. and in Europe) primarily on university- and lab-/center-level as well as start-ups. In 1999, the U.S. government started nanofunding and launched the NNI. Primarily universities profited from this initiative. The prevailing institutional type is the nanocenter, integrating different disciplines.

In Germany, most significant was the foundation of a nanotechnology institute by the Research Center Karlsruhe which collaborated with the local university. This institute became the leader in nanotechnology and publications in Europe. In 1999, Jülich followed Karlsruhe in creating a nanoinstitute. Institutionalization in Germany took place mainly at university-level (nanocenters, departments). In contrast to the U.S., German governmental research labs are quite active in creating nanoinstitutions and have a higher degree of institutionalization strength than the U.S.. In Germany, a combination of governmental research institutes and university centers which are governmentally funded prevails.

Globally, centers are the most important institutions (30-40%) of all nanoinstitutions, followed by departments and institutes (35%) and nanogroups (13%). Labs declined in importance. In the U.S.

for example, many labs were turned into centers because the NNI aimed at funding this type of institutions which are comparatively big and multidisciplinary. Industry has given up its nanounits by and by as well as collaboration with university so that their impact on public institutionalization declined. Yet, business associations have been founded both in the U.S. (U.S. NanoBusiness Assocation) and in Europe (European NanoBusiness Assocation). In sum, nanodepartments are most likely to remain active after center will have been stopped being funded. With regards to the role of the governments involved in funding nanotechnology, like Grodal (2007), Schummer (2007, p. 691) notes that the government bases its funding on a broader definition of nanotechnology, which means that now practically all classical science and engineering disciplines are worth being funded in their nanoscale research. Yet, Schummer (2007, p. 691) raises concerns saying "it is unclear why they have focused their efforts particularly on institutes of higher education, and how that will affect the future of education. All in all, it rather looks like a social experiment that has run out of control."

Fields of application

Fields of nanotechnology are nanoanalysis, nanoelectronics, nanooptics, nanobiotechnology/ nanomedical technology, and nanochemistry whereby nanoanalysis can be applied in all these fields. Another classification leaves out nanooptics and adds "Other Applications" but stays otherwise with the same categories (Wong et al., 2007, p. 720). Poh Kam Wong, Yuen Ping Ho, and Casey K. Chan (2007, p. 720), whose classification is less precise, list examples to the respective areas with "nanoelectronics" applying nanotube semiconductor devices; "medical and biotechnology" referring to drug delivery systems and cosmetics; "chemical processes and materials" developing nanocatalysts and nanocomposite polymers; "instrumentation, tools, metrology, and standards" using the atomic force microscope and nano-positioning device; and, finally, "other applications" focusing water purification and treatment as well as coatings.

Comparing the periods of 1976 to 1999 and 2000 to 2004 (Wong et al., 2007, p. 727), it can be observed that patents in the field of "other applications" increased by about ten percentage points, nanoelectronics stayed the same with 31.1%, instrumentation, tools, metrology, and standards decreased by about half percentage points, chemical and materials declined by about four percentage points, and medical and biotech stayed about the same with 18%. These findings suggest that there has been a shift toward "other applications," which makes additional classification necessary. Nanotechnology patents are more and more developed in other than the major categories. Another overview lists the application area of specialization with the U.S. specializing in nanoelectronics and Germany in nanoelectronics and chemical processes and materials (Wong et al., 2007, p. 728).

Expenditures

The estimated worldwide public funding for research and development in nanotechnology suggests that the German government spends most after the U.S. (Federal), Japan, the European Commission, and the U.S., i.e., 293,100 thousand € in 2004 (Hullmann, 2007, p. 745). Until 2009, 15 billion € of the German government's budget is dedicated to its high-tech initiative, in particular funding nanotechnology research and development (Rieland et al., 2009, p. 6). The U.S., however, came first with spending public money on nanotechnology by launching the NNI (Wong et al., 2007, p. 716), which is institutionalized in universities in the form of research centers. The graph in Figure 4 (Hullmann, 2007, p. 746) demonstrates that in Europe most funding stems from the member states, whereas in the U.S., the private sector is the main sponsor of nanotechnology providing risk capital.

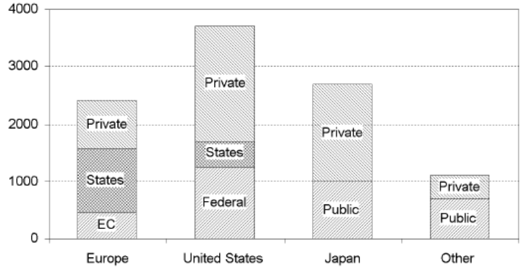


Figure 4: Sources of Funding in Selected Countries in million €; Source: Hullmann 2007

Figure 5**Fehler! Verweisquelle konnte nicht gefunden werden.**, the "Nations Ranking Grid" by Lux Research (Lux Research, 2010, p. 28), lists the ranking of countries according to their nanotech activity based on their technology development strength.

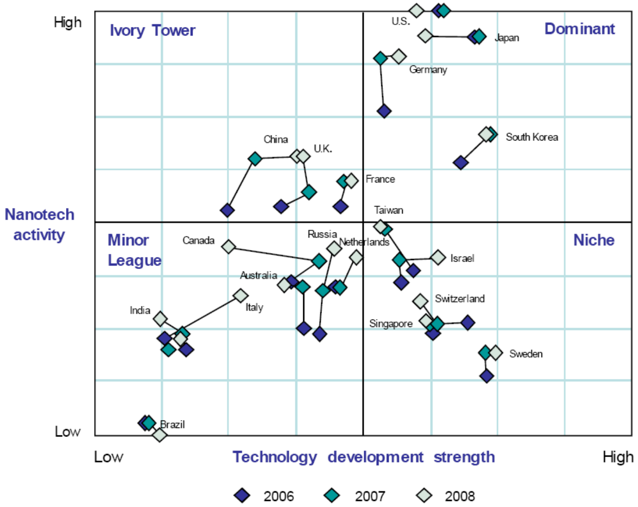
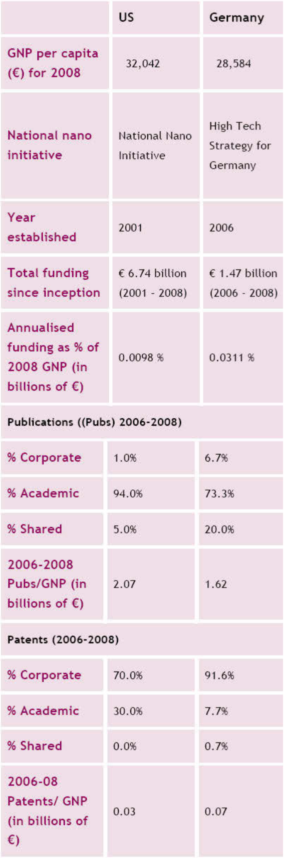


Figure 5: Nations Ranking Grid; Source: Lux Research 2010

The criteria for nanotechnology activity were nanotech initiatives, nanotech centers, government spending, risk capital, corporate nanotech funding, nanotechnology publications, issued international patents, and active companies. The technology development strength criteria were high-tech manufacturing as % of GDP, R&D spending as % of GDP, technology and science work force, science and engineering PhDs, expatriation of the highly educated, and infrastructure. The grid demonstrates the top three nations in nanotechnology being the U.S., Japan, and Germany.

Table 2 compares central data from the U.S. and Germany (Lux Research, 2010, p. 48). It shows the high involvement of corporations in patenting and the higher percentage of nanotech funding as % of GDP in Germany with 0.0311% versus 0.0098% in the U.S.. The latter indicates the priority Germany gives to nanotechnology in the frame of its "High Tech Strategy for Germany" that funds nanotechnology next to other high-technologies, such as materials engineering. The "High Tech Strategy," however, does not mean that nanotechnology was not funded by the German government before 2006. Already at the end of the 1990s, the federal government put nanotechnology on its list for R&D funding.



	US	Germany
GNP per capita (€) for 2008	32,042	28,584
National nano initiative	National Nano Initiative	High Tech Strategy for Germany
Year established	2001	2006
Total funding since inception	€ 6.74 billion (2001 - 2008)	€ 1.47 billion (2006 - 2008)
Annualised funding as % of 2008 GNP (in billions of €)	0.0098 %	0.0311 %
Publications ((Pubs) 2006-2008)		
% Corporate	1.0%	6.7%
% Academic	94.0%	73.3%
% Shared	5.0%	20.0%
2006-2008 Pubs/GNP (in billions of €)	2.07	1.62
Patents (2006-2008)		
% Corporate	70.0%	91.6%
% Academic	30.0%	7.7%
% Shared	0.0%	0.7%
2006-08 Patents/ GNP (in billions of €)	0.03	0.07

Table 2: Comparison of Germany and the U.S.; Source: Lux Research 2010

Networks and Clusters

Networks in Europe are highly concentrated in Germany, France, the UK, and Switzerland. Whereas the UK and Switzerland offer largely national networks, Germany and France provide both national and international networks, with national ones outnumbering international ones (Abicht et al., 2006, p. 27). In terms of expenditures, it is suggested that the U.S. indeed develop faster with regards to nanotechnology as, worldwide, it spends most on nanotechnology research and development. Europe has caught up with Japan and other countries and comes second by 2004 in public expenditures after the U.S..

In the U.S. where nanoresearch is concentrated more strongly in higher education institutions whose transfer technology offices link them to non-university research (Heinze, 2005, p. 72), most important clusters are “universities with National Nanotechnology Infrastructure Network (NNIN) facilities” (Stephan, Black, & Chang, 2007, p. 890): Cornell, Stanford, Georgia Institute of Technology, University of Washington, University of Michigan, University of Minnesota, Pennsylvania State University, University of California at Santa Barbara, University of Texas-Austin, University of New Mexico, Harvard University, Howard University, and North Carolina State University. Institutions with at least one nanocenter are Rice University, University of California Los Angeles, Northwestern, MIT, and University of Wisconsin Madison. SUNY Albany even created a “nanocollege” called College of Nanoscale Science and Engineering (Schummer, 2007, p. 680).

In Germany, the clusters are Technical University in Berlin, University of Hamburg, Technical University of Karlsruhe, LMU Munich, University of Münster, University of Saarbrücken, and University of Würzburg. The most central networks supported by the German Federal Ministry for Education and Research (BMBF) are the competence centers (CCs). In the Saxony Region, there is the Nanotechnology Centre of Competence “Ultrathin Functional Films” (Rieland et al., 2009, p. 36) with a network of 51 companies, ten university institutes, 22 research establishments and five associations. Its coordinator is the Fraunhofer Institute for Material and Beam Technology (IWS) in Dresden. There are the CC-NanoChem/NanoBioNet (Networks for Chemical Nanotechnology/Nanobiotechnology) in Saarbrücken, the ENNaB (Excellence Network NanoBioTechnology) in the Munich region, the CCN (Competence Center for Nanoanalytics) in the Münster region, the IVAM Microtechnology Network in the Ruhr region, the HanseNanoTec Competence Centre in the Hamburg region, the UPOB (Competence Centre Ultraprecise Surface Figuring) in the Brunswick region, the NanoMat in the Karlsruhe region, and the NanOp (Competence Centre for the Application of Nanostructures in Optoelectronics) in the Berlin/Brandenburg region (Abicht et al., 2006, p. 28; Rieland et al., 2009, pp. 37-39). Another Center is the CeNTech (Center for Nanotechnology) in Münster (Abicht et al., 2006, p. 29). The cluster of the projects NanoCare, INOS, and TRACER is subsumed under the governmental “Nano Initiative─Action Plan 2010” (Rieland et al., 2009, p. 42). Additionally, there is the BMBF campaign “’nanoTruck’” informing about nanotechnology by travelling through Germany. Roundabout 450 enterprises are involved in nanotechnology. Thus, after 2000, the German government invested heavily in nanoscience and nanotechnology and caught up with European countries as well as the U.S. and Japan. This is why for example in 1999 when the U.S. IWGN (Interagency Working Group on Nano Science, Engineering, and Technology) Workshop Report was published, Germany was not even mentioned among the leading the countries. Yet, this changed in the subsequent years and the governmental initiative certainly accounted for it (Roco et al., 1999, p. 288).

Patents

The number of patents in nanotechnology in comparison with the overall patents “reclassified by the U.S. Patent and Trademark Office (USPTO) as nanotechnology” (Wong et al., 2007, p. 717) show that after 1989, there has been a steep increase in patents in nanotechnology compared to the overall number of patents (Figure 6). With the exception of 2000, this increase lasted until 2003 and then decreased sharply by 2005 (Wong et al., 2007, p. 722).

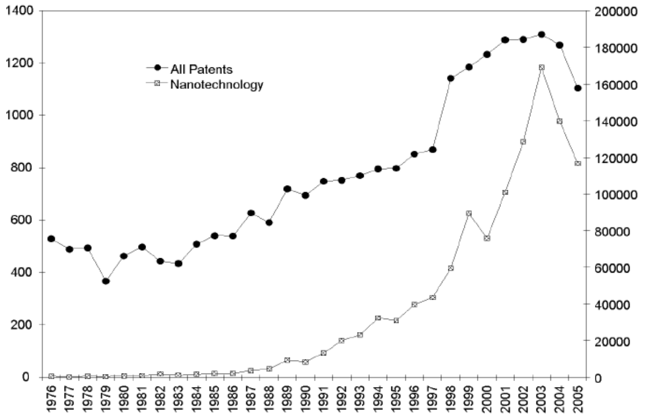


Figure 6: Number of Nanotechnology Patents Compared to All Patents, USPTO, 1976-2005; Source: Wong et al. 2007

Thus, nanotechnology measured by patents, the indicator "for technological performance as [an] indicator[s] for quantitative innovation research" (Hullmann & Meyer, 2003, p. 509) has experienced a "boost" in the 1990s and at the beginning of the 21st century.

Worldwide, most nanotechnology patents are owned by the private sector with around 70% of all patents in all periods shown, by universities with roughly 17% in the period of 2000-2004 and having increased form 11% in the period of 1976-1989, and, the last specified sector, by public sector institutions and the government at around 8% in 2000-2004 having remained approximately the same. Another interesting comparison delivers the trends in non-private sector ownership. Whereas in the U.S., nanotechnology patents are owned more and more by universities, in Germany, the ownership has declined about half from the period of 1990-1999 to 2000-2004. This trend is reversed in patents possessed by the government and public sector institutions: There is a decline in the U.S. from 6.6% in 1976-1989 via 9.1% in the period of 1990-1999 to merely 5.6% in 2000-2004. In Germany, by contrast, publicly owned patents rose from 0% in 1976-1989 to 13.3% in 2000-2004. The steepest increase occurred from 1976-1989 to 1990-1999 from 0% to 12.2%. (Wong et al., 2007, pp. 732-733) The trend in Germany toward publicly owned patents is certainly due to public research institutions, such as the Max Planck Society and the Fraunhofer Society, of which there are no complements in the U.S.. Especially the Fraunhofer Society is oriented strongly toward applied research (Heinze, 2005, p. 72). With regards to the central role of universities, patent citations by organizational categories show that universities are both most probably the patent assignee and the author of patents (in 24.7% of all cases) (Hullmann & Meyer, 2003, p. 523).

Publications

Publications in nanotechnology are used next to patents as an indicator for innovations as they measure scientific performance (Hullmann & Meyer, 2003, p. 509). The development of publications in the Science Citation Index measured in numbers shows a steady and steep increase in publications from 1989 on from roughly 1,000 publications to 12,000 in 1998 (Figure 7). By contrast, patents also rose steadily but suffered from more fluctuations and a decline after 1991 from which they did not recover till 1997. Thus, it is evident that the indicators of patents and publications need to be evaluated separately but brought together because scientific output interacts with patents. The curve could be interpreted in that the cure of patents demonstrates "technological development at an early stage": Small progress in science can lead to relatively higher patenting output. (Hullmann & Meyer, 2003, p. 510)

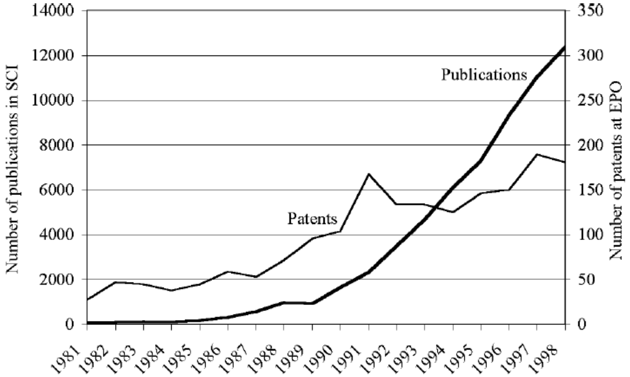


Figure 7: Number of Publications in SCI (left) and Patents at the European Patent Office (right); Source: Hullmann & Meyer 2003

The regional shares of publications worldwide show that Asia caught up compared to other regions. Its share rose from 17% in 1991-1993 to 25% in 1997-1999. This could happen at the cost of the share of the U.S. and Canada whose share declined from 42% in 1991-1993 to 28% in 1997-1999. The European Union-15 and the European Free Trade Association gained one percentage point in the same periods. (Hullmann & Meyer, 2003, p. 512) A more recent overview based on the SCI database demonstrates that Europe has become first in publications in nanotechnology with 41% in the period of 1998-2001. The U.S. and Canada come second with 24%, Japan third with 13%, and finally Asia with 14% (compared to 7% in 1992-1995) (Hullmann, 2007, p. 754).

It has been mentioned before that Germany belongs to the top three most active countries in nanotechnology. In publications on nanotechnology, this holds true as well. For example in 1997-1999, Germany accounts for 10.7% of publications worldwide following the U.S. (23.7%) and Japan (12.5%) (Hullmann & Meyer, 2003, p. 512). However, the most dynamic countries in terms of nanoscientific output are South Korea and China when it comes to total growth rates from 1995 to 1999. Thus, the trend indicated by the regional shares mentioned in this paragraph is confirmed: Asia is starting to overhaul the "big players" U.S., Japan, and Germany.

Nanoscientific publications worldwide show that by 1999, most publications stemmed from materials science, condensed matter physics, applied physics, physical chemistry, polymer science, chemistry, and physics (ranked according to number of publications top-down) (cf. Heinze, 2004, p. 431; Hullmann & Meyer, 2003, p. 514). This alludes to the importance of physics in nanoscience publications and suggests that a country like Germany has had a good starting position in nanotechnology and has been able to become a leader in the core technology of nanotechnology because it has been showing high performance in the realm of physics. The fact that the German sample of interviewees includes more physicists than the U.S. sample underlines that Germany had an advantageous position for nanotechnology in physics as prominent physicists to be interviewed were easily to be recruited in Germany whereas in the U.S., outstanding chemists and material or electrical engineers were rather recruited from the nanosciences than physicists. In the U.S. sample, there is one physicist, compared to eight in Germany. Furthermore, institutional permeability in the German public research sector, which is the most important sector in research in technology, leads to knowledge flows in nanoscience and –technology between universities and the extra-university research sector ensuring Germany's strong position in the field of nanoscience and –technology (Heinze & Kuhlmann, 2008). With regards to the relationship between patents and publications, Heinze (2004, p. 435) speaks of a highly significant, almost deterministic relationship between the number of patents and publications even if country size measured by the GDP is taken into consideration. A relationship between science and technology is also to be noticed (Heinze, 2004, p. 435).

Market Size

The next graph (Hullmann, 2007, p. 741) forecasts the size of the market for nanotechnology products (see Figure 8). Certainly, it must be interpreted carefully and the predicted numbers of the same year can vary substantially. However, a substantial increase is assumed by each prognostic curve just as an increase of the world market potential for nanotechnology is predicted by other prognoses as well (Abicht et al., 2006, p. 24; see also CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 1).

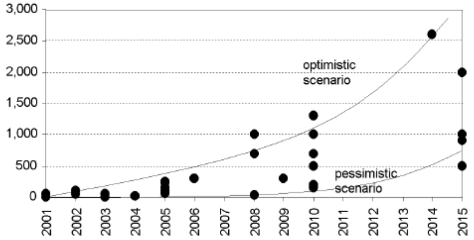


Figure 8: Forecasts Nanotechnology Market in billion US-$; Source: Hullmann 2007

Accordingly, venture capital funding worldwide in nanotechnology escalates both in absolute venture capital investment and in the share of total venture capital investments. From 1999 to 2005, the share of total venture capital investments rose from about 0.1% to 2.2% with a steep increase from 2001 to 2002 (Hullmann, 2007, p. 747). This supported an increase in nanotech companies worldwide outlined by the following graph (Hullmann, 2007, p. 749):

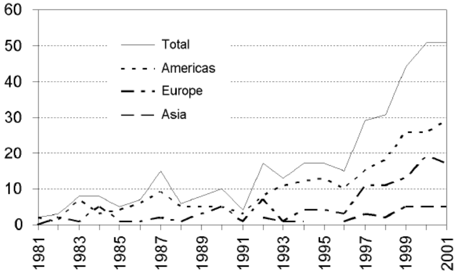


Figure 9: Nanotechnology Companies Worldwide, 1981-2001; Source: Hullmann 2007

Figure 9 shows that the most precipitous increase was from 1997 to 2001 overall. The Americas are second in the number of companies followed by Europe.

All in all, projections in nanotechnology vary. For now, nanotechnology is without doubt one of the mostly funded high-technologies in Germany and the U.S., as well as other countries. Some see nanotechnology as a promising factor driving economic growth and providing jobs in the labor market for college-educated professionals and technicians. Others, such as a market analysis by Lux Research (Lux Research, 2010, pp. 29-30), project that beyond 2015, nanotechnology funding will have reached its peak. “Nano” will become routine and gradually vanish as a term in industry.

2.2 Nanotechnology in the Context of Teaching

With respect to funding on a national level, the German government is involved in fostering materials/ manufacturing, devices (including electronics and optics), energy and environment, biotechnology/medicine, and instrument development. In contrast to Germany, the U.S. also funds education (Abicht et al., 2006, p. 23). This, and the fact that the U.S. higher education system enabled the proliferation of high-technology industries (Gibbons et al., 1994, p. 74), are to be kept in mind when comparing both countries in terms of educational development in nanotechnology. Study programs as well as Ph.D. programs are offered both in Germany and the U.S., however differently developed due to institutional structures and different market and education and training systems (see chapter 3).

In the U.S., course offerings, graduate programs, and Ph.D. programs were offered very sparsely, at least on a regular basis, before the 1990s. Drexler taught the first course on molecular nanotechnology at Stanford in 1988, which, however, was unique. Then, in 1991, the first courses in nanotechnology were offered at Cornell University. It was not until 1994 that the first regular course in nanotechnology was offered for graduate students at the University of Southern California. (Newton, 2002, pp. 113-114) The first Ph.D. program was established at the University of Washington. However, it was designed as a regular program anchored in traditional disciplines with an additional option of obtaining additional competence in nanotechnology as basic and profound instruction in a discipline was deemed indispensable in preparing students for a professional career (Vogel & Campbell, 2002). Other universities, such as Rice University, the University of Massachusetts Amherst or the University of Texas, followed by implementing Ph.D. programs (Stephan et al., 2007, p. 890). Graduate programs are also in the pipeline (e.g. Johns Hopkins) (Stephan et al., 2007, p. 890). Stephan and colleagues (2007, p. 890) list all universities offering courses with “nano” as part of their descriptions. These are, as already mentioned in chapter 5.1., the 13 NNIN institutions, ten institutions with at least one nanocenter, and seven institutions randomly selected as universities offering at least one program in bioinformatics. After 2000, the number of nano-related courses rose steeply by 900% from about 25 to 225 (Stephan et al., 2007, p. 890).

In Germany, there are also nano-related courses offered at departments, such as the departments of physics, chemistry, material sciences, electrical engineering, computer sciences, engineering sciences, mechanical engineering, biology, and pharmacology and medicine respectively. Autonomous and interdisciplinary lectures in nanotechnology are harder to find. Examples are ‘NanoEngineering’ at the University of Duisburg-Essen, ‘Nanostructure Science’ at the University of Kassel, ‘Micro- and Nanostructures’ at the University of Saarbrücken, ‘Nanostructure Technology’ at the University of Würzburg, or ‘Molecular Science’ at the Erlangen-Nuremberg University. Courses related to nanotechnology as additional options are offered at Aachen, Chemnitz, and Bielefeld. (Rieland et al., 2009, p. 7)

Postgraduate courses are rather offered at universities than at universities of applied sciences. There is a Master of Science degree at Ilmenau University, Jacobs University Bremen, and the Technical University Dresden with an E-learning course offered at Kaiserslautern University. The small range of course provided by universities of applied sciences (UAS) is anchored in the departments of electrical engineering and computer sciences, physics, mechanical engineering, and materials science. ‘Bio- and Nanotechnology’ is offered by Iserlohn UAS, ‘Optical engineering and Nanotechnologies’ by Isny UAS, ‘Micro- and Nanotechnology’ at Munich UAS, ‘Nano- and Production Technology’ at Nuremberg UAS, and ‘Nano- and Surface Technologies’ at Zwickau UAS. (Rieland et al., 2009, p. 8)

Eva Cebulla, Norbert Malanowski, and Axel Zweck (2006) offer a broad overview of higher education offers in nanotechnology. They show that most offers refer to nano-related courses but graduate programs are also already registered by universities (Cebulla et al., 2006, p. 18): Examples are the Master’s program in material sciences at RWTH Aachen, the diploma in biophysics at the Technical University Kaiserslautern, a master of science in optoelectronics and photonics at the HTW

Aalen, a diploma in nanostructure technology at the University of Würzburg, a diploma in precision production technology and a master in optical engineering/photonics at the Technical University Dresden, or a Bachelor degree in physics with a focal point in material sciences. Single courses are polymer and colloid chemistry at the University of Bayreuth, nanoscience at the University of Bielefeld, nanostructure physics at the University of Bielefeld, molecular bioengineering at the Technical University Dresden, chemistry and bioengineering at Nuremberg-Erlangen University, microelectronics and microsystems at the Technical University Hamburg-Harburg, life science at the University of Hannover, micro- and nano-electronic systems at the Ilmenau University, nanostructure science at the University of Kassel, microsystems technology at the UAS Regensburg, engineering at the University of Siegen, bio and nanotechnologies at the UAS Südwestfalen, advanced materials at the University of Ulm or environmental biotechnology/environmental engineering at the International University Institute of Zittau. Furthermore, many interviewees in the authors' study (39,6%) indicate that graduate programs with a focal point in nanotechnology are planned (Cebulla et al., 2006, p. 24). Additionally, vocational education courses are offered by university lecturers which are also open for externs (Cebulla et al., 2006, p. 25).

When comparing the number of graduate courses and degrees on nanotechnology (the fact that both types of teaching are combined underlines that degrees might still be underrepresented) on a European level, it becomes clear that the UK comes first with 20 courses and degrees in 2005, France second with 18, and Germany third with 17. This demonstrates that the German government and universities lag behind in fostering nano-related education by introducing new courses and degrees or modifying existing ones. Furthermore, other overviews show that Germany does not come first in terms of education in nanotechnology when counting the number of courses and degrees offered. One summary (Abicht et al., 2006, p. 35) that, again, the UK comes first with ten undergraduate degrees and courses, Germany second with five, and Denmark third with three. Another overview from 2005 (Abicht et al., 2006, p. 36) shows that in terms of the number of short courses in nanotechnology, Denmark comes first with ten courses and Germany second with five. Lothar Abicht, Henriette Freikamp, and Uwe Schumann (2006, p. 35) conclude with regards to the status quo of education in nanotechnology that "in intermediate skills and qualifications, little higher education is offered [in Germany]and even less initial training. Publications on the syllabuses of these apprenticeships and further training are rare." Compared to other countries, however, Germany, although it is not number one in education, provides a "relatively equal concentration across the educational range" (Abicht et al., 2006, p. 36).

In terms of Ph.D. programs in Germany, it must be remarked that traditionally, nanotechnology can only be integrated into a dissertation by the student's focus on nanotechnology in his or her topic and research design and/or by working with a professor who specializes in nanoscience. However, there are as of now six graduate colleges funded by the DFG. These six university colleges are: "Nanotronics—Photovoltaics and Optoelectronics of nanoparticles" at Duisburg; "Analysis, Simulation and Design of nanotechnological processes" at Karlsruhe; "Calcium-Signals and cellular nanodomains" at Saarbrücken; "Nano- and Biotechnologies for packaging electronic systems" at Dresden; "Micro- and Nanostructures in Optoelectronics and Photonics" at Paderborn; and the international graduate college "Self-Assembled Soft-Matter Nanostructures at Interfaces" at Berlin, Golm, Chapel Hill, Philadelphia, Raleigh (Deutsche Forschungsgemeinschaft (DFG)). These graduate colleges differ from the traditional form of obtaining a Ph.D. degree in Germany by an educational program which graduate students participate in parallel to doing research and writing their dissertation.

The question arises to what extent educational institutions–in the realm of nanotechnology mostly higher education institutions–must react to labor market demands. If it is assumed that education systems must consider qualification demands of employers, results indicate that receiving a first degree in a scientific discipline, such as chemistry or physics, is preferred by over 34% of the companies combined with a master's degree in nanotechnology. Or, with the same percentage of companies

asked, a Ph.D. graduate with a degree in a scientific discipline and in nanotechnology is most likely to be useful. This survey result demonstrates that nanotechnology is still seen as a domain where college-educated graduates are desired, in particular Ph.Ds. and with an advanced degree (Abicht et al., 2006, p. 34).

2.3 Nanotechnology as a Future Profession in the Labor Market

The positive expectations on the future of nanotechnology as a core technology are not only extant in the area of market size but also in the realm of the labor market. Nevertheless, an online survey from 2004 showed that Europe still lags behind the U.S. in nanoscale science and in transfer of nanotechnologies to industries. Nanotechnology is considered most important in the future in following sectors and branches: "chemistry and materials, information and telecommunication technologies, health service and security/defence" (Abicht et al., 2006, p. 31). It is assumed that the size of the nanotechnology labor market will increase significantly in the future. This fact is illustrated by Figure 10. It indicates the (projected) number of jobs and the share of all manufacturing jobs (Hullmann, 2007, p. 748). It is evident that in both calculations, a steep increase is foretold.

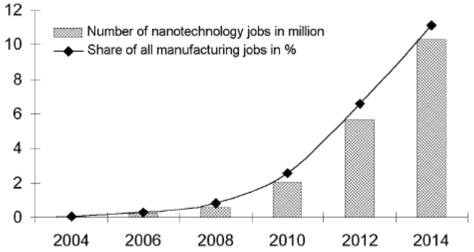


Figure 10: (Projected) Number of Jobs in Million and Share of All Manufacturing Jobs, 2004-2014; Source: Hullmann 2007

Like Figure 10, there are several projections on the labor market size in nanotechnology. A dearth of skilled personnel is expected until 2015-2020. There is an urgent demand for education and training focusing interdisciplinarity and the need to monitor societal effects of nanotechnology. Based on a VDI Technologiezentrum study, an "increase in employment of 10 000 to 15 000 jobs in nanotechnology is expected throughout Germany within 2006" (Abicht et al., 2006, p. 32). A projection by the Business Communication Company asserts that by 2015, 160,000 skilled personnel is needed worldwide in nanoBIOtechnology the project Nanotec in Germany describes the cluster development via a company questionnaire (altogether 42 companies responded). The manpower requirement in 2007 shows that most personnel needed is scientists, above all in small (<10 employees) and medium (50-250 employees) companies, then engineers, and, finally, (intermediate) qualified personnel. (Abicht et al., 2006, p. 32)

Thus, the question is if this confirms that academics are not pushed away by dual system graduates. So far, there has been a high demand for university graduates and a rather low demand for personnel with qualifications below a university degree. Yet, structural changes in firms are probable because of an increasingly high degree of automation. Tasks, such as "process control, quality assurance and documentation", can be delegated to staff qualified below university level. (Abicht et al., 2006, p. 47) There are experts who speak of a significant growth in the need for employees with intermediate skills, above all in conjunction with increasing mass production in nanotechnology (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 2). However, with the predicted growth of the market size in nanotechnology, there does not have to be necessarily a push-effect as with growing markets, both employees with tertiary education and intermediate-level skills will be needed. Jobs for graduates from different levels of education will most likely be created "at different occupational levels:" researchers and scientists with tertiary education, technicians and specialists with secondary, post-secondary, and non-university tertiary education (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 1). With regards to difficulties in recruiting, which are mentioned by most people interviewed in the European nanobusiness survey 2005, the need for improvement of "links between academia and industry" is cited (Abicht et al., 2006, p. 37).

An interesting and for the comparison of the U.S. and Germany relevant question might be to what extent higher education systems recruit researchers by focusing on nanotechnology and thus, poach companies' employees (cf. the field of artificial intelligence where this circumstance could be observed). The "production" of graduates in nanotechnology will have an impact on the professionalization of nanotechnology as the question is to what degree these graduates are re-integrated into universities or find a job in transdisciplinary research centers and industry. This can be compared to the professionalization in the field of artificial intelligence as observed by Petra Ahrweiler (1995).

Lothar Abicht, Ekkehard Schlicht, and Uwe Schumann (2005) published a study on qualification profiles in nanotechnology. In the case of nanotechnology, general skills include "interdisciplinary cross-sectoral knowledge in natural sciences and in engineering as well as basic business management knowledge and entrepreneurial spirit" (Abicht et al., 2006, p. 39). Specific skills address "master certain nanotechnological procedures" (Abicht et al., 2006, p. 39). Qualification profiles are complex trend qualifications, which cover a structured and relatively precisely confined field of activity (Abicht et al., 2005, p. 12). Trend qualifications are constituted by professional, methodological, and social skills (Abicht et al., 2005, p. 11), but also "entrepreneurial and management skills" (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 2). Professional skills refer to interdisciplinary knowledge in natural sciences, i.e., physics, chemistry, biology, and engineering sciences. Examples of knowledge relevant for both intermediate and higher skills are "characteristics of materials and surfaces on the nanoscale" or "quantum mechanics, molecular biology or polymer chemistry" (Abicht et al., 2006, p. 40). Intermediate skills involve specific interdisciplinary knowledge and highly pronounced social competences and are even less easy to be predicted than other skills because of the cross-disciplinary disposition of nanotechnology (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 2). Overall, "a modular qualification system" is suggested to implement nanotechnology and nanosciences into educational programs, both at universities and in vocational training (CEDEFOP European Centre for the Development of Vocational Training, 2006, p. 2).

2.4 Conclusion

The elaborations above have shown that once nanotechnology has been launched through radical innovations, above all the scanning tunneling microscope in the 1980s, the dynamics of diffusion in Germany and the U.S. concerning research, teaching, and the labor market set off in directions that are overall the same, yet exhibiting national procedures and processes with different nuances and foci. This makes clear that the development of advanced technologies does not take place in a vacuum. The development depends on institutional structures and actors', in the case of nanotechnology in particular the government's, interests. For now, one can say that nanotechnology is an important, politically pushed high-technology in both countries' policy agendas that cannot be ignored. It is institutionally anchored in research, higher education–in the U.S. also in secondary education, in Germany with a focus on nanotechnology degrees–, and in the labor market. The future of nanotechnology is unanimously regarded as thriving globally and influencing everyday lives in way that computers have. Naturally, prognoses must be regarded with caution concerning the calculations and projections of volumina and market shares. Nevertheless, one has reason to observe more closely what the field of nanotechnology develops into and will bring about in the future. The way in particular governments are promoting shows that the competition has already started–worldwide.

3. Science, Technology, and Work: Theoretical Perspectives[2]

This chapter presents the theoretical framework of the study. While there is an abundance of studies on the interconnectedness between science and industry/labor market, the author focuses on the academic sector and its inner life by combining several theoretical perspectives: the VoC approach (3.1) with a subsequent section on professional associations (3.2), Mode 2 and Mode 1 (3.3), organizational analysis from the neoinstitutionalist perspective (3.4), and professionalization concepts (3.5). Whereas patents and publications provide a mere macro-perspective, the selected approaches allow for an analysis of the macro-level (VoC), the meso-level (neoinstitutionalism, Mode 1 and Mode 2 knowledge production), and the micro-level (professions). These theories represent analytical schemes for the interview data (chapter 7). They allow for a detailed, multi-faceted interpretation and understanding of the micro-level interview data and for the setup of the explorative hypotheses on meanings of nanotechnology, on identity construction, the characteristics of the field of nanotechnology, and institutional comparisons of Germany and the U.S.. Several concepts from sociological neoinstitutionalism are selected from the repertoire of theories available for an analysis of the inner life of an organizational field, the present study's research interest. They are not selected out of a need for further theoretical perspectives, which would lead to a mode of theoretical eclecticism. Instead, they promise to contribute to a better understanding of the field and the empirically observed phenomena. These concepts are integrated into the Mode 2 concept for a deeper and more detailed analysis of the mode of knowledge production within the field of nanotechnology. Mode 2 as a concept does not include theoretical tools for an analysis of knowledge production. The selected neoinstitutionalist concepts make up for this lack of tools and promise to be valuable perspectives for the analysis of the empirical data that were gathered within the field.

The VoC approach, however, is discussed merely by the use of literature, for interview data were not gathered to test for this approach. This study does not provide a theoretical production for VoC. Instead, the VoC concept serves as an entry point for the analysis of the field of nanotechnology by raising the question how it can be that nanotechnology has been successfully implemented in Germany and the U.S.. Germany namely does not represent a political economy where such a success would be expected according to VoC theory. VoC cannot answer and explain the interest of the present study which lies in the make-up of the inner organizational life of nanotechnology in academia. Yet, the importance of VoC consists of the fact that it stresses the necessity of a deeper look into nanotechnology. Then, one realizes that the case of nanotechnology is much too complex for its subsumption under a general macro-theory like VoC. As a consequence, the meso- and micro-level are examined from different theoretical perspectives. The theoretical analysis of interview data contributes to the understanding of the field without testing the applied perspectives. The quantitative simulation chapter (chapter 6), another methodological approach presented next to interview techniques, focuses on nanotechnology as a general field. The chapter has a broader emphasis on social structure and networks, as addressed in section 3.4., which is why it precedes the interview analysis.

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[2] This chapter is partly derived from Hoser, N. (2010). Nanotechnology and its Institutionalization as an Innovative Technology: Professional Associations and the Market as Two Mechanisms of Intervention in the Field of Nanotechnology. *Nanotechnology Law & Business 7*(2), 180-197.

3.1 Varieties of Capitalism: Central Features, Related Research, and Relevance for the Study

3.1.1 Main features of the Varieties-of-Capitalism Approach and Discussion

The VoC approach was founded by Peter A. Hall und David Soskice (2001b). This approach basically states that Western political economies can be distinguished according to the way national subsystems (i.e., firms, education and training systems, inter-company relations, industrial relations, and corporate governance) are coordinated and regulated (Hall & Soskice, 2001a, p. 28). Hall and Soskice argue that education and vocational training systems are relevant factors in the organization of innovations in both social democratic and liberal market economies (Hall & Soskice, 2001a, p. 8). One example for a vocational training system is the dual system in Germany, which provides apprenticeships where high school graduates work in a company and go to vocational schools for about three years. In social democratic economies, social security is guaranteed by the state. In LMEs, relationships between firms are formed by contracts and strategic interaction in competitive markets. (Hall & Soskice, 2001a)

The VoC's principal assumption is that institutional structures, including labor market regulation, education and training, depend on the regulatory regimes which safeguard the nation state (Hall & Soskice, 2001a). The core ideas of the VoC approach are institutional "complementarities [and] system coordination" (Hall & Soskice, 2001a, p. 3). The subsystems, such as education and training and the labor market, are synchronized differently in CMEs and LMEs but always in a way to keep balance between them. Building on the notion of complementarities, Bob Hancké, Martin Rhodes, and Mark Thatcher (2007) further argue that "[i]nstitutional subsystems (which govern capital, labour, and product markets) shape the evolution of political economies and often mutually reinforce each other. The presence of several 'correctly calibrated' subsystems increases the performance of the system as a whole, while producing specific adjustment paths in response to pressures for change." (p. 3) The VoC approach aims to demonstrate the relationship "between the competitiveness of the firm and the 'institutional comparative advantage' of national economies" (Hancké et al., 2007, p. 4). Thus, under the VoC approach, countries would have a difficult time inducing change because any change in a subsystem would disturb the balance between the subsystems. This for example is one of the major critical points that have been directed at the VoC approach.

The VoC approach draws a basic distinction between LMEs and CMEs (or also called organized market economies). CMEs are characterized by non-market relations, collaboration, credible commitments, the "deliberative calculation" of firms, long-term employment strategies, rule-bound behavior, the production of "specific or co-specific assets" as well as durable ties between firms and banks ("patient capital provision predisposes firms to 'incremental innovation' in capital goods industries, machine tools, and equipment of all kinds" (Hancké et al., 2007, p. 5)). LMEs, by contrast, are marked by "competitive relations," "formal contracting," "supply-and-demand price signalling," "fluid labour markets," "stock market capital," "producing 'radical-innovator' firms" (biotechnology, semiconductors, software, advertising to corporate finance), and "'switchable assets'" (Hancké et al., 2007, p. 5). The exemplar for an LME is the U.S. where the dominance of the market as the coordinating mechanism can be clearly noticed (Vitols & Engelhardt, 2005, p. 2). Gregory Jackson and Richard Deeg (2006) characterize an LME by "short-term orientated company finance, deregulated labor markets, general education, and strong inter-company competition," a CME, on the other hand, by "long-term industrial finance, cooperative industrial relations, high levels of vocational training, and cooperation in technology and standard setting across companies" (p. 22). The paradigm for a CME is Germany.

Critique

The critique on the VoC approach is directed toward its static, permanent, path-dependent, and functionalist orientation. The approach is assumed to neglect endogenous change of nation-states and “’within-system’ diversity” (Hancké et al., 2007, p. 7). In particular Wolfgang Streeck and Kathleen Thelen (2001, p. 5) point out that VoC understates contemporary change and its effects. Instead, VoC defends a conservative model of equilibrium which does not take change and tendencies toward discontinuity into consideration properly by focusing primarily on “continuing cross-national divergence” (Streeck & Thelen, 2001, pp. 5, 16) and differing employer interests. Streeck and Thelen (2001) argue that there are internal conflicts in nation-states resulting from endogenous–or also called incremental and transformative–change. This implies the replacement of existing and “taken-for-granted organizational forms and practices” (Streeck & Thelen, 2001, p. 19) but also “the rediscovery or activation of previously suppressed or suspended possibilities” (Streeck & Thelen, 2001, p. 21). Actors have decisive influence by participating in several institutions, not only one, and, by having different “action spaces” (Streeck & Thelen, 2001, p. 21), they cause internal conflicts. Both authors suggest the analytical distinction between “processes of change” (abrupt or incremental) and “results of change” (leading to continuity or discontinuity) (Streeck & Thelen, 2001, p. 8). The case of nanotechnology shows that actors indeed can bring about change through their involvement with national higher education policies and the reconcilement of their interests with political and/or economic ones.

“’Institutional determinism’” (Hancké et al., 2007, p. 7) and the missing autonomy of firms are additional points of critique. Seen as a methodological deficit, the VoC theory is merely inductive, not deductive by using Germany and the U.S. as paradigm cases. The critique here aims at dismantling the transferal of findings about the two paradigm cases to other countries of the same type of VoC. As the VoC approach focuses the manufacturing sector, the question arises where service sectors, which increasingly play an important role, come into play and how they are integrated into VoC theory. Other contested aspects are the neglect of convergence and globalization, the role of the state, and the inequality of the sexes. Hancké, Rhodes, and Thatcher (2007) counter that VoC is not a “unified theory of everything” and that VoC purveys a “strong non-deterministic understanding of change” (p. 8). (Hancké et al., 2007, pp. 7-8)

Economic Performance of CMEs and LMEs

LMEs and CMEs do not differ much with respect to their economic performance except for the distribution of income and employment as well as their capacities for innovation; the latter will be discussed in more detail shortly. Unemployment rates are usually higher in LMEs, income is distributed more unequally, and working hours are longer by tendency. (Akkermans, Castaldi, & Los, 2007, p. 5; Hall & Soskice, 2001a, pp. 20-21) LMEs and CMEs obtain their competitiveness in times of exogenous shocks and domestic change “from distinctive sources of comparative institutional advantage” (Hancké et al., 2007, p. 29) and react effectively in their own way. Boyer (2005, p. 29) also links the VoC concept of change to external shocks.

Yet, Jackson and Deeg (2006, p. 21) assert that economic growth rates are usually higher in LMEs at least for the period from the late 1990s till the beginning 21st century. They notice higher mobility in LMEs because of a higher number of newly created jobs within this period, probably attributable to rapid innovations and the foundations of start-ups. In CMEs, skills are industry- or firm-specific. Hancké, Rhodes, and Thatcher (2007, p. 32) trace Germany’s specialization in high-value export sectors back to high levels of training and specialization in skills. Related problems according to the authors consist in the combination of strong vocational training, of associated risk-aversion to loss of jobs and income, and proportional representation in collective bargaining, which leads to high transfer payments with the result of higher labor costs. In short, CME firms pursue a high-value and high-quality product strategy in contrast to LMEs where a low-price and low-cost strategy respectively prevails.

Moreover, a “high proportion of specific skills” leads to a demand for a “higher level of social insurance” (i.e., redistributive spending) than in LMEs, which focus on general skills. As skill profiles in LMEs are more general, choices to be made are more complex. (Hall & Gingerich, 2004, p. 9; Hancké et al., 2007, p. 20; Thelen, 2004, pp. 16-17) Pepper D. Culpepper (2001, p. 275) writes about the system of vocational education and training in CMEs such as Germany and France. He points to the German dual system of apprenticeship training which receives international attention for “a smooth transition to work” (Culpepper, 2001, p. 276) and for successfully reducing youth unemployment. Referring to Germany, he speaks of a “’high-skill equilibrium’” because companies there have incentives to invest in portable skills. The success of Germany to sustain this equilibrium is explained by institutions of employer coordination. “[A]ssociations can negotiate the content of skill qualifications with unions, while circulating information about training behavior that is necessary to ensure that firms continue to invest heavily in apprenticeship training” (Culpepper, 2001, p. 276). In this context, the main actors of coordination in Germany to look at are employers’ associations, unions, and chambers such as the DIHK (Deutsche Industrie- und Handelskammer, the “national umbrella organization of the chambers” (Hassel, 2007, p. 271)) (Culpepper, 2001, p. 289). Finally, a major issue in the VoC approach is the provision of training conveying either specific or general skills to workers and as a result, framing the production strategies of companies (Hassel, 2007, p. 264). “[S]pecific skill provision, combined with tight dismissal laws and a generalized wage structure” is a pillar in “the incremental production regime of engineering firms in Germany” (Hassel, 2007, p. 264).

Role of the State

Stewart Wood (2001) remarks on the role of the state as an institutional subsystem within the regulatory framework of coordinated and liberal market economies. According to him, “governments should produce policies that complement the institutional comparative advantage of their respective market economies. In an LME, where relations between firms are mediated by markets, the state will be more effective if it restores and ‘sharpens’ market mechanisms. In a CME, effective policy consists in supporting the institutions and networks of coordination that connect companies” (Wood, 2001, p. 274).

Education and Training Systems in the Context of Innovations

Abundant case studies and discussions are available applying the VoC approach on the institutional subsystems of labor markets and educational and vocational training systems, the two subsystems that are relevant in this dissertation (Hall, 2007; Hall & Gingerich, 2004; Hassel, 2007; G. Jackson & Deeg, 2006; Thelen, 2001; Thelen & Kume, 2006; Vitols & Engelhardt, 2005; Wood, 2001). As firms are the central actors of the VoC approach, their interaction with other subsystems—in the present case employees, unions, professional associations, and the state—is commonly at the center of empirical analyses. A focus on innovation is adopted by numerous analyses (see Akkermans et al., 2007; Boyer, 2003; Teipen, 2008; Vitols & Engelhardt, 2005), with several including a focus on economic sectors such as “Neuer Markt” (Vitols & Engelhardt, 2005) or “New Economy” (Teipen, 2008) showing the need for further differentiation within liberal and coordinated market economies. Hall and Soskice claim that “the technological specialization patterns of developed countries are largely determined by the ‘varieties of capitalism’ prevailing in these countries” (Akkermans et al., 2007, p. 3; Hall & Soskice, 2001a, p. 21). This thesis is based on the observation that U.S. patents are attributed largely to technology sectors (biotechnology, telecommunications, semiconductors) whereas German patents originate from technology fields such as transport and mechanical engineering (Akkermans et al., 2007, p. 3). Within the context of this dissertation, the differentiation between radical and incremental innovations is most important. Radical innovations are ascribed to LMEs, incremental innovations to CMEs (Akkermans et al., 2007, p. 3; Boyer, 2003, pp. 181-182; Hall & Soskice, 2001a, pp. 38-39). Jackson and Deeg (2006) cite Michael E. Porter (1990) who attributes to Britain and the U.S. the capacities for “radical innovation and changing technologies” (G. Jackson & Deeg, 2006, p. 20). Accordingly, Germany and Japan are supposed to be more successful in "incremental innovations in the processes and products of well-established industrial sectors" (G. Jackson & Deeg, 2006, p. 20). Jackson and Deeg (2006) conclude that

> "[t]he basic answer is that highly coordinated economies often prove better able to generate the collective inputs necessary to foster incremental innovations within stable organizational settings. Highly skilled manual workers, long-term capital investments, cooperative labor relations or standard setting across companies all help foster the innovations that depend on incremental improvement of process or product design. By contrast, more market-oriented and competitive economies are better able to generate the labor mobility and venture capital necessary to pursue or incorporate radical science-based innovation" (p. 20).

Technologies differ with respect to two criteria: asset-specificity and uncertainty. Examples are computer software and biotechnology which are both earmarked by great uncertainty and vicissitude (compared to for example "nuclear energy and space exploration" (G. Jackson & Deeg, 2006, p. 20)) but less demand for "asset-specific investments" (G. Jackson & Deeg, 2006, p. 20). With regards to nanotechnology in Germany, this high-technology is similar to biotechnology in terms of an available public R&D infrastructure (government-sponsored programs such as the "Nano Initiative–Action Plan 2010" (Rieland et al., 2009), the "TechPortal Nanotechnologie" (VDI Technologiezentrum: TechPortal), or the "High-Tech Strategy" (Rieland et al., 2009)), flexible institutions (university and non-university research centers (Rieland et al., 2009, p. 42)), necessary supportive technical equipment, and a public research network that ensures sufficient knowledge flow in nanoscience (Heinze & Kuhlmann, 2008). In biotechnology, Germany has made some progress in the late 1990s compared to the UK (Casper & Kettler, 2001), above all in terms of the number of start-up companies and the circumvention of traditional VoC complementarities that normally hinder the emergence of a successful biotechnology sector in a national economy (Herrmann, 2008). This finding is an indicator for the invalidity of the VoC approach used by Steven Casper and Hannah Kettler (2001) who replace the "national level institution" (Casper & Kettler, 2001, p. 27) focus in the VoC approach by a "firm-centered approach" (Casper & Kettler, 2001, p. 27) and argue for the hybridization of business models in Germany as a reason for the late success of Germany's biotechnology sector rather than a hybridization "at the level of national institutional frameworks" (Casper & Kettler, 2001, p. 27). Similarly, Mats Benner and Hans Löfgren (2007) found that in the case of the bio-economy in Finland, Sweden, the U.S., the UK, and Australia the dichotomy between CME and LME does not hold. The selected countries namely converge with regards to the mounting public funding in bio-economy. There is policy consensus on "loose steering and coordination of the bio-economy" (Benner & Löfgren, 2007, p. 94), an interdependency between private and public actors, and "public-private networks supported by pragmatic, business-oriented public policy" (Benner & Löfgren, 2007, p. 95).

The advancement of Germany in nanotechnology as the third largest leader after the U.S. and Japan (Wong et al., 2007, pp. 724, 726 e.g.) could be explained by two circumstances: First, German scientific research is strong in physics (Hinze, Tang, & Gauch, 2007, pp. 8-10) so that the initial condition for Germany to become "a big player" in nanotechnology, in particular with regards to technical equipment and skills, was favorable. After all, it is the discipline of physics to which nanoscience and nanotechnology and their patent citations refer the most (Hullmann & Meyer, 2003, p. 520), with a small observable shift lately to chemistry and engineering (Heinze, 2004, p. 431, 2006a, p. 110; Hullmann & Meyer, 2003, p. 514). The categorization into disciplines is questioned insofar as nanotechnology and nanoscience are commonly characterized as interdisciplinary (Abicht et al., 2006, pp. 39-40; Hullmann & Meyer, 2003, p. 508; Vogel & Campbell, 2002, p. 498) although this is controversially discussed as there are no communicative structures between the disciplines involved (Heinze, 2006a, p. 111). The difficulty of defining the scope of nanoscience and -technology because of their

cross-disciplinary or multidisciplinary character is, however, unanimously recognized (Hullmann & Meyer, 2003, pp. 507-508; Jopp, 2006, pp. 40-41; Rieland et al., 2009, p. 7).

A second explanation is that Germany provides certain organizational aspects which favor innovations in new technologies such as small research groups and centers, visionary leaders giving young scientists enough freedom, scientific diversity, an environment with complementary diversity, and flexibility, above all in financing (Heinze, 2007, pp. 6-8; Hollingsworth, 2008, p. 321) and a public research sector (see Heinze & Kuhlmann, 2008). This has been confirmed in selected cases in nanoscience and human genetics (Heinze, 2007).

Yet, what seems to be a disadvantage of Germany in innovative nanotechnological research, is that Germany's educational and training system lacks features which are seen as central promoters for innovations in the realm of education and training (Finegold, 2006). David Finegold (2006, pp. 391-392) sees education and training systems as central for economic growth which is based on a country's capacity for innovation. These attributes are (Finegold, 2006, p. 405): decentralization, variety in educational content/assessment, diversity of higher education institutions and funding, diversity of students, and adult access. In all these domains, the U.S. obtains a high value, Germany a low to medium value. Only in work-based learning, Germany is ranked high as opposed to the U.S.. However, work-based learning for which Germany's dual system is seen as a paradigm is not considered a beneficial factor for radical innovation, but for incremental innovations and processes (Finegold, 2006, pp. 407-408). Finegold's perspective is evidently an economic and functionalist perspective in accordance with the VoC approach: Education and training systems are crucial in securing institutional comparative advantages in economic performance.

Boyer (2003, p. 180) specifies when comparing the Germany and the U.S. that in the 19th century, Germany was successfully applying academic research in new sectors, e.g. chemicals and equipment goods. After all, Germany had a "strong tradition of basic research" (Boyer, 2003, p. 180; see also Münch, 1993b). By the 20th century, incremental innovations prevailed in already established sectors. No "sunrise sector" (Boyer, 2003, p. 180) like in the U.S. was established because feedback from academic research to economic activity was nonsatisfying and the stance of banks and large firms rather conservative so that radical innovations and the provision of risk capital were prevented.

In the context of radical innovations, the occurrence of major discoveries at universities in the U.S. is additionally fostered by their departmental structures which have already been described earlier. Despite a high involvement of public research institutes and industry, "pioneering discoveries" (W. W. Powell & Owen-Smith, 2005, p. 117) that require basic research still take place at universities, which was demonstrated with the example of the life sciences where "government and industry money go hand in hand" (W. W. Powell & Owen-Smith, 2005, p. 120). As J. Rogers Hollingsworth (2008) remarks, major breakthroughs take place in new departments, not in existing ones, which tend to be inert. An example of a "cluster of major discoveries" (Hollingsworth, 2008, p. 327) are the Department of Biochemistry and Molecular Biology and the Department of Organismic and Evolutionary Biology of Harvard University. Thus, it can also be explained by organizational structures why the U.S. is more advantageous than Germany in terms of its rather flexible departmental structure. However, this period of discoveries does not continue perennially. After 20 to 30 years, in average, the innovative potential of these newly founded departments declines (Hollingsworth, 2008, p. 328), which makes the creation of new departments necessary.

Dirk Akkermans, Carolina Castaldi, and Bart Los (2007) in particular question the distinction between radical and incremental innovations demanding a more precise distinction between countries and their varieties of capitalism. The authors conclude that "H&S's [i.e., Hall's and Soskice's, author's note] empirical analysis tells much more about economic specialization patterns than about technological specialization" (Akkermans et al., 2007, p. 7). They found that LMEs are more specialized in radical innovations when it comes to certain industrial sectors, such as chemicals and electronics, whereas CMEs are more competitive in radical innovations in fields like metals, machinery, and transport equipment (Akkermans et al., 2007, p. 22). Additionally, one cannot claim that all countries of the same variety of capitalism specialize in the same technologies; they are rather heterogeneous with respect to their specialization patterns in existing industries (see also G. Jackson & Deeg, 2006, p. 20).

After all, the assumption of technology life cycles undermines the categorization of countries into types of innovation because phases of radical and incremental innovations alternate. This finding is confirmed by Grodal (2007, p. 97) who ascribes incremental innovations, representing "technical advances," to the third (and last) emergence phase of nanotechnology as an organizational field called the "institutionalization phase". Martin Meyer (2007, p. 801) also emphasizes the "incremental nature" of innovations in nanotechnology. He focuses on the "'sub-fields'" of nanotechnology and nanoscience and their innovation patterns and therefore goes along with other studies focusing on fields of applications and industry sectors (Akkermans et al., 2007; Casper & Kettler, 2001). One finding is that "most exploration and exploitation activity will follow sector-typical search regimes, possibly leading to lock-ins and thus potentially also slowing down cross-boundary exchange" (M. Meyer, 2007, p. 803). His case studies do not detect any radical innovations which differ from the "technological trajectories" of the industries examined (M. Meyer, 2007, p. 801).

What might also play an important role in the comparison of innovation systems of Germany and the U.S., is the role of the government in promoting either radical or incremental innovations that are not necessarily in accordance with the competitive advantages of the production of innovations of the respective country (Akkermans et al., 2007, p. 24). Especially in Germany where nanotechnology is funded mostly by the government (Hullmann, 2007, p. 745), the question is to what extent government funding can ensure successful research and science in the long run, for example after government funding expires. Furthermore, Meyer (2007, p. 803) remarks that there is more exchange between non-nano science and nanotechnology than between nanoscience and nanotechnology. This raises doubts on the effectiveness of nano-related programs. These issues are believed to be observed in the future of 'nano.'

3.1.2 Applicability and Relevance to Present Study

The VoC approach is applied in this study because as a macro-economic theory, it is deemed suitable to compare or rather situate the U.S. and Germany on a macro-level before turning to a micro-level of analysis. As the educational and training system as well as the labor market are central institutional subsystems (Hancké et al., 2007, p. 3) in the VoC approach, the approach seems appropriate for two reasons. First, the topic of this dissertation deals with the higher education and training system in the nanotechnology sector and with the issue of professionalization in nanotechnology. Second, and more specifically, the focus on the higher education system is legitimate in the sense that a large part of job announcements and positions is directed toward academe (Abicht et al., 2006, p. 47; Stephan et al., 2007, pp. 888, 890). Studies on nanotechnology in the academic sector have been missing so far, which increases the urgency to address this topic.

In the context of this dissertation, the question is to what extent Hall's and Soskice's assumptions, in particular on innovations, must be more differentiated, when it comes to a German-U.S. comparison. Do their conclusions withstand the technological field of nanotechnology, after all, when taking Akkermans', Castaldi's, and Los' findings (2007) into consideration? Does the U.S. indeed have an edge over Germany with regards to faster diffusion of radical innovations? As the example of Germany shows us, radical innovations in this technology sector are viable. Therefore, there are two possible conclusions: Nanotechnology does not follow the distinction between radical and incremental innovations. It either includes both radical and incremental innovations, or, Germany has adapted central features of the liberal U.S. which enable radical innovations also in Germany. The results will demonstrate that a micro-level perspective is necessary because nanotechnology presents a fairly differentiated case of high-technology, as most advanced technologies (see also W. W. Powell, White, Koput, & Owen-Smith, 2005).

Diffusion within the two countries can be observed according to several criteria, including patent citations (which has already been done by Heinze (2005, 2006a, 2006b)), study programs, and job announcements (already been done for the U.S. by Stephan and colleagues (2007)). The main interest of this dissertation is the diffusion of nanotechnology as a research field in the higher education system and the labor market. That is why researchers in the field are interviewed to find out about the work environment, i.e., conditions of doing basic and applied research, at universities and the link to education by looking at research groups of professors being principal investigators for Ph.D. students.

3.1.3 Conclusions on the Usefulness of the Varieties-of-Capitalism Approach in an Analysis of Nanotechnology

The emerging nanotechnology field aptly demonstrates the VoC approach. Start-ups and venture capital are both characteristics of an LME, such as the U.S. are. Germany does not have these characteristics. Suggestions prevail demanding that the German government should change the country's financial structures and foster the founding of start-up companies and venture capitalist agencies. Such changes would clearly disturb the principle of long-term relationships between firms and banks which are based on collaboration and mutual trust. Banks operating in Germany expect lower returns on investment than do venture capitalists. In addition, it would be hard for large firms to adjust to venture capitalists. Finally, despite its lack of start-ups and venture capital, Germany is nonetheless among the top countries in nanotechnology.

A major assumption of the VoC approach is that "a firm fits into a network of interdependencies with its general institutional environment" (Boyer, 2005, p. 32). Hall and Soskice claim that a firm can neither construct nor control the economy's institutional architecture, including the coordinating institutions, which are "markets, institutional networks, and the organizations supporting collaborative endeavour," (Hall & Soskice, 2001a, p. 15) because the respective institutions are collective ones. Thus, "strategy follows structure" (Hall & Soskice, 2001a, p. 15). This argument is contested by Andrea M. Herrmann (2009) and Knut Lange (2009) who found that firms can combine LME and CME elements in their competitive strategies.

Jackson and Deeg (2006) built on Hall's and Soskice's definitions of CMEs and LMEs and added a few additional characteristics. They point out that CME's have "long-term industrial finance, cooperative industrial relations, high levels of vocational training, and cooperation in technology and standard setting across companies" (G. Jackson & Deeg, 2006, p. 22). Conversely, LMEs have "short-term orientated company finance, deregulated labor markets, general education, and strong inter-company competition" (G. Jackson & Deeg, 2006, p. 22). The exemplar country for an LME is the U.S. where the market is the clear coordinating mechanism (Vitols & Engelhardt, 2005). The paradigm for a CME is Germany where long-term relationships between companies are enforced and made possible by corporate governance.

Given this LME and CME market framework, it can be assumed that nanotechnology evolved earlier and differently in the U.S. than it did in Germany. Specifically, compared to Germany, in the U.S. nanotechnology was researched in a larger number of research institutes as well as specialized university centers and departments. Additionally, it is assumed that the transfer of research breakthroughs from extra-university institutes (i.e., companies) into universities (and vice versa) is more feasible in the U.S. than in Germany where less collaboration with universities takes place. In Germany, extra-university research institutes funded by the state are more dispersed (e.g., the Fraunhofer Societies or the Max Planck Societies) whereas in the U.S., such research institutes are funded by industry (e.g., Bell Labs, IBM Almaden Research Center).

The differing localization of nanoresearch, however, does not mean that Germany lacks advantages in promoting nanotechnology as a high-technology. The fact that Germany is among the top three countries in nanotechnology research (Abicht et al., 2006; Roco, 2005) means that Germany does have institutional dynamics in higher education and research which favor the development of nanotechnology. One major reason for Germany's success in nanotechnology research and development lies in the public research structure which has very productive extra-university institutes funded by the government and they are permeable enough to ensure that sufficient knowledge flows in the field of nanotechnology (Heinze & Kuhlmann, 2008, p. 897).

Although the perspective the VoC theory offers is insightful, what is most interesting is that the proliferation of nanotechnology in Germany contradicts the country's VoC classification as a CME. That is, under the VoC theory, nanotechnology should not have developed as successfully as it has in Germany. This fact shows that nanotechnology provides a case that is not considered by the VoC approach. Nanotechnology is a high-technology and still fostered by radical innovations that occur not only in the U.S., but also in Europe (e.g., the scanning tunneling microscope was made by Binnig and Rohrer from Germany and Switzerland respectively) (Eigler, 1999; Heinze, 2006a, p. 106).

It is also possible that nanotechnology may not fit within the assumptions provided by the VoC theory. This idea can be examined by looking at the development and the processes taking place in nanotechnology research in Germany and the U.S. The institutional complementarities between labor relations and corporate governance, labor relations and the national training system, and corporate governance and inter-firm relations in market capitalist economies seem to be formed differently in the case of nanotechnology, specifically, the ascription of incremental innovations to CMEs and radical innovations to LMEs.

One important factor for these ascriptions not applying to Germany and the U.S. can be governmental activities. In both countries, nanotechnology research is heavily funded by the government. In the U.S., for example, nanotechnology is thriving largely based on government initiatives such as the National Nanotechnology Initiative launched in 2001 (Rieland et al., 2009). Similarly, Germany launched the Nano Initiative─Action Plan 2010 (Rieland et al., 2009). Thus, the balance of institutional complementarities has shifted toward governmental interests that actively foster high-technology such as nanotechnology. These initiatives and media publications (Grodal, 2007) created an environment where organizations, including companies, could benefit from the 'nano' label. The relationships of government, labor relations, and the national training system including research centers and universities seem to be differently coordinated in Germany in the case of nanotechnology as compared to traditional industry sectors such as engineering, which Germany is known for and which made Germany a typical CME due to the long-term employment strategies and incremental innovations that coin the engineering sector. In the U.S., there is still a sound network of venture capitalists. The field of nanotechnology is either highly unbalanced (its success would speak against this) or an exceptional case of institutional complementarities.

To conclude, nanotechnology provides an exceptional empirical case for the VoC approach. The macro-level distinction between coordinated and liberal market economies does not hold here and requires a closer look at the micro-level of nanotechnology. Specifically, nanotechnology innovations did not occur only in the U.S. where radical innovations are more typical due to the financing and liberal market structures. From the 1980s on, Europe has also been a major player in the nanotechnology field which can be seen by the development of the scanning tunneling microscope that was made possible by a German-Swiss research collaboration. Thus, through government funding, Germany might have changed the institutional balance between subsystems including the education and training system, the labor market, and company relations which allowed Germany to rise to the top of nano-active countries like the U.S.. In this study, the focus on the education and training system will elaborate the characteristics of the field of nanotechnology in this subsystem. To see if Germany has actually digressed from its focus on education systems, bottom-up empirical data from interviews with nanoscientists on the micro-level are combined with an institutional analysis of the nanotechnology sector in academia. Nanoscientists as mediating actors between the micro- and meso-level can reveal how

government funding for nanotechnology is used and how it affects the institutional setup of universities. If Germany's focus has shifted, it might explain its success in nanotechnology. If not, the implementation of nanotechnology in education systems might have turned out favorable or at least not presented an impediment for nanotechnology research and innovations that have been realized within these systems of teaching and research.

3.2 Role and Importance of Associations in Germany and the U.S.: An Overview

With regards to the role and importance of associations in Germany and the U.S., a glance is thrown first at Germany, then at the U.S. This topic is relevant for this study because in the field of nanotechnology, the question arises to what extent associations dealing with nanotechnology–which would be mainly chemistry, engineering, materials sciences, and physics–influence legislation, study programs, and vocational training. In Germany, there are for historical reasons strong unions and associations. Anke Hassel (2007, p. 253) stresses that industrial relations with wage bargaining and training are the core institutions of CMEs, including Germany. It is after all through institutions, not through markets as in LMEs, that firms in CMEs are coordinated. As Peter A. Hall (2007) notes, after the Second World War, West Germany still had "strong industry unions, well-developed employers associations, collaborative institutions for skill formation, and a Bismarckian welfare regime" (p. 46). Similarly, Hancké, Rhodes, and Thatcher (2007, p. 35) emphasize Germany's strong business organization characterized by industry-led strategies as well as privatization and liberalization governed by networks of industry associations, government, and suppliers.

This observation is validated by Kathleen Thelen and Ikuo Kume (1999) who ascribe to Germany a traditionally high degree of organization of employers with a "statutory system for labor representation at the plant level" (p. 479). Thelen and Kume (1999, p. 480) observe two negative developments in Germany: the decline in membership in big employers' associations due to German unification and the increasing proclivity of member firms to neglect informally the central agreement they signed. The consequence is that employers' solidarity is undermined, and employers who have not been part of the central agreement benefit less and less from negotiations on the side of the employers and unions (Thelen & Kume, 1999, p. 487). Thelen and Kume (1999) emphasize that it is most often forgotten that along with globalization, there is not only a decline in importance of unions and associations to be noticed. Moreover, with "tightly coupled production networks and the demands of producing at high quality on a just-in-time basis" (Thelen & Kume, 1999, p. 478), employers are increasingly dependent on foreseeable and stabilized relations with the workforce at the company level. Overall, gradual destabilization has been observed because of more intense cooperation among a smaller number of firms so that less workers are covered in their firms by a collectively bargained central agreement (Thelen & Kume, 1999, p. 500). The problem does not consist in a gap between labor and capital, but in a growing cleavage between companies for which traditional structures remain important and those companies which abandon these structures and rather focus on plant-level bargaining (Thelen & Kume, 1999, p. 490). The larger and the more established the company, the higher the density of unions, and the higher the risk of industrial conflict, the more likely a German company is member of an association (Thelen & Kume, 1999, p. 491). Therefore, small firms are in a less advantaged position compared to employers' association when it comes to bargaining. This is contrary to the U.S. where small firms are in a better position to bargain because of a less dense associational structure (Hassel, 2007, p. 273).

Nevertheless, above all in the chemical industry, German employers prefer collective bargaining and are committed to social partnership. Thus, contrary to common expectations, employers are not at all interested in cutting the bargaining role and autonomy of German unions. The demand for more flexibility in plant regulations and, at the same time, being part of and being able to rely on an industry-wide bargaining system is the current trend in Germany. (Thelen & Kume, 1999, p. 482)

Furthermore, Thelen and Kume (2006, p. 11) discuss the importance of employer coordination when it comes to uphold the national varieties of capitalism. They describe what was formerly called corporatism as the "the capacity of employers to coordinate among themselves" (Thelen & Kume, 2006, p. 11). It is the "clusters of institutions" of a national economy, which influence significantly the employer strategies pursued in an LME or CME. Next to other scientists (see Boyer, 2003; Streeck & Yamamura, 2003), the authors reiteratively point out that no convergence is observable between LMEs and CMEs, but rather continuity, diversity, and divergence (Thelen & Kume, 2006, p. 12).

Therefore, employers derive their competitiveness from the very circumstance of adhering to those coordinative institutions that are characteristic of the respective national variety of capitalism such as "centralized wage bargaining in corporatist democracies" (Thelen & Kume, 2006, p. 12) and bring them into more advantageous positions in the market (Thelen & Kume, 2006, p. 13). For Germany, they outline the status quo as an "organizational disarray in the Association of German Metalworking firms (Gesamtmetall) and its union counterpart (IG Metall), which together have played the key flagship role in Germany's de facto system of pattern bargaining over most of the postwar period" (Thelen & Kume, 2006, p. 21). This destabilization can be traced back to increasing collaboration between capital and labor at the plant level of mostly larger firms so that cooperation at the industry-wide level becomes more complicated. In summary, the system of collective bargaining is formally sustained, but informally eroded. This makes it questionable if organizations can be reconsolidated or reconstructed, and it might additionally be against employers' collective and individual interests. (Thelen & Kume, 2006, pp. 26-27)

Training in Germany and the U.S.

With regards to the status quo in Germany, Hall (2007) concludes that strategic coordination (a feature of CMEs) has been weakened in Germany but not completely given up. Also, the German welfare state still remains intact despite cuts of social benefits. About 60% of the workforce in Germany is covered by a collective bargain (compared to 20% in Britain). Industry and labor still rely on collaborative training systems where high-end industry-specific skills are conveyed. (Hall, 2007, pp. 69-70)

Current developments suggest that the labor market has become less homogenous, because of the dominance of plant-level agreements (i.e., one third of firms in the private sector) over collective agreements (Hassel, 2007, pp. 259-260). A present-day example is working time, which has risen with the flexibilization of working hours, whereas union proposals have been blocked. In the recent reform of collective bargaining in 2003, the following sectorial employers' associations have been involved: chemical employers, metal sector employers, the BDI (industry associations), and the BDA (employers' confederation) showing that the "culture of associations" is still prevalent in Germany and as such institutionalized in relationships of industry, labor market, and government. (Hassel, 2007, p. 263) Another example from the area of the training regime in Germany is the "reform of the regulatory framework of vocational training" passed in 2005. By this reform, cooperative training structures between schools and firms were supposed to offer work certificates, if the completion of an apprenticeship is not possible ("modularization of training schedules") (Hassel, 2007, p. 271).

Another major difference between LMEs and CMEs is mentioned by Wood (2001) emphasizing that in a CME, the state is supposed to guarantee the protection of networks of business coordination. Vocational training in Germany is particularly "governed by framework laws that establish chambers of commerce (Kammern) as the sole 'competent authorities' (zuständige Behörde) for oversight of training activities within" (Wood, 2001, p. 251). By contrast, in LMEs, the state is supposed to ensure market mechanisms (Wood, 2001, p. 251). In Germany, the state is constrained, which makes interventions against institutions of coordination improbably. Wood (2001) concludes that

> "[t]his is crucial to business coordination because the investments required of companies in CMEs are specific or co-specific investments (such as industry-specific skills, or specialized technologies). These investments are costly and risky, with returns that may only be reaped over a long period. Although the institutions and networks of coordination in CMEs make these investments profitable, the limits to government power in the FRG [Federal Republic of Germany, author] provide an additional assurance that the returns to these investments are safe" (Wood, 2001, p. 257).

Along with this comes the collective action problem because free riding on other employers' investments, recruiting workers from other companies or copying innovation processes is made possible. These problems can be circumvented by the circulation of information among companies, business, and banks and by monitoring institutions such as employers' associations and chambers of commerce. (Wood, 2001, p. 257)

Innovations in Germany and the U.S.

With respect to convergence of innovation systems, Boyer (2003) argues for a trend toward specialization and divergence. He explains that the German and U.S. innovation systems were complementary in the early 1980s: Germany was successful in civil engineering, agricultural machines, mechanical equipment engines, and machine tools whereas the U.S. was successful in information technologies, semiconductors, biotechnologies, and new materials. The reasons were increasing internationalization, above all of R&D centers, including national comparative advantages. (Boyer, 2003, p. 172) This reversal pattern cannot be validated for Europe and the U.S. in patent applications and publications in the sub-fields of nanotechnology in the late 1990s and at the beginning of the 21st century (Heinze, 2004, p. 432). Therefore, Europe and the U.S. indeed have almost come on par with each other in nanotechnology. Boyer (2003, p. 179) outlines three mechanisms fostering innovation: First, growth of the division of labor parallel to market growth; second, skilled workers indispensable for incremental innovations; third, the contribution of engineers and scientists to innovations and productivity of companies. A "highly polyvalent workforce and moderate use of basic science" (Boyer, 2003, p. 179) have attributed largely to the success of the German manufacturing sector. These mechanisms can also explain Germany's advantage in nanotechnology where skills in engineering and the sciences are indispensable.

According to Boyer, there is dissatisfaction in Germany on the cooperation between academic and applied research. Furthermore, the German dual system is challenged by the increasing attractiveness of universities and other choices for young people to pursue general education. (Boyer, 2003, pp. 180-181) To sum up, Boyer (2003, p. 181) concludes that "Germany has to reassess the legitimacy and efficiency of many of its core institutions concerning the welfare system, taxation, the relationship between general education and training, and links between the academic world and firms." With government initiatives such as those by the BMBF demanding industry–university cooperation, a political step was done. Data in this study, however, show that this form of cooperation is still difficult in areas where basic research is dominant such as in nanotechnology.

3.3 Mode 2 Knowledge Production

As an innovative science and technology, nanotechnology must be seen in the context of knowledge production to see how nanotechnology, for now being a specialty and analytical tool and not yet a discipline, contributes to science. Mode 2 production refers to the increasing social accountability of research in knowledge societies and a shift away from one-way science-to-society communication with the increasing involvement of social actors other than academic members (Nowotny, Scott, & Gibbons, 2001, p. 66), such as people from "different institutions, participation of business people, patent lawyers, production engineers," venture capitalists, and other extra-university affiliations (Gibbons et al., 1994, p. 70). Accountability refers to the "the social demand for quality, performance and value for money" (Gibbons et al., 1994, p. 85). Transdisciplinarity in the Mode 2 sense refers to the dissolved boundaries between disciplines and the "shared use of academic and industrial facilities and technology" (Gibbons et al., 1994, p. 75). As Michael Gibbons et al. remark (1994) "[i]n Mode 2, not only are more actors involved in the genesis of knowledge but they remain socially distributed." This is apparent with nanotechnology, as research takes place both at university and extra-university institutions, such as industry. In Germany, applied nanotechnology research is done rather in extra-university research institutions, such as the Max-Planck-Society. The distinction between applied and basic research, so Gibbons et al., however, become blurred with Mode 2 knowledge production (Gibbons et al., 1994, p. 87) leading to competition among university and non-university institutions. With mass education both in the U.S. and Germany as industrialized countries, funding sources also moved away from government to industry introducing the rational of profit-making, so far not an organizing principle with regards to funding of discipline-based research. Next to the changes in the verge of Mode 2, academic socialization in one discipline and the regard of research as an elite activity despite its massification are still persistent in contemporary societies. (Gibbons et al., 1994, pp. 70-71)

Another observation made in the context of a Mode 2 society is that the traditional university will be superseded by the Mode 2 university (Nowotny et al., 2001, pp. 91-94). A Mode 2 university is no more defined by the distinction of research and teaching and the differentiation between a university's scientific and social role due to the contextualization of knowledge production (Nowotny et al., 2001, p. 95). It is a "synergistic institution" (Nowotny et al., 2001, p. 91). This comes along with the knowledge where there is a "much wider range of social, economic and even cultural activities" with "'research components'", which also leads to the de-institutionalization of the traditional university. This fact is supposed to have an effect on curricula which are assumed to become more diverse in order to meet the various social and scientific demands of a more diversified student body. Yet, like the 'traditional' Mode 1 university, the Mode 2 university produces the "next generation of researchers" (Nowotny et al., 2001, p. 93) as well as cultural norms followed by university and other social actors next to formal certification and the consolidation and stabilization of knowledge. Still, the Mode 2 university must be adaptable due to constant reconfigurations of knowledge produced in the scientific system and in society at large and resilient in order to provide a site for expert training and to preserve cultural-scientific norms. (Nowotny et al., 2001, pp. 89, 91, 95) Long-term projects, the collaboration of basic and applied research, and flexible access to resources across disciplines are crucial in the support of scientific innovations (Holton, Chang, & Jurkowitz, 1996, p. 373; Nowotny, 2001, p. 131).

Universities do play a significant role in innovations, as they form relationships with industry and the state (Editorial, 2009), especially in sectors like biotechnology (Klevorick, Levin, Nelson, & Winter, 1995). They are even called the 'engines of growth' concerning national competitiveness, since firms draw upon them in search of innovations (Laursen & Salter, 2004). As Mode 2 has not replaced Mode 1, researchers who are differently inclined to collaboration bear a cost to balance Mode 1 and Mode 2 (Estabrooks et al., 2008). This means that on the one hand, they are in a culture of 'pure' learning and academic freedom and autonomy, on the other hand, they more and more need to focus on applicable results, social accountability, and cooperation with heterogeneous groups not least because third-party funding is needed. In short, researchers find themselves between an autonomous academic and an entrepreneur.

Stefan Beck (2006, p. 114) pointed out that especially in biotechnology, the logic of commercialization and production are getting enmeshed in the natural sciences, such as in biotechnology laboratories. At universities, values are produced that are evaluated according to economic criteria (Beck, 2006, p. 97). Knowledge production and knowledge commercialization are approaching each other. With knowledge being a resource, not an asset (Beck, 2006, p. 115), there is no differentiation between the production of knowledge and the production of goods any more. Solely the modes of laboratory work "'of market and research'" still differ (Beck, 2006, p. 114). Here, the concept of Pasteur scientists (Baba, Shichijo, & Sedita, 2009) comes into play who provide both patent applications and authorship of publications as opposed to 'star scientists' (Zucker & Darby, 2001) who are strong

in publications. Mode 1 and Mode 2 are juxtaposed in Table 3 by Laurens K. Hessels and Harro van Lente (2008, p. 741):

Attributes of Mode 1 and Mode 2 knowledge production	
Mode 1	*Mode 2*
Academic context	Context of application
Disciplinary	Transdisciplinary
Homogeneity	Heterogeneity
Autonomy	Reflexivity/social accountability
Traditional quality control (peer review)	Novel quality control

Table 3: Attributes of Mode 1 and Mode 2 Knowledge Production; Source: Hessels & van Lente 2008

Some major critique has addressed the generality of the Mode 2 model and its expansion in science without empirical evidence. The validity for the few selected disciplines and loci as well as the degree of transdisciplinarity versus interdisciplinarity are disputed, not least because of the lack of clarity of definitions (Hessels & Lente, 2008, pp. 752-753). This is why, Mode 2 is dubbed as a concept rather than a theory. To Dorothea Jansen, Regina von Görtz, and Richard Heidler, who analyzed if nanoscience is a Mode 2 field, transdisciplinarity in the Mode 2 sense is but a "high level of interdisciplinarity" (Jansen et al., 2010, p. 54). They found that nanoscience reveals Mode 2 characteristics to a certain degree, namely interdisciplinarity and application-orientation. However, the diversity of network partners is not higher than in other disciplines, the hierarchical structure not less developed than in other disciplines. Besides, basic research is still dominant in nanoscience contrary to Mode 2 knowledge production. Yet, the difference to other disciplines is that nanoscience is heavily funded by public policy on which nanoscience depends heavily. That is why focusing on interdisciplinarity and international and interorganizational networks becomes important for nanoscientists who need to acquire public funding for their research and thus pick up these ideas. However, as it has been shown in the life sciences for instance, the influence of legislative changes and public policies in the emergence of a field should be seen as facilitative rather than causal (W. W. Powell & Owen-Smith, 2005, p. 116). In a study on health researchers (Estabrooks et al., 2008), it was found that researchers at university following Mode 1 and Mode 2 activities reinforced each other by advancing innovation and technology and increase "scholarly Mode I activities" (Estabrooks et al., 2008, p. 1075).

Henry Etzkowitz and Loet Leydesdorff (2000) propose another explanation for innovative systems by introducing the Triple-Helix of university – industry – government relations. To the authors, the Mode 2 knowledge production had already existed before Mode 1 emerged in the 19th century (Etzkowitz & Leydesdorff, 2000, p. 116). The Triple-Helix model emphasizes the transformation of the respective systems. Governments can intervene in the institutional dynamics and be transformed just like the actors in university and industry. The Triple-Helix is not expressed by a causal relationship (input ==> output) in innovative systems (national systems) but by reciprocity and interaction, i.e., in a non-linear way (Etzkowitz & Leydesdorff, 2000, p. 114).

Mode 1 and Mode 2 are extended by the concept of Mode 3. Mode 3 is based on the conceptualization of academic capitalism and new economy. The central hypothesis is: "although not-for-profit colleges and universities are analytically and legally distinct from for-profit enterprises, they are also players in and part of the private sector marketplace" (Rhoades & Slaughter, 2006, p. 10). One mode of knowledge production is "the forms by which knowledge is produced and the ways, in which it is evaluated, legitimized and distributed" (Rhoades & Slaughter, 2006, p. 11). This means that problems are differently identified, studied, and solved according to the respective mode. The main difference between Mode 1 and 2 is the societal embedding of Mode 2 knowledge production implying social accountability and the consideration of the implications of academic research due to the context of application. This context of application also implies "broader criteria of evaluation … including cost efficiency, value in the private marketplace and social effects [with a] review system [that] incorporates … constituencies outside the academy" (Rhoades & Slaughter, 2006, p. 12).

Other points of critique toward Mode 2 are the neglect of national contexts (Rhoades & Slaughter, 2006, p. 15) and the neglect of "concrete issues of application by whom, for what purposes and in whose interests" combined with a lack of empirical studies on the relationship between Mode 1 and Mode 2 (Rhoades & Slaughter, 2006, p. 13). It has been shown that the commitment to traditional disciplines overweigh the noticeable tendencies of inter- or transdisciplinary. Traditional disciplines still dominate academic culture (Rhoades & Slaughter, 2006, p. 13). Thus, the assumption of transdisciplinarity in Mode 2 is mitigated with regards to its universality. With Mode 3, the authors refer to the layering of new structures such as Technological Transfer Offices and the installment of new positions, such as managerial professionals in the context of the 'capitalization' of academia leading to a more interdisciplinary structure (Rhoades & Slaughter, 2006, pp. 14-15). This means that in contrast to the Triple Helix model by Etzkowitz and Leydesdorff (2000), Mode 3 assumes that higher education, government and industry are no longer distinct realms or intertwined but universities become "capitalistic enterprises themselves" (Rhoades & Slaughter, 2006, p. 16). This tendency is exemplified by the fact that universities hire more and more professionals that are closer to management than to professorial work (in the U.S. more so than in Europe) (Rhoades & Slaughter, 2006, p. 16). Accountability is central both in Mode 2 and Mode 3 knowledge production. In Mode 3 terms, accountability is interpreted as "the potential to generate revenue, for the academic organization and/or its corporate partners [coming from] the private sector marketplace, which is not a demanding taskmaster in terms of a range of public good considerations" (Rhoades & Slaughter, 2006, p. 18).

Mode 3 can be seen as embedded into the theory of academic capitalism. This theory developed by Sheila Slaughter and Gary Rhoades (2004, p. 1) "explains the process of college and university integration into the new economy", whereby this process is not irresistible. Yet, universities engage themselves in this process actively by accepting market logic and cooperating with industry, thus increasingly internalizing the value of money. Moreover, this process does not replace the public good regime where values of public good such as publications and free flow of information are still appreciated by professors (Slaughter & Rhoades, 2004, p. 129). However, accepting market values by professors leads to withholding research results and the delay of publications among other things (Slaughter & Rhoades, 2004, p. 129). Thus, the academic capitalist knowledge/learning regime coexists with other regimes (Slaughter & Rhoades, 2004, p. 322).

3.4 Nanotechnology as a Field?

For an organizational analysis, it is first required to define what is understood by organizational field and why such an analysis is regarded as valuable for the understanding of the status quo of nanotechnology. As the VoC theory is a macro-approach and focusing on nation states, a theory on the meso-level is necessary to analyze how nanotechnology as an organizational field is constructed. With that, organizational characteristics of nanotechnology always also involve a micro-level analysis, here on the basis of interviews with central actors in the academic field of nanotechnology acting as mediators between the micro- and meso-/macro-level. The VoC approach with its categories of LMEs or CMEs is not a prolific tool for addressing the characteristics of a technology sector, in this case nanotechnology, since it does not explain, compared to the U.S., the equally successful role of Germany in nanotechnology. Instead, a focus on the dominant actors in the field and the opportunities and circumstances scientists face on the micro-level helps to understand how this field is constructed.

To Neil Fligstein (1990, p. 5), a field comprises larger groups of organizations classified by product line, industry, or firm size. An organization faces competitors, but also suppliers, distributors, or owners. Its behavior and courses of actions are regulated by state rules framing legal and illegal conduct. In this study, the organizational level is broken down to the individual level to integrate mediators whose actions co-construct the organizational level.

As the early definition of Fligstein focuses on the business sector and addresses organizations as a whole, another, rather broad but useful definition guides this analysis of nanotechnology. This definition identifies an organizational field as "a community of organizations that engage in common activities and are subject to similar reputational and regulatory pressures" (W. W. Powell et al., 2005, p. 1134). "Collective actors" are located at the intersection between academia and politics, allowing for the integration of (nanotechnology) institutions into organizational fields (Fligstein, 2001, p. 15). For actors, this implies that they are "socialized and constrained by a complex institutional environment" (J. W. Meyer, 2010, p. 4). Further, to W. Richard Scott (2004, p. 58), the creation of meaning is a crucial criterion for an organizational field, which is why meanings, leading to individuals' maxims of actions, are at the center of the case study's interviews. Universities and research centers, the organizations under study in this doctoral thesis, face state governments, industry, and public funding agencies in their daily activities. There are further formal and informal rules (as mentioned in the definition of institutions in chapter 1) that can be effective in the form of state regulations for higher education or the conditions for the acquisition of third-party funding. Finally, organizations are determined by "a set of strategies, structures, technologies, and physical limits that shape and constrain their patterns of growth and change" (Fligstein, 1990, p. 5). Fields are constituted and determined by its "most powerful members" (Fligstein, 1990, p. 6) and have primarily a stabilizing function by providing conceptions and rules for legitimate behavior for actors in that field. Courses of actions in such a field are not only shaped by the legal framework but also by "a self-conscious version of the world that make both old and new courses of action possible and desirable" (Fligstein, 1990, p. 4). Actors can be distinguished according to their conception of control which prescribes "how they perceive the world, and what they define as appropriate organizational behavior" (Fligstein, 1990, p. 10). This conception, which functions like a filter of the complexity of the world and the abundance of information outside the field, must be differentiated from strategies that include the organizational goals and policies and which can overlap although the conceptions of control might differ. In the present case study, informants' conceptions filter their work context and develop strategies that cope with national technology and higher education policies.

Paul J. DiMaggio and Walter W. Powell (1983) define organizational fields in a similar way as Fligstein, namely as "those organizations that, in the aggregate, constitute a recognized area of institutional life" (p. 148). Fligstein, DiMaggio, and Powell stress the importance of agreement and mutual awareness among participants for meaning creation and, thus, for a field to emerge. Fligstein (2001, p. 15) says "fields contain collective actors who try to produce a system of domination in that space. To do so requires the production of a local culture that defines local social relations between actors." DiMaggio and Powell (1983, p. 148) emphasize "the development of a mutual awareness among participants in a set of organizations that they are involved in a common enterprise." An example for such "mutual awareness" in the U.S. is the NNIN or the 'Excellence Initiative' in Germany. The "local social relations" as well as "mutual awareness" are topics addressed in the interviews with nanoresearchers that were conducted for the present study. Another aspect of the make-up of an organizational field is delivered by Scott (2004) to whom the creation of a meaning system is indispensable for the emergence of an field. He concludes "[a] cultural-cognitive conception of institutions stresses the central role played by the socially mediated construction of a common framework of meaning" (Scott, 2004, p. 58). Through interview data, a cross-sectional analysis is provided on the current state of the field of nanotechnology.

Finally, with regards to the analysis of this study that looks at nanotechnology from an organizational field perspective, the definition by Walter W. Powell, Douglas R. Koput, Kenneth W. White, and Jason Owen-Smith (2005) is used as a major guideline for analysis. This definition is based on DiMaggio's and Powell's (1983) conception of an organizational field. The applied definition is fairly broad but still suitable for nanotechnology: "an organizational field is a community of organizations that engage in common activities and are subject to similar reputational and regulatory pressures" (W.

W. Powell et al., 2005, p. 1134). It is suitable because the authors use this definition for the analysis of the life sciences that are part of the sciences in academia like nanotechnology is. The interview results also suggest Grodal's conception of a "socially negotiated process" (Grodal, 2007, p. 171), which marks the emergence of a nanotechnology field. This study does not look only at the meanings and scientific actors that make up the nanotechnology field. It also examines identities that are constructed in a broader context, namely within scientific communities. In the interview analysis, the meanings and the construction of identities of scientists, being constitutive of meanings (Fuhse, 2009, pp. 52-53), are extended by looking not only at professional identities, but also at the cognitive, historical, and social identities, which are part of the organizational field of nanotechnology (Lepenies, 1981). This field is not only constructed by social processes, but also by cultural processes when scientists adjust their professional identities based on the context that demands from scientists to situate themselves. Scientists in nanotechnology, finally, are not only part of the nanotechnology field, but also of the scientific community, which reproduced them out of disciplinary structures.

Mechanisms of Innovation

In organizational fields, institutional change in line with historical institutionalism represents a "complex research process that follows whereby actors actually determine what institutional changes to make" (Campbell, 2010, p. 92). The two mechanisms of innovation which are relevant in this study, 'layering' and 'translation,' lead to gradual institutional change: "institutions change when new institutional layers are grafted on to existing institutions" (Campbell, 2010, p. 100). 'Layering' constitutes one institutional type of gradual transformation. It implies the attachment of new elements to existing institutions, which leads to gradual change of their status and structure (Streeck & Thelen, 2001). The mechanism for layering is differential growth (Streeck & Thelen, 2001, p. 31). 'Translation' describes the "blending of new elements into already existing institutional arrangements" (Campbell, 2010, pp. 98-99).

The Neo-sociological Perspective on Fields

From a neoinstitutionalist perspective, homogenization of "practices and procedures defined by prevailing rationalized concepts of organizational work and institutionalized in society" (J. W. Meyer & Rowan, 1977, pp. 340-341) leads to "loose coupling" (J. W. Meyer & Rowan, 1977, p. 341) between formal organizational structures and activities. The reason is that institutional rules and organizational actors' conformity to these rules do not follow rules of efficiency. Institutional rules are defined following Peter L. Berger and Thomas Luckmann as "classifications built into society as reciprocated typifications or interpretations" (J. W. Meyer & Rowan, 1977, p. 341). "Powerful myths" (J. W. Meyer & Rowan, 1977, p. 340) as general and abstract interpretive frames (G. Jackson, 2010, p. 77), e.g. national technology policies and economic growth, become the reference point for 'formal structures,' not the demand of 'work activities.' This leads to a 'gap' between 'formal structures' and 'work activities.' Resulting conflicts between ceremonial rules and efficiency are resolved by decoupling and the logic of confidence and faith (J. W. Meyer & Rowan, 1977, p. 356). As shown by Lauren B. Edelman, Christopher Uggen, and Howard S. Erlanger (1999), legal action as a 'rationalized concept' does not necessarily ensure efficiency. Resulting conflicts between ceremonial rules and efficiency are resolved by decoupling and the logic of confidence and faith (J. W. Meyer & Rowan, 1977, p. 356).

'Formal Structures' and 'Work Activities'

A sociological neoinstitutionalist perspective further elucidates the difference between 'formal structures' and 'work activities' and conceptualizes isomorphism (i.e., a structural convergence of institutions worldwide) that occurs in nanotechnology as the interview data show (J. W. Meyer, 1982; J. W. Meyer & Rowan, 1977). This perspective assumes that formally, nation states adopt rationalized models, such as individualism, mass education or human rights. These models become myths because the way they are actually applied differs from these models. Organizations, accordingly, strive to incorporate a "rational formal structure … [as] the most effective way to coordinate and control the complex relational networks involved in modern technical or work activities" (J. W. Meyer & Rowan, 1977, p. 342). However, when it comes to 'work activities' the actual activities within a nation state and within organizations do not always follow the rationalized procedures as provided by 'formal structures.' For instance, developing countries establish a 'formal structure' of mass education and schooling. This structure, however, is not functional because most of their inhabitants are farmers and thus do not need a college education to perform their job (Drori, Meyer, Ramirez, & Schofer, 2003). Social institutions are loosely coupled because national differences remain intact and global convergence thus remains confined (Krücken, Kosmützky, & Torka, 2007, p. 11). Compliance with 'formal structures' nevertheless can occur: from DiMaggio's and Powell's perspective (1983), mimetic compliance can result from the institutionalization of social institutions, meaning that actors are not fully aware or purposive of their compliance (J. W. Meyer, 2010, p. 4). A closer look at Germany and the U.S. suggests that 'formal structures' of organizations, such as research institutes, are indeed different from actual organizational activities, such as basic research.

Decoupling is to be observed in the academic field of nanoscience and -technology. Decoupling includes structures, policies, or plans, i.e., "actor identities," that report about "what should happen, but will probably not happen" (J. W. Meyer, 2010, p. 14). The more actors strive to maintain these actor identities, the greater pressure is exerted in the field. Similar to John W. Meyer and Brian Rowan (1977, p. 340), new formal organizational structures emerge when legitimacy is increased by the integration of rationalized concepts. 'Formal structures' (institutions and their rules) and 'work activities' can deviate from the intended effect of 'formal structures,' which function as 'rationalized myths' to legitimate organizational actions (J. W. Meyer & Rowan, 1977): Both realms function differently but complementarily to each other in order to cope with the problem of legitimacy. This problem can only be solved when 'formal structures,' embedded in a social environment, comply with general models or 'myths' that are legitimated in the environment. "Powerful myths" (J. W. Meyer & Rowan, 1977, p. 340) ask for conformity to institutional rules that make 'work activities' efficient. This leads to "loose coupling" (J. W. Meyer & Rowan, 1977, p. 341) between 'formal structures' and ongoing activities. Decoupling precisely helps to resolve conflicts that arise between ceremonial rules, i.e., myths, and rules of efficiency (J. W. Meyer & Rowan, 1977, p. 356).

As documented in a network study on the life sciences, a field can emerge for different reasons, such as social, economic or technological change (W. W. Powell et al., 2005). Each high-technology field, then, must be studied separately, as it most probably exhibits features different from other high-technology fields, except for the common characteristic of a high developing pace (W. W. Powell et al., 2005, p. 1190). This is what must be done for nanotechnology as well and is done here for the academic field of nanotechnology.

The Social Constructivist Approach

Applying a social constructivist approach in a work-related field, Penny Dick (2005) uses the social construction framework "to argue that 'dirty workers' perform their identities in two conceptually distinct contexts" (2005, p. 1363). Her paper analyzes how organizational identity and cultures at work are created subjectively. Among the applied methods, in-depth interviews are used for example to analyze the "reframing," i.e., the transformation (Dick, 2005, p. 1369) of meanings of coercive authority. "Reframing" refers to the "fact that certain meanings become privileged, taken-for-granted as truths, reflecting the power that some groups have to define the world and its events for us" (Dick, 2005, p. 1386). Dick's approach demonstrates how power can indeed be delineated in a social constructivist framework by way of "reframing:" meanings can change indeed, among others by coercive authority.

In the context of nanotechnology, legitimacy is crucial as well: However, the meanings on nanotechnology scientists display are by no means already altered 1:1 due to coercive authority, such as by the DFG or by national innovation policies where politics pursues their interests powerfully and successfully. Yet, the legitimacy of nanotechnology in politics and industry or innovation contexts leads to an acceptance of nanotechnology institutes, programs and courses within academia. In the interviews, however, it is shown that institutional legitimacy does not automatically lead to an internalization (Berger & Luckmann, 2004 [1969]) of political or, more broadly, external meanings by scientists. It is a process that takes place and that might result in quite hybrid constellations of meanings and strategies that combine the legitimacy of nanotechnology in institutionalization and the prevalence of discipline-based professional identities of scientists.

Examples of Fields

Next, more empirical examples of organizational fields are addressed. Education, legal regulation, and nanotechnology are studies drawn on shortly in the following. John W. Meyer and Francisco O. Ramirez (2005) illustrate the spread of education systems and universities in the 19th and 20th century, even in countries where e.g. higher education does not seem efficient or necessary (Drori et al., 2003, p. 41). Education and, in particular, science are not seen any more as a common good but as indispensable instruments in the development of nations (J. W. Meyer, 2005, p. 150). An influential international organizational structure and the triumph of the authority of common, worldwide scientific and professional groups and ideologies have increased pressures on the international diffusion and standardization of education models (J. W. Meyer & Ramirez, 2005, p. 233).

The fact that forms of institutionalization, such as professionalization, can be a driving force of organizational change by executing normative pressures is illustrated compellingly by Edelman, Uggen, and Erlanger (1999). The authors demonstrate that market rationality can occur due to rationalized myths by professions advocating a compliance strategy, in this case grievance procedures, by organizations, and by courts resting their decisions on these organizational practices. This way, rationalized myths legitimized courses of action to foster anti-discrimination. The study shows that a field can be constructed in alternative ways than commonly assumed. Usually, laws are supposed to be followed and not vice versa by organizational practices constructing judicial decisions. Grievance procedures were propagated by professions even before courts took them into considerations in their decisions. Edelman, Uggen, and Erlanger (1999, p. 446) demonstrate that professions did not base their preference for grievance procedures on facts. Only by circulating among organizations, organizations by and by implemented grievance procedures successfully, and more and more actors in the field, i.e., companies, followed. In the end, installing grievance procedures actually turned out to be efficient by reducing costs and legal suits.

Fligstein's definition of an organizational field is business-oriented and redefined to fit the context of nanotechnology which is constituted by fields of commercial application just as economic organizations are. However, additional actors are introduced here on the meso-level next to business organizations as foci of analysis. These are universities, extra-university research institutes, professional organizations, and the market as logic of action on the abstract level. Grodal (2007) analyzes the emergence of nanotechnology as an organizational field from a broad, socio-political perspective. This means she attributes the causes for the emergence to processes of meaning creation (Grodal, 2007, p. 2), not to scientific breakthroughs being responsible for knowledge production and new commercial products. To her, an organizational field is negotiated and constructed, not given or founded (Grodal, 2007, p. 3). Meaning is defined as "the connotations of a label" (Grodal, 2007, p. 4). The construction of a label is one of the "first pivotal events" (Grodal, 2007, p. 4) which stand at the beginning of the emergence. To Grodal (2007, p. 41), nanotechnology is appropriate as the object of a study of organizational fields due to four criteria: a well-defined beginning, currency of the field, the interaction of communities (at conferences or networking events), and an accessible paper trail. She divides the emergence process into three periods: mobilization characterized in particular by excitement (and stories related to this excitement), legitimation given by the participation of the government and service providers ensuring funds and support, and, finally, institutionalization marked by incremental innovations and the participation of scientists and entrepreneurs (Grodal, 2007, pp. 96-97).

Grodal's results are that the emergence process of an organizational field needs to be reconceptualized as a categorization process, a "socially negotiated process" (Grodal, 2007, p. 171). The motor of field emergence is the "communities' adoption of a field's label" (Grodal, 2007, p. 171), not the founding of organizations or innovations. Categorization is done not only by new firms, but also by already existing ones (Grodal, 2007, p. 193). Fundamental processes during the emergence phase are translation, renaming, labeling, and abandonment of a label such as nanotechnology by participants, which was formerly understated in research on the emergence of organizational fields (Grodal, 2007, p. 193). For example, the meaning of nanotechnology first centralized on nanotechnology as a device. Then, its meaning focused on material and nanoparticles as a result of the influence of the government and service providers, such as lawyers and venture capitalists. (Grodal, 2007, p. 170)

Self-categorization and Social Networks

The unique case, with nanotechnology being a high-technology and a field that overlaps with the scientific community of scientists, finally draws attention to the salience of self-categorization in these social negotiations of meanings but also of identities that are constitutive of the field. Self-categorization in this context is expected to be as socially embedded as the process of negotiating meanings in an organizational field. The term 'self-categorization' refers to the importance of social categories, in the present case within the realm of academic professions, for an individual's perception and their impact on other individuals' behavior (Ayoko, Härtel, Fisher, & Fujimoto, 2004, p. 162). As Turner and colleagues (1987, p. 13) point out, "perception, evaluation and judgment are relative: they depend on 'stable anchorages' or 'frames of reference,' i.e., standards or contexts against which one compares things." Self-identities are socially constructed by way of social norms and values that form these 'frames of reference'. Social identities (not to be confused with Wolf Lepenies' definition of social identity that is discussed later when analyzing the scientific community) hereby are part of one's self-concept, which derives from social group categories and their corresponding evaluative or emotional frames of reference. Members of a social group can behave according to the social norms and standards of the group or distance themselves from the group. A self-categorization then is defined as the "stereotypical self-perception … and adherence to and expression of ingroup normative behavior" (Turner et al., 1987, p. 102). The topic of professional identities will be addressed in chapter 7.5, which delivers an overview of professional theories and the context of work in sociology.

The focus with respect to self-categorization is on groups rather than social networks although both concepts can be combined. In that regard, Jan A. Fuhse (2009, p. 57) summarizes: social networks constitute "subjective constructs" providing orientation to individual behavior in a given social situation (Stebbins, 1969, p. 1). As network concepts do, symbolic interactionism takes a "relational approach" to analyze social order focusing on social structure as "a set of relationships between individuals" (Fine & Kleinman, 1983, p. 1) interacting with other group members. In the social simulation model presented in chapter 6, small-world-networks (Watts, 1999) with cliques, such as research groups, and short path distances between actors are simulated to create a realistic social network by varying parameters. Rules on the likelihood of interaction are defined for agents, such as the more likely engagement in interactions with spatially close agents (dubbed as 'spatial proximity,' for more information see chapters 4 and 6). Although empirical data and theories are included as well, this certainly does not make the model an empirical model, as social research networks are not measured empirically for this study. Thus, the network approach applied here would be a hybrid model with a strong focus on random-based network modeling but with empirical elements integrated into the agent-based modeling technique.

Structural Opportunities

After analyzing the meanings, identities and self-categorizations of scientists that are actors in the field of nanotechnology, an institutional comparison of the nanotechnology field in Germany and the U.S. follows, in which the focus is directed among others toward the structural opportunities: A change in positions or individual life courses does not occur due to changes in the individual but also due to changes in the structures of a society: A vacant position must arise before an individual can even think about taking up that position (Blau, 1994). These positions are then filled according to the principle of homophily (Blau, 1994, pp. 121-122): members of a group or, as in our case, organizations that are in charge of recruitment search for members that are alike with regards to at least one membership in a group. With institutional change in the form of establishing new institutes and enlarging universities by new laboratories new positions are created that are filled by university members. These are the situations where new generations of scientists are reproduced and decisions are made in a more or less conservative manner, by reproducing the social associations of current members, in particular of those who recruit. Here, the role of networks in informal recruitment turns out to be crucial in filling vacant positions (Blau, 1994, p. 124).

With regards to the last paragraph on self-categorization and social groups, it must be noted here that in Peter M. Blau's concept on structures, meanings attributed to social relationships and groups that are formed of relationships play an inferior if not to say a neglected role (Fine & Kleinman, 1983, p. 101). This is where interactionist concepts step in and bridge the gap between social structures or orders and meaningful social relationships that shape social networks. In the present study, the social simulation model therefore addresses the social structures of research networks in nanotechnology whereas the interviews look at the meanings that go along with these relationship-based structures and make actions understandable. The topic of structural opportunities will be addressed in chapter 6.1 when talking about the constitution of the field of nanotechnology, in 6.3.1 when analyzing the department and chair structure at German and U.S. universities, and in chapter 7 when interpreting the findings from the simulation model.

3.5 Work and the Sociology of Professions

Another pillar of this study, as depicted in the static 'Model of Intervening Mechanisms' in section 1.2, is the realm of work and professions. Thelen (2004) provides a comparison of political economies with a focus on skills formation, institutional evolvement and change and, thus, delivers a macro-level perspective on the topic. Skill formation represents a central issue in today's political economies because it is commonly considered as an engine for productivity and economic growth (Finegold, 2006; Thelen, 2004, pp. 8-9). Productivity and economic growth meanwhile have become the core of national agendas on science and technology both in the U.S. and in Europe because innovations and advanced technologies are considered central factors for international competitiveness (see e.g. Edler, 2003). Thelen (2004) also applies the VoC approach with its distinction between general and specific skills. The VoC approach explains phenomena and change largely on a macro-level, although it includes agents on a micro level such as firms, employees, shareholders (G. Jackson & Deeg, 2006, p. 21) or transfers micro-concepts, e.g. variation within corporate structure and hierarchies among national types of economies, to issues in the macro-economy (Boyer, 2005, p. 31).

However, this doctoral thesis does not stay on the macro-level to discuss the professionalization of nanotechnology. It discusses the probability for the emergence of nanotechnology as a profession in the countries under study and does so by taking a micro-level approach including institutional factors such as professional association. To give such an outlook on the future of nanotechnology as a profession, better-suited theories dealing with processes on the micro-level are required to examine the skill profiles of nanotechnologists and to trace professionalization. This analysis asks both for specialized and interdisciplinary skill profiles in the nanotechnology sector. Theories which suit these requirements are industrial sociology, studies on individual biographies and on the transition from education systems to the labor market, and the sociology of professions in German and U.S. American literature. It is important to differentiate between the sociology of vocations and the sociology of professions (Kurtz, 2002, p. 23). In the following, the sociology of work and individual biographies is presented before the role of professions is discussed.

The World of Work: from Macro-Theories on Society to Micro-Level Individual Biographies

From Weber's times on, the uniqueness of the German "vocation" as opposed to a job merely done to make a living has become widely acknowledged and even admired. Other industrialized nations feared the economic boost Germany experienced around 1900 and attributed this circumstance to the German system of education and vocational tradition (Ben-David, 1972). Vocation or also occupation is strongly related to status, to a rank somebody has in society or the social prestige someone enjoys because of pursuing a respective vocation.

The meaning of vocation as a divine call, however, has experienced some alteration due to social and technological change one experiences in times of industrialization and globalization. By the 19th century, guilds had become powerful small and middle enterprises enjoying protectionism and corporative rights. It was the guilds–not the chambers–that determined work relationships between apprentices and master craftsmen or certification. In this stratified society of *Stände*, socialization of apprentices was vocational-corporative, i.e., based on morale. Apprentices were prepared for a vocation and it was assumed that this succeeded by familial socialization within the master's household and family unit, which at that time was more than the familial nucleus of parents and children, but also maids, servants, and everybody who contributed to the economic survival of the household. (Kurtz, 1997, pp. 17-18) Chambers of commerce and industry corporations gained power in successive legislation that had written documentation as their logic, which the guilds did not have. The guilds rather based their reputation on prestige and status they gained because of their long tradition and premodern history. (Schriewer & Harney, 2000) German corporative structures survived into modern times. Vocations as a functional feature link economy and education in today's differentiated social system (Kurtz, 1997, pp. 33-34).

Transition from Educational Systems to the Labor Market

The meaning of vocations points to the transition from the educational system to the labor market or rather to the relationship between education and economy of which the labor market is part. Different concepts exist on the relationship between education and the labor market. The functional conception sees educational and labor systems as interacting reciprocally with the work organization being the dependent variable. The assumption is that education fulfills in society the function of allocation while the labor system structures the educational system according to qualifications it demands. In an educational economy, the specific technology that is applied decides on the specific form of work divisions and a determined structure of qualifications of the work force. Thus, for example, the scientification of production requires a higher qualified work force, which is supplied by the expansion of university access to more and more students since the 1960s/1970s. This is the subordination thesis meaning that the education system is oriented toward the labor system.

By contrast, another concept speaks of a decoupling of the educational system because of the demand for education as a civil right (Windolf, 1981, pp. 95-96). This decoupling (not to be confused with the neo-sociological mechanism of decoupling) also results from the fact that education and economy function according to different logics. The economy functions according to the logic of production (or "scarcity" as Thomas Kurtz (2002) would describe it), the educational system according to the logic of formal education (Windolf, 1981, p. 112). Systems theory emphasizes the distinctive codes of communication of the educational system and the economic system whereas one system cannot influence the other in a direct way (Kurtz, 2002). Thus, the labor market cannot 'require' qualifications of the educational system which, in turn, adapts to changing demands of qualifications. Each system 'acts,' i.e., communicates in systems theory only according to their code, which is in the educational system better/worse and in the economic system money/no money.

As nanotechnology and its field is the object of study, the polarization theory is mentioned here, too. It refers to the technical conditions of the work processes representing objective determinants of vocational socialization (Windolf, 1981, p. 86). Thus, technological revolutions always affect the organization of work and the occupational profiles that come with it. This assumption of polarization is analyzed in the present study by looking at the influence of nanotechnology on the academic work setting.

Kurtz concludes that, across national segments and differences, the relation of education and gainful employment marked by occupations will always be relevant. Vocational training will gain more and more relevance and will become equal in importance to general education taking place before entering the labor market. Kurtz speaks of a change of occupations with regards to content and more and more open qualification potentials. Referring to Voß, one can speak of an increasingly individualized economic creation, marketing and instrumentalization of human capital. The result thereof is insecurity of actions, which becomes characteristic for the unity of work and education. In regard to the term 'occupation,' this term is suggested to be positioned between work and profession, integrating less qualified gainful employment and highly qualified professional knowledge work (Kurtz, 2002, pp. 68-70).

The meaning of occupations according to a functional view can alter depending on changing social relations or material bases, e.g. technological changes. Occupations just like professions function by credentials that are required to perform the 'work activities' of a profession: "occupations are ultimately constituted by the legitimation of their covering devices through the grant of a license, not necessarily in a narrow legal sense but in terms of the right 'to carry out certain activities rather different from those of other people ... in exchange for money, goods or services'" (Dingwall, 1983, p. 619). Members of an occupation sometimes select their own official histories, which function like tribal myths containing fixed key elements that evolve when histories continue to be told in a changing society. (Dingwall, 1983, pp. 605, 607, 619-620) An example is certainly Drexler who is a contested but nevertheless 'historic symbol' of the development of nanotechnology. In particular in Germany, nanocertificates and degrees support the notion of the emergence of a nanotechnology occupation. In the U.S., on the other hand, certificates attached to regular degrees in the main disciplines of the sciences underlie credentialing in nanotechnology.

Kurtz (2002) purveys a (mainly German) sociological overview of professions and its distinction to occupation and vocation respectively. Occupation is analyzed as a link between the economy and education as well as the economy and morale, whereas main professions are characterized by associational organization, code of ethics, link to social values, asymmetric expert-client relation, social prestige, and the prohibition of public advertisement (Kurtz, 2002, p. 49). In the present analysis, the latter elements will be at the core because the focus here is on the academic world of nanotechnology.

Definition of Professions

In the sociology of professions, several reviews are available on literature on professions and, above all, professionalization. Profession (*Beruf*) has had a different development and imprint in Germany than in the United States. Professions emerge through the process of professionalization. Successful professionalization takes place where functional reductions within a system are managed successfully by a profession. Professions are marked by codes and norms directing the behavior of the respective professionals. This way the profession demarcates itself from others. There can be many identities, values and interests that identify a profession. Structural elements of professions are institutions, personnel, organizations, recruitment policies, stands and codes, political activities, relations with the public, informal mechanisms of sociability and control. (Bucher & Strauss, 1961, pp. 325-326)

Therefore, professions have a relatively high standing compared to other occupations and imply "theoretically based discretionary specialization," not mechanical specialization: "work that cannot be performed mechanically because the contingencies of its tasks vary so greatly from one another that the worker must exercise considerable discretion to adapt his knowledge and skill to each circumstance in order to work successfully" (Freidson, 1999, p. 119) Professions are marked by long-term career paths and "distinct personal and public occupational identity," features that are analyzed in the field of nanotechnology for academia. They are socially closed and constitute "labor market shelters" (Freidson, 1999, p. 120). Credentials are required to get access to professions that give graduates "membership in an educated rather than a merely technically proficient class" providing them and requiring of them cultural capital (see Pierre Bourdieu) (Freidson, 1999, pp. 120, 122).

Professions give "ideological justification for basic or pure research" (Freidson, 1999, p. 122) and involve independence of politics and economy. The division within groups is more distinct in the case of professions because of the cognitive authority some members in particular obtain, thus, representing a professional hierarchy within the profession. The only resource that is "intrinsic" to occupations is their "body of knowledge and skill," (Freidson, 1999, p. 122) constituting the core of the profession. Eliot Freidson defines "the main conditioning variables to be the state, the professional association, ideology, and the particular institutional requirements for the practice of the substance, or body of knowledge, of different professions" (Freidson, 1999, p. 122). With professionalism being the "occupational control of work" (Freidson, 1999, p. 118), institutions as part of the model perform such control whereby merely the state has the power to establish and maintain such professionalism. To establish professionalism, professional associations are not a condition sine qua non according to the author. Thus, an association is not just equivalent with the respective profession (Freidson, 1999, pp. 122, 125).

One can speak of a profession if a group coordinates through its actions the problems of application for a functional system of stocks of knowledge and if this is done by the group in a monopolistic or dominant way. This implies that coordination is done in such a way that it directs the activities of others within the functional realm of vocations. Professions can be differentiated from vocations by the fact that professions must bring individuals to perfection, whereas e.g. corporations strive primarily for survival. Perfection in the sciences refers to scientists who strive to do cutting-edge and innovative research on an international competitive level. Professions are in charge of problems that cannot be solved due to structural deficits that are structured in a way that a just in time attribution of concrete difficulties and patterns of solution that can be generalized are impeded. (Kurtz, 1997, pp. 62, 204) Whereas the English word professionalization refers to a process that aims in a planned way toward the attainment of a social status for a professional group, the German word "Professionalisierung" in the economic context aims in a planned way at the increase of the individual potential of achievement. … [Professionalization also focuses on the] elaboration of a specific competence for action required by the structure of professional actions. (Hesse, 1968; Hesse cited in Kurtz, 1997, p. 136) It is important to remark as it is often confounded when defining professionalization that the formulation and institutionalization of pedagogical vocational models and their legitimation through certificates are not a guarantee for professionalism. (Dewe, Ferchhoff, & Radtke, 1992; Dewe, Ferchhoff, & Radtke cited in Kurtz, 1997, p. 148)

Other features of professions are their focus on single cases and the non-standardization of professional actions with several logics involved: the logic of the market, of bureaucracy, of a specific ethos, and of expert knowledge. A professional habitus, as mentioned above, is developed resulting from the practice of a profession. (Schützeichel, 2009) Professions are well-organized occupations that close markets (social closure) and maintain their social status as a collective. However, the social structure determines the structure of the professional market and cannot be neglected. (Dingwall, 1999, p. 131)

Therefore, in the context of this study, the terms vocation and occupation are used interchangeably (not as in many studies occupation and profession). As it must still be determined if individuals working in the field of nanotechnology are professionals in the strict sense, profession and occupation are the terms used in this study in general to refer to the nanotechnology labor market.

Historical Overview of Selected Professions: Chemistry and Engineering

Charles E. McClelland (1991) delivers a historical overview of the development of German professions from the 19th century to the post-war era after World War II. The author lists "ideal" features of professions conceptualized in the social sciences which are more in number than the definition mentioned above: highly specialized and advance education, a special code of conduct, altruism and public service, rigorous competency tests, examinations, licensing, high social prestige, high economic awards, occupational career pattern/ladder, monopolization of market in services, and autonomy (McClelland, 1991, p. 14). Certainly, not every profession has fulfilled these criteria to the same degree.

McClelland differentiates between professionalization and "Berufskonstruktion" (construction of occupation). "Berufskonstruktion" is applied as a concept e.g. in chemistry saying that a profession emerges in order to serve social and economic interests. Thus, it is constructed from the outside (McClelland, 1991, pp. 13, 144). McClelland concludes that this distinction is rather "misleading" and suggests instead the differentiation between internal pressures (e.g. by sub-groups, entrepreneurs versus employees, democratic versus elitist tendencies) and external pressures (e.g. outside authorities like the state). This distinction has been followed in this study by examining not only the academic setting but also the external "regulatory pressures" (W. W. Powell et al., 2005, p. 1134), namely the German and U.S. governments and their national science and technology agendas.

McClelland illustrates the struggles and organizational development of professions, including free professions such as chemistry, medicine, and engineering. In Germany, an upgrading of educational qualifications was raised on university level earlier than in the U.S. or the UK, where self-taught lawyers and medical schools were common for a long time. McClelland (1991, p. 76) mentions two measures of success: the profession's level of autonomy and the exclusiveness by elevating standards of education and certification. Both are measures which have been changing over time. In Germany, the autonomy of professions always came along with some form of dependency on the subsidizing state or "outside authorities" (McClelland, 1991, p. 133) in contrast to the U.S., where the question is if government control exists at all (McClelland, 1991, p. 21). This circumstance naturally meant less autonomy and more compromises, but it did not limit the influence of professions e.g. in educational affairs. Professors were often "guided" by leaders in industry and in leader positions of the VDC [Verein Deutscher Chemiker (German Chemists Association)], e.g. Duisberg (McClelland, 1991, p. 144). This relational network became known as the "new 'social corporatism'" (McClelland, 1991, p. 133). Professors in turn used to be "leading members" in professional associations (McClelland, 1991, p. 117).

Thus, professional organizations and academia were tightly linked and therefore ensured the influence of organizations on academic programs and the skills that were taught in higher education. Interestingly, in the U.S., Slaughter (2005) argues that professional associations along with the rise of academic professions do influence study programs. The author compared physics to women's studies and found that "strong programs have strong professional associations" (Slaughter, 2005, p. 283). Additionally, external resource providers such as the Department of Defense, Department of Energy, the National Science Foundation and the National Institutes of Health have a say in the development of curricula. This is important for nanotechnology as nanoscientists depend heavily on public funding and forge links with industry. Therefore, one can expect such as in the case of Penn State University (PSU) that professional associations and external resource providers govern programs (cf. the 'Model of Intervening Mechanisms' in section 1.2). In chemistry, as becomes evident in one interview, the American Chemical Society (ACS) has a say in curricula and endorses study program credentials with a specific ACS acknowledgement.

In engineering, there were several associations next to the VDI. Thus, it has not been always clear that the VDI, the politically most neutral association among all engineering associations of which some were "minority 'pressure group[s],'" would survive nationwide as the most influential of all engineering associations.

In the case of the VDC, a national chemistry association had not existed until 1900. Back then, two-thirds of all chemists were member of the VDC (i.e., 2,100), whose role model was the VDI organization (McClelland, 1991, pp. 95-96). Economic concerns were prevailing as more and more chemists were employees rather than entrepreneurs. This was due to an increase in the number of big companies which employed 41-60% of all chemists and which lead to structural changes, i.e., less autonomy, income, and respect (McClelland, 1991, pp. 97, 144).

To conclude, McClelland asserts that German professions are characterized by early bureaucratization which was followed in the 1860s by a deregulation of professions resulting into the so-called "free" professions. The modernity of these free professions consisted in a lengthy education for a lifelong occupation, differentiation and growth of professions, career ladders, and academization. Engineering, chemistry, and teaching became the "new 'professionalized' occupations" because of "scientization" in the 19th century. The collaboration among the state, modern professional organizations, and the education system elevated standards, led to uniformization and "mental nationalization of professional practice." This development is contrary to the UK and the U.S. where political institutions were manipulated in order to establish own endeavors. High educational and certification standards in Germany represent a mechanism of market control, which has not been achieved e.g. in the U.S.. German higher education is more inclusive than in other countries at the end of the 19th century and the beginning of the 20th century. Access was less expensive than in Great Britain and in the U.S. With regards to autonomy, engineering and chemistry were not much more autonomous than other professions. When it comes to the role of education, the question remains, according to McClelland, if educational requirements are set by scientific knowledge or by political struggles or by the longing for social prestige. The influence of self-interest e.g. by the professoriate and by professional elites must not be underestimated in this context. (McClelland, 1991, pp. 231-233, 240) In nanotechnology, the influence of politics in Germany becomes clear in its interest in producing nanotechnologists for the labor market; in the U.S., the creation of cutting-edge research centers stands at the core of federal initiatives and grant policies.

Professions under Discussion

One perspective that provides deeper insights into how professions work is to see professions as "in process" and structured into segments, i.e., groupings within a profession that arise among others through coalitions (Bucher & Strauss, 1961, p. 326). This perspective gives new aspects of analysis, namely the work situation and institutions, careers, socialization, recruitment, public images, relations with other professions, and leadership. In this study, certainly the work situation and institutions, socialization referring to the competition of segments for students, careers, recruitment, public images, and relations are relevant. Work situation and institutions that are perceived as arenas focus the relationships that evolve due to changing professions. Recruitment is another ongoing process in professions because candidates for membership are chosen according to the professional images and self-concepts. Relations take into account that professions or segments can develop relations with other professions. This is certainly an important aspect in the analysis of nanotechnology as an interdisciplinary field. Provided interdisciplinarity, professions involved in nanotechnology must have relations to other professions, i.e., chemists, physicists, and engineers rather than developing a profession or segment of their own. This is to be examined when looking at the professional field of nanotechnology. If a nanotechnology segment emerges, public images in nanotechnology must be analyzed as well to find out which alternative images on nanotechnology as a profession exist. (Bucher & Strauss, 1961, pp. 333-334)

Nevertheless, the concept of professionalization is not completely uncontested among authors in the field. Abbott (1988) provides another, more systematic approach to professions. He criticizes the concept of professionalization because it "ignored who was doing what to whom and how, concentrating instead on association, licensure, ethics code." (Abbott, 1988, p. 1) Whereas in the Anglo-American model, "professions [were seen] as market dominating organizations," in the Continental professions model, expertise was always related to the state (Abbott, 1988, p. 6). This led to a split between the functionalist and monopolist perspective, two of four concepts of professionalization besides the structural and cultural one (Abbott, 1988, p. 15).

The functional version defines profession as a "means to control the asymmetric expert-client relation." (Abbott, 1988, p. 15) The process of professionalization implies the "evolution of structural guarantees for that control" (Abbott, 1988, p. 15). The structural concept assumes the disappearance of functions and considers profession only as a form of occupational control (no content of work or expert-client relation of importance). It is historical forces that are responsible for shaping the structure. The monopolist stance attributes structural developments to struggles of power and authority, influence of control of work on status and power of professions or on social functions (e.g. healing, justice). The cultural concept views cultural legitimation as a part of professionalization and expertise as a social relation. (Abbott, 1988, p. 15) The cultural version is always linked to values: "Culturally, professions legitimate their control by attaching their expertise to values with general cultural legitimacy, increasingly the values of rationality, efficiency, and science." (Abbott, 1988, p. 16)

The problem of professionalization theories, however, lies in its focus on structure rather than work and its control and differentiation (Abbott, 1988, p. 19). Abbott himself instead concentrates on "interprofessional competition" (Abbott, 1988, p. 2) and, thus, changes the perspective on professions from an individualistic to a systematic one. He links profession to its work, which he calls jurisdiction: "To analyze professional development is to analyze how this link is created in work, how it is anchored by formal and informal social structure, and how the interplay of jurisdictional links between professions determines the history of the individual professions themselves." (Abbott, 1988, p. 20) Abbott establishes a definition of profession with a focus on the abstraction of knowledge:

> "As is traditional, abstract knowledge is central. But the justification for it is new; knowledge is the currency of competition. Only the move by treatment contradicts this rule, and it has, in the clergy's case at least, proved remarkably ineffective. The recent expansion of expert systems research illustrates the rule about abstraction perfectly. Practitioners of artificial intelligence argue that all professional inference follows a certain form, which can be generated by a suitably programmed machine. This is in some sense the ultimate abstraction, reducing all professional inference to one form and all jurisdictions to a single unit." (Abbott, 1988, p. 102)

Competition in nanotechnology becomes apparent not only in the federal state that fosters nanotechnology as a profession in the labor market but also in the sciences. There researchers compete for innovations and breakthroughs in knowledge production justified by advances in knowledge and technological progress that improves human life. Furthermore, competition might arise, if it not already has, between professional associations in chemistry and physics in particular since these are the most powerful associations in the sciences. They integrated nanotechnology one way or the other. Yet, it is still unclear how nanotechnology sections evolve in the future: if they are subsumed as specialties (Abbott, 1988, p. 106) under the ACS, IEEE (Institute of Electrical and Electronics Engineers), SPIE (Society of Photographic Instrumentation Engineers/International Society for Optics and Photonics), DPG (German Physical Society) or DECHEMA or if they leave and split from these associations. To Abbott (1988, p. 92), the former is more probable as he writes: "New technological jurisdictions are therefore usually absorbed by existing professions with their strong organizations. Yet not always". Abstract

knowledge is given in nanotechnology because the field is not characterized by a common field of application, rather by a common tool and method to examine material at the nanolevel and to find out about changing functionalities. Scientists compete for the newest detections of properties and nanomaterials and become experts for policy-makers for instance in terms of nanofunding (see interviews in chapter 7).

Contemporary Views on the Profession

There are many studies on selected professions such as midwifery, medicine, education, social work, and law, usually under a national perspective. One article by Raymond DeVries, Robert Dingwall, and Kristina Orfali (2009) discusses bioethics as a new profession in the medical sector. The authors outline the cultural and historical factors of the emergence of the profession of bioethicists in the U.S. and France as well as the actual desires of bioethicists for a bioethics profession to develop. The example of bioethics shows that there can be such a thing as "'a profession in process'" (DeVries et al., 2009, p. 557) when there is not yet a precise definition of a profession such as a bioethicist. This is also to be examined with nanotechnologists.

As Freidson distinguished between the official labor market, the criminal labor market, informal labor market, and the subjective labor market, it is the subjective labor market in which "goods and services traded without direct economic exchange" and many occupations evolve. The lack of direct economic exchange is valid in nanotechnology as research at universities still represents a public good (Slaughter & Rhoades, 2004). Professions as opposed to the more generally defined occupations "monopolize institutionalized positions" (DeVries et al., 2009, p. 557). The supply theory of professionalization is advocated by DeVries, Dingwall, and Orfali with regards to the professionalization of bioethicists because it assumes a more independent role of the state whose interest must coincide with the interest of the professional group so that this group can gain professional status. U.S. bioethicists did not use to have "institutionalized support of centers for bioethics, professional journals, government commissions or graduate programs and professorships" just like nanotechnologists. But this has changed. Nowadays, there are centers, journals, and study programs in both bioethics and nanotechnology. To become a discrete occupation, bioethics must do intellectual work ("defining and claiming ownership of a jurisdiction" (DeVries et al., 2009, p. 559)) and organizational work ("to secure recognition and legitimacy for that claim" (DeVries et al., 2009, p. 559)). Intellectual work refers to creating a story, which in the case of bioethics was scientific progress that requires ethics, as scientists tend to think about social and political implications less and less. Furthermore, issues in the respective professional field such as bioethics must be on an open agenda. This meant in the case of the U.S. that non-religious solutions had to be found to reflect U.S. individualism and culturalism not least because a profession always also needs to produce its own legitimacy. Thus, intellectual work defines a niche. (DeVries et al., 2009, pp. 559, 561-562) The production of legitimacy, as the interviews show, turns out to be quite complex in the case of nanotechnology when juxtaposing the federal states' and scientists' perspectives. Nanoscience is legitimized according to scientists by doing basic research to create innovations and cutting-edge, specialized research, i.e., to contribute to scientific progress. States, by contrast, have in interest in innovations for reasons of economic growth and productivity in order not to lose international competitiveness (see e.g. J. W. Meyer & Ramirez, 2009, p. 216; Schaper-Rinkel, 2006, p. 484).

Organizational work, by contrast implies the "powerful isomorphic pressures" that influence "the legitimate colonization of a niche" (DeVries et al., 2009, p. 562). As with nanotechnology, credentialing and interdisciplinary coexist in bioethics and are seen as conflicting forces. On the one hand, a homogeneous basis is needed to judge competences. On the other hand, the personal backgrounds that are examined in this study in nanotechnology are very diverse, first of all in regard to the participating disciplines, just like there is diversity in bioethics with regards to education, occupation, and experience. (DeVries et al., 2009, pp. 562, 564)

After introducing the theoretical background, which suggests that different theoretical concepts provide different viewpoints depending on the focus each concept has, these perspectives are applied and juxtaposed in chapter 7. Hereby, an analysis of the interview data of this study combines these theoretical perspectives to give multifaceted insights into the field of nanotechnology. But before turning to chapter 7, the methods and the German and U.S. higher education systems are outlined, and the agent-based model on nanotechnology research networks is discussed. This discussion provides a frame for the analysis of the semi-structured interviews. The results of the latter raises further questions on the inner life of nanotechnology at universities that are comprehensively addressed in chapter 7. In 7.5, the state of professionalization of nanotechnology in not only in a theoretical but also in a general sense is introduced. In that section, it is inquired if nanotechnology constitutes a profession per se or if rather nanotechnological skills are incorporated into existing job profiles. If not indicated otherwise, in the following the term professionalization refers to the development of nanotechnology into a profession.

4. Methods

In this chapter, the applied methods are outlined to explicate the reasons why they are used to answer the research questions presented in chapter 1. Agent-based modeling and interviewing applied under the frame of a case study on Germany and the U.S. are seen as complementary methods that address the field of nanotechnology at universities in two different ways. Both interviewing and agent-based modeling are bottom-up approaches that enable the investigation of the inner life of nanotechnology and the meanings related to that advanced technology. The related findings further provide insights into the identity construction at the micro-level and into characteristics of the organizational field of nanotechnology with universities being the organizations that are looked at.

4.1 Social Simulation

In the social sciences, there has been arising a third, fairly recent approach of simulation (Macy & Willer, 2002, p. 145), which is neither deductive, i.e., starting from theorems to be tested, nor inductive, i.e., developing theorems from empirical data. The method is abductive (Axelrod, 1997, p. 24) in the sense that “simulation modeling can be used as an aid intuition”. The approach is “bottom-up,” meaning that individual agents are equipped with attributes and interaction rules, and deals with the emergence of collective behavior or social order, here the emergence of the field of nanotechnology in science, “based on the individual behaviour of agents or actors” (Cioffi-Revilla, 2010, p. 264).

Naturally, several premises come along with simulation modeling, more precisely with agent-based modeling, the type of social simulation used here. It is used to analyze the effects of the behavior of multiple autonomous individuals on the whole system, field or society. One major assumption is that “agents use adaptive rather than optimizing strategies” (Axelrod, 1997, p. 25), i.e., agents are not entirely rational at all. In the model, agents adapt to others by interacting with other researchers when looking for cooperation partners that are near and when already cooperating by adopting another researcher’s topics but also when interacting with funding agencies and their agendas. Flaminio Squazzoni (2010) condenses the position of agent-based modeling (ABM) stating: “ABM has been often viewed as a ‘third way of doing science’ that combines deduction and induction (i.e., abduction). Like deduction, ABM starts with a rigorously specified set of assumptions regarding a system under scrutiny, but does not result in analytical proofs of theorems. Rather, it generates (artificial) data suitable for analysis by induction.” Note also that simulated models are dynamic, i.e., the models presented in the following are not to be confused with the static model of the introductory chapter. The models are dynamic in the sense that the individual agents interact with each other at the micro-level leading to a distinct collective behavior at the macro-level.

This must be kept in mind when dealing with simulated data. As with quantitative and qualitative methods, ABM cannot achieve what it is not intended to do. The goal in this study is to generate data for analysis by induction, not to “test” theories this study applies in the analysis of interviews. More concisely, empirical observations on detectable social phenomena and mechanisms rather than empirical numerical data form the assumptions of the network simulation model of academic research links with public funding as the independent variable. The simulation results are then analyzed and compared with the interview results. The evaluation takes place using statistical tests (Kruskal-Walls and Nemenyi test). As the use of social simulations is a fairly new field in social science methods and still at an early stage, it is debated in academe if tests that are designed for empirical data can also be applied for artificial data. Yet, these statistical tests are the only instrument so far to analyze numerical data so that they are also implemented in this doctoral thesis. The present study does not infer representative assumptions about academic research in nanotechnology like quantitative surveys or other methods intend to do.

Recognizing the limits of interviewing, social simulation represents a complement to generate additional qualitative and quantitative data (“artificial” data (Squazzoni, 2010), i.e., computer-generated data). This enables the detection and explanation of social relationships by means of simulated mechanisms. These mechanisms focus on the intended and unintended consequences of individual behavior for the macro-level rather than variables that are to be statistically evaluated (Hedström, 2008, p. 330). In the present study, the mechanisms increase the likelihood of interaction. They include the formation of publicly funded research alliances based on spatial proximity (Blau, 1977; Pattison & Robins, 2002; W. W. Powell et al., 2005; Schweinberger & Snijders, 2003), personal acquaintance and relationships (seen as a result of homophily (Blau, 1977)[3]), transitivity (also known as clustering (Davis, 1970)) in research collaboration and citations as well as the tendency to cite ‘star scientists’ (Zucker & Darby, 2001) (‘Matthew Effect’ (de Solla Price, 1965, pp. 511-512; Merton, 1968) and ‘Lotka’s Law’ (cf. Gläser, 2006; Lotka, 1926)). Homophily is also discussed in section 7.1.4, which deals with the recruitment mechanism that applies when hiring doctoral students. It becomes clear that personal attachment to an applicant is important in the decision to let him or her join a research team. Furthermore, the reproduction of the research networks are also modeled by studies producing graduates that follow research interests based on their university education. As a result, nanotechnology diffuses within the network and thus nanotechnologists emerge who identify themselves as nanotechnologists. A social mechanism, following Peter Hedström, is hence defined as “a constellation of entities and activities that are organized such that they regularly bring about a particular type of outcome” (Hedström, 2008). Since simulation data, in turn, cannot provide information on the thoughts, meanings, and motivations of individual researchers and the inner organizational life of the institutions these researchers work in, interviews are used to provide in-depth data on the micro-level and the influence of researchers on the organizational sphere.

As Nigel Gilbert and Klaus G. Troitzsch (1999b, p. 16) point out, “both simulation models and statistical models can be used for explanation and prediction.” Targets, i.e., “’real-world’ phenomena” (Gilbert & Troitzsch, 1999b, p. 14), explored in qualitative interviews are to be explained in the model presented here. The interview results are extended by simulating different parameter settings. The experimental framework is illustrated in greater detail in the analysis chapter. The main interest is to explore the influence of public funding on research cooperation between researchers, i.e., agents, and on the development of main disciplines and specialties measured in terms of the number of agents that belong to that field of research or graduated from a study program. The main parameters, i.e., factors, are interdisciplinarity and the readiness to change disciplinary identities (dubbed as ‘identity-change’). It is examined how funding affects the network of researchers and their collaboration. Basic characteristics from network analysis are adopted, such as spatial proximity (Pattison & Robins, 2002; W. W. Powell et al., 2005, p. 1189; Schweinberger & Snijders, 2003) and prestige measured by the number of citations (M. O. Jackson, 2008, p. 40) influencing the probability of effecting relationships between researchers. In sum, the model results show how funding can induce network effects in research cooperation and, in general, how social phenomena emerge that are not laid into the model at the beginning of the simulation. Emergence thus “occurs when interactions among objects at one level give rise to different types of objects at another level. More precisely, a phenomenon is emergent if it requires new categories to describe it which are not required to describe the behavior of the underlying components” (Gilbert & Troitzsch, 1999a, p. 10). From a methodical point of view, a network analysis including empirical network data thus would be an extension of the spectrum of methods used here.

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[3] For a current issue on homophily, see the theoretical and methodological discussion on the mechanisms of influence (e.g. by peers) and selection (homophily) and the difficulty of differentiating between the two. A discussion from a statistical-methodological point of view is provided in Christian Steglich, Tom A. B. Snijders, and Michael Pearson (2010).

The evaluation of significant differences due to the way of distribution for public funding is done by Kruskal-Walls and Nemenyi tests as a result of the non-normal distribution of the simulation data. One must be aware that these data are artificial and not empirical. Therefore, the results must be interpreted cautiously knowing that technically, significant effects could be obtained by increasing the number of simulation runs. The fact, however, that significant differences are already reached by a moderate number of runs, namely 100, indicates that network effects lead to mass effects and significant differences already with a low number of n, with n being the number of simulation runs.

4.2 Case Study Comparison

With Germany and the U.S. being the two cases of analysis here, the doctoral study is an international case study comparison. There are two styles of macro-comparisons: either large-nation comparisons are designed across contrasting cultural areas or all units within one cultural area are compared (Rokkan, 1996, p. 21). In the present study, the first type is used to compare the fields of nanotechnology in Germany and the U.S.. However, in contrast to most macro-comparisons, this study is neither quantitative nor representative. Rather, the national setting of both countries is used and explored under the perspective of education, research, and profession, domains that have been exposed to nanotechnology innovations (Heinze, 2006a, p. 130). Germany and the U.S. show many similarities, such as industrialization, capitalism, economic growth (Esping-Andersen, 1990, p. 29; Thelen, 2001), and expansion in higher education (e.g. Münch, 1984). They also demonstrate differences in terms of the institutionalization of nanotechnology into higher education due to different national systems, here particularly higher education systems. Thus, the study seeks to find (institutional and individual) differences and similarities in an explorative way by interviewing nanoscientists on their views of nanotechnology and on the implementation of nanotechnology at their universities.

When social phenomena are to be explained, conditions and causes of variation must be controlled. This is the goal of comparative social science. (Ragin, 1996, p. 74) The data of comparative social science are cross societal and have a multilevel character, i.e., the macro-level of systems and the within-system level (Ragin, 1996, p. 75). The focus here is on the meso-level and micro-level as universities on the basis of individual researchers are compared. Comparative social sciences are not adequate for testing theories. Yet, qualitatively oriented comparativists like the author of this study are interested in applying theory to single cases and interpreting these cases with the theories at hand. (Ragin, 1996, p. 80) By doing qualitative comparisons, they are “interested in the cases themselves, their different historical experiences in particular, not simply in relations between variables characterizing broad categories of cases” (Ragin, 1996, p. 77). Researchers ought to consider carefully under which circumstances case studies are fruitful. Doing case study research out of necessity because the number of cases was too small for a quantitative research design is certainly not a justified reason to use this method (Wrede et al., 2006, p. 2989). Basic steps in comparisons are the identification of similarities, here characteristics of nanotechnology as an organizational field, the establishment and expansion of specific differences into hierarchies or sequences, and the recognition of differences, here the different higher education contexts and grant policies. These processes can occur to different degrees depending on the style of comparison. (Schriewer & Holmes, 1988, p. 35)

The selected universities and scientists are the observational units in this study, i.e., the “unit[s] used in data collection and data analysis.” The explanatory units for the way how nanotechnology is realized in academia, i.e., the “unit that is used to account for the pattern of results obtained,” (Ragin, 1996, p. 79) are individual meanings and maxims of action, the institutional settings of work, and influence of national science and technology policies and higher education reforms respectively. The comparative method is superior to statistical methods when it comes to “interpreting specific cases and addressing historical specificity” and “synthesizing existing theories” (Ragin, 1996, p. 83). Depending on the research questions, it is the researcher who defines the “boundaries of a comparative examination” (Ragin, 1996, p. 83). As academic professions in nanotechnology and related theories as well as the German and U.S. higher education system with respect to the implementation of nanotechnology are of interest here, this determined the "boundaries" of comparison.

Comparative Social Science

There are different styles in comparative social science, in particular in the international context. Sirpa Wrede et al. (2006) use the decentered comparative method. It "addresses the often unacknowledged ethnocentrism of traditional comparative research" (Wrede et al., 2006, p. 2986) and can be applied at the meso-level of organizations in a multilevel framework. The authors emphasize the "comparison of high-income countries, where researchers often unthinkingly assume similarity and convergence in terms of economic development, social structure, and medical practice" (Wrede et al., 2006, p. 2987). These comparisons provide outcome data from a number of countries on the macro-level but ignore social and cultural contexts (Wrede et al., 2006, p. 2987). Wrede and colleagues plead for the connection of necessary internationalization and the "understanding of knowledge as socially situated" (Wrede et al., 2006, p. 2995) be it the knowledge of researchers or the knowledge of the subjects interviewed in the present study (Gibbons et al., 1994; Nowotny et al., 2001).

This is why in the present study the social and cultural contexts of the countries of comparison are analyzed primarily in an explorative way (Wrede et al., 2006, p. 2988) to integrate context and be self-reflective. A partial perspective of the investigator is unavoidable: "instead of adopting the traditional position of the objective scientific observer describing the 'state of affairs,' researchers need to reflect on the situated and political nature of their own knowledge in relation to the studied phenomenon" (Wrede et al., 2006, p. 2989). "Decentred contextual analysis of several cases" and establishing analytical concepts to define theoretical phenomena of each case constitute the core of comparative research (Wrede et al., 2006, p. 2989). To account for the complexity of cases, the "social construction of concepts" are to be analyzed, and concepts with meaning across nations reconciling complexity, detail, and context are to be set up (Wrede et al., 2006, p. 2990).

Another integral part of decentered comparisons is a "focussed, in-depth analysis" next to "narratives describing linear developments of the macro-level process," (Wrede et al., 2006, p. 2992) which in the case of this study is the VoC approach used as a macro-perspective. This macro-level approach using VoC is complemented by meso- and micro-level theories to provide an in-depth analysis. In conclusion, a 'thick description' is given when cases are examined "on their own terms in relation to questions that bring different cases into a shared framework" (Wrede et al., 2006, p. 2993). This also means that single cases and their unique context must be considered before relating them to other cases and overlook several (national) social and cultural settings. The former is done here because the VoC approach does not grasp the processes that adhere to the construction of nanotechnology as a field. It is considered of greater relevance in the present study to focus the contexts of single cases for now rather than to narratively describe the two countries as macro-level developments.

Wrede at al. (2006, p. 2993) develop an analytical framework that accounts for the necessity not to limit the context of a country to one aspect only: "contextual interpretation requires integration of culture as a significant dimension of analysis so that organisations, rules, routines, procedures and assumptions are regarded as cultural products that shape and are shaped by the distinctive milieu of each country." Macro-, meso- and micro-level research questions are to be linked but they are to be kept analytically separate. As in the present study, Wrede et al. focus professional groups and organizations in their meso-level analysis. The authors use the meso level to compare the advantages and disadvantages of "different styles" of informal education in midwifery concluding that "a culturally situated educational model enables particular forms of knowledge at the same time as others are excluded" (Wrede et al., 2006, pp. 2993-2994). Micro-level studies, on the other hand, can bring individual experience back to the center and look simultaneously on how this experience is influenced by culture and history (Wrede et al., 2006, p. 2994). In the case of nanotechnology, personal experiences

are problematized by in-depth interviews to find out about cultural forces. Thus, there is a focus on the "shaping and making," (Wrede et al., 2006, p. 2994) not on outcomes.

When it comes to the question why a German–U.S. comparison is considered relevant and even indispensable in the realm of nanotechnology, one must look at the institutional settings and organizational structures of how nanoscience and -technology are embedded. The chapter on the comparison of tertiary education in Germany and the U.S. showed that significant differences prevail: the greater diversity of the U.S. college system, the departmental structures that are set up in a more vertical than horizontal way in the U.S., the existence of a dual-system that is not, as in the U.S., formally integrated into higher education, and public funding structures. Public funding is crucial since in Germany private universities still represent a minority and public universities largely funded by the state dominate research. In the U.S., however, there is a well-established private sector of universities that provide a large budget for research. Third-party funding also plays a bigger role in ensuring university funds than in Germany where, only just recently due to the Bologna process, third-party funding has increased in importance. However, the case of nanotechnology shows that the governments provide the largest share of nanotechnology third-party funding regardless if universities are public or private. The assumption then is that these national institutional differences that have emerged over time, most noticeably since the 19th century, lead to differences in the adoption of nanoscience and –technology and to different ways of adapting this new specialty. The results of this supposition will be derived from interview data with scientists from different kinds of national higher education settings (research universities, universities of applied sciences, private non-research universities, and technical universities).

Figure 11 illustrates the influencing variables that coin the context of those social actors that are at the center of the present study:

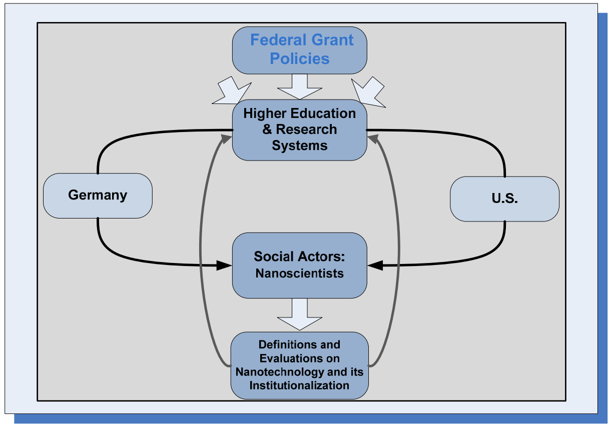

Figure 11: Model of Influencing Variables; Own Source

Federal grant policies feed money into national higher education and research systems being prominent social systems in modern societies. Here, Germany and the U.S. have been chosen as two national cases of investigation. Social actors that belong to the German and U.S. higher education and research system have been selected and interviewed since they are influenced by their national higher education contexts. These actors were nanoscientists from universities, predominantly professors and Ph.D./doctoral students. In the interviews, their definitions and evaluations on nanotechnology were asked for as well as their involvement in the institutionalization of nanotechnology. The actors' definitions and evaluations that are part of their repertoire of maxims of action in turn impact higher education and research systems because these maxims of action affect the institutionalization of nanotechnology in which professors, in particular, but also other social actors from universities are engaged. Of course, this diagram is not comprehensive in all variables that influence social actors and their maxims of action. Science-industry relations also play a role (see Merz & Biniok, 2010 for Switzerland e.g.). The selected variables, however, are crucial for the institutional diffusion of nanotechnology as they exemplify how a high-technology meets social actors in their everyday lives and how these actors deal with the external "regulatory pressure" (W. W. Powell et al., 2005, p. 1134) to foster nanotechnology.

4.3 Interviewing

It goes without saying that each method is only capable of answering a limited range of research questions. This is the same with social simulation. Interviews were therefore used in this study to explore more deeply the work environment and culture cumulated in maxims of action of nanoscientists that are presented in their views about research, nanotechnology, knowledge production, and research collaboration. These interview results form an extension and enrichment of the simulation. With social simulation and interviewing, two fruitful and, in the case of social simulation, new approaches are used to address the study of the field of nanotechnology from both a macro- and micro-level.

Similar to Grit Laudel (1999, p. 59), the present study of comparison is supposed to distinguish the variable part from the invariable part of the institutional setting and to establish the relationship between institutional variation, i.e., higher education institutions, and the workplace environment and professional activities of academic researchers. This distinction will be done in the chapter of analysis. It is comparable to the neoinstitutionalist differentiation between 'formal structures' (institutions and their rules) and 'work activities' that can deviate from the intended effect of 'formal structures,' which function as 'rationalized myths' to legitimate organizational actions (J. W. Meyer & Rowan, 1977): Both realms function differently but complementarily to each other in order to cope with the problem of legitimacy. This problem can only be solved when 'formal structures,' embedded in a social environment, comply with general models that are legitimated in the environment. Accordingly, looking only at institutional settings and their change veils a large portion of what is 'really' going on, i.e., the 'work activities' that do not follow rules of efficacy and rationality.

Two methods dominate the current sociology of science that applies qualitative methods in case studies: laboratory studies with the method of observation on the one hand and qualitative interviews on the other. As by observation, not every question of interest could have been answered because only the situation of an academic researcher at the time of the observation could have been documented. Life courses, motivations, and personal interests that are responsible for the construction of meaning and just as effective at the time of the interview would have been omitted. Furthermore, it is insufficient to merely grasp observable interactions. Institutional structures, such as the organizational research system existent in Germany and the U.S., are only partly accessible by observation. Therefore, interviewing was chosen as an inductive method to explore the meanings and evaluations of nanotechnology that form the maxims of action when dealing with the implementation of nanotechnology at universities.

By choosing in-depth interviews, one has to be aware that on the one hand, access to the socially constructed "life worlds" (Merleau-Ponty cited in Kvale, 1996, p. 54) of the interviewee can be provided by posing open questions. On the other hand, one needs to be aware that in interview situations, the interviewer is also the "coauthor" (Kvale, 1996, p. 183) of what is said. The interview situation is interactive. What is told and transcribed is the result of the "interplay" between informant and interviewer. The narratives given by the interviewee are always the "product" and the construction of both interview partners. This construction also means that the interviewees presented here might have given different answers to a representative from industry or to a politician. The fact that the interviewer was a social science researcher meant that the interviewee talked to the scientific community, not

the industrial or political community or the media. Thus, it was certainly positive that the interviewer was a neutral researcher who was looking from the outside on the field of academic nanotechnology. This gave the interviewees the opportunity to utter critical points on the one hand. On the other hand, some informants saw the interview as an opportunity to give their subjective, at times political opinions and to deplore in the presence of the interviewer about the grievances at universities. This circumstance was taken into consideration in the analysis. The reader must be aware that the chapter of interview analysis is about personal meanings and evaluations of nanoresearchers and their interrelationship with higher education contexts, not about the structural and institutional diffusion of nanotechnology as presented in other chapters of this study.

The previously mentioned "access to the 'life worlds'" provides researchers the opportunity to ask interviewees for an explication of central rules of action and relevant maxims of action respectively. These maxims of action can be viewed as internalized meanings as expressed by social constructivism. In this study, Berger's und Luckmann's theory on "The Social Construction of Reality" (2004 [1969]) is used as an approach and heuristics to argue that scientists internalize meanings that guide their actions in the form of patterns and associations with nanotechnology that are constructed socially. Indirectly, patterns of interpretations of nanoscientists result in how nanoscientists deal with the term nanotechnology in everyday research within their research group and toward external institutions and persons and how they act upon it. There is no coherence on the definition of nanotechnology among those scientists that were interviewed. In the analytical chapter, thus, the range of meanings of nanotechnology, definitions, and evaluations from the perspective of nanoresearchers are presented.

Humans "produce" the world they experience, whereas simultaneously, humans are products of this socially constructed reality (Berger & Luckmann, 2004 [1969], p. 54). The way they experience and create reality is characterized by social interaction, communication, and language. These elements emerged from the in-depth interviews applied in the present study. By communication and use of language, by observing and describing social interactions, a picture of the interviewees emerges which reflects patterns of thought and interpretation of the interview partners' experienced reality (Lamnek, 2005, p. 452). What the interviewees convey is embedded in conversation on selected issues relevant to the topic of the study and in "vis-à-vis-situations," i.e., direct interactions by co-presence (Berger & Luckmann, 2004 [1969], p. 37). By performing roles, i.e., repeating typical actions by the same person, subjects participate in the social reality and everyday life: individuals internalize their roles and enable each other to experience a common social reality (Berger & Luckmann, 2004 [1969]). In this study, interviewees are professors, researchers, coordinators, doctoral students, teachers, and nanoscientists. This means they perform various roles in everyday life, which makes 'work activities' much more complex. Interviews therefore present a valuable technique to disentangle these roles.

To clarify how constructivism is to be interpreted in the context of the theory on the social construction of reality, Thomas Luckmann's notion on the term regards constructivism as the conception of reality from different perspectives and in "capacities of awareness," not in an immediate and direct manner. These capacities of awareness are socialized and used intersubjectively in society (Pawlowski & Schmitz, 2003, p. 50). The capacities, or here, interests determine how interviewees present their opinions and thinking patterns on everyday life. Still, one must differentiate between constructivism and construction. Berger's and Luckmann's book is explicitly on the social construction, *not* on the social constructivism of reality. "Construction" according to Luckmann (2007, p. 137) is "the goal-oriented human, social activity under contingent conditions", i.e., with both intentional and non-intentional consequences. The emphasis is not on constructivism as a scientific approach, but on how humans perform the construction of their reality and how subjective and objective meanings are related to each other in the form of a constant reciprocal relationship (Luckmann, 2007, p. 148). These objective meanings belong to a "system of relevance" (Luckmann, 2007, pp. 132-133) which is socially reinforced and represented among others by social institutions. Subjects internalize these objective meanings and orient themselves toward them. It is exactly the mutual relationship between objective and subjective meanings which play a role in the descriptions of the “relevance systems” and experiences interview partners convey in conversations.

The question is if there are remarks in the interviews where one can identify the influence of objective, socially institutionalized meanings in particular. Where is it evident that the interviewee does not deviate from socially given meanings, or where does he or she refer to them explicitly? In the interviews, it becomes clear that nanoscientists have their own meanings of nanotechnology as compared to politicians or the media. They create their meaning based on daily interactions and communication with their peers and with external actors, in particular when scientists occupy positions of speakers or coordinators. Thus, one must be aware of the interview situation in that the data presented here was ‘constructed:’ Nanoscientists talking to the author were aware of the situation and saw the interview as an opportunity to influence policy or to reinforce their personal views on nanotechnology as a field of research. There is a range of papers using the approach of the social construction of reality, proving “the richness of the social construction framework and its continuing prestige” (Hirsch & Boal, 2000, p. 257).

In conclusion, it can be seen that individuals constitute the central actors in this study. Their processes of the construction of meaning with respect to their work are at the very heart of this study. Individuals perform the construction of meaning and thus, give meaning to their professional ‘work activities.’ Qualitative interviews are the very method to reconstruct this creation of meaning. Personal perspectives of actors are described; relationships and forms of mediation between individual action and existing institutional structures are established. (Koch, 2005, p. 323)

Process of Analysis

The material gathered from the qualitative interviews was analyzed in the following way: First, the answers were coded according to biography, higher education, institutionalization processes, job description, knowledge production, labor market, market, MEMS, nanotechnology (definition and related meanings), nanoeducation, nano as organization, nanoscience, professional associations, research alliances, and transition from education to the labor market. These codes are oriented toward the interview guide whose questions were developed according to the literature and theory that frame this study. One test-interview was done to check the feasibility of the interview guide and to make corrections. Then, the texts were paraphrased, also called “text-reduction” (i.e., “Textreduktionsverfahren” by Ulrike Froschauer and Manfred Lueger (2003, pp. 159-162)). Finally, some passages of the texts were interpreted by “fine-structure analysis” (i.e., “Feinstrukturanalyse,” also by Froschauer and Lueger (2003, pp. 110-142)). The main goal of “text-reduction” is to provide patterns of interpretation and experience of social reality and their individual scientific and professional identity by the interview partners. These patterns are then interrelated to each other to compare and resituate them into the life contexts of the interviewees. The author herself translated all the paraphrases and the final quotes from the German interviews into English.

The passages which are interpreted by “fine-structure analysis” were selected according to their relevance for the research interest of this study and considered of central importance for the research findings. By “fine-structure analysis”, the research findings from “text-reduction” were supposed to be supported or contradicted and thus, verified. Consequently, the analyzing process consists of three steps the main part of the study results from. This procedure provides the findings of the empirical research analysis in this paper.

4.3.1 Sample

A careful selection of cases (“most likely” and “least likely cases” according to Harry Eckstein (1975)) is indispensable for a qualitative comparative analysis. This is why the U.S., being an LME, and Germany, being a CME, were selected. Whereas the success in nanotechnology is not surprising for the LME of the U.S., making the U.S. a “most likely case,” Germany is, from the perspective of

the VoC theory, not suited to be a prolific country for a high-technology that is dependent on risky radical innovations. Germany therefore represents a “‘least likely case” of the analysis of nanotechnology demonstrating that a high-technology can thrive also in a CME. Due to the crucial but small sample of two countries, this study is a qualitative comparative analysis establishing relationships of variables. For example, the Bologna process in Germany represents a favorable opportunity, yet not a causal variable, for the implementation of nanotechnology into higher education in the form of new study programs. Due to the focus on nanotechnology as a research area and on the micro-level effects of public funding and government programs or reforms on the institutional context of academic research, the sample is made along institutional differences in tertiary education.

Sample Selection

The research goal of this study consists of the exploration of researchers’ perception of nanotechnology, evaluations, and their contribution to the organizational field of nanotechnology in academia. On the micro-level, narrative interviews with nanoscientists from U.S.-American and German universities were conducted to address these issues. The 33 interview partners from Germany and the U.S. were recruited from universities throughout the country. The interviewees were contacted randomly via email, several times if no reply was given or if interviewees did not feel to be a relevant informant. Telephone interviews of equal length to personal interviews were conducted with two U.S. researchers and one German researcher. Every interview was recorded with the permission of the informants. The response rate was higher in Germany with 75% (four out of 16 did not reply at all and one apologized for not participating due to time problems) than in the U.S.. It turned out during the interview that some of the respondents saw the interview as part of public relations because the professors were coordinators or speakers of centers and institutes or academic counselors of study programs (e.g. S1, P1, R1, M2, N1, and K1). In Germany, there were more Ph.D. students who did not reply upon email contact or who just stopped answering when asked about an appointment (two out of four). This is why it was decided to ask in situ after interviewing professors if Ph.D. students were willing to participate in an interview. This procedure has proven to be the most effective way to recruit graduate students as they would not deny an interview when being asked by their PI. Naturally, this way of contacting could impact the interview dynamic negatively. However, this was not the case. Some Ph.D. students were more talkative than others but none would impede the interview or boycott the interview after starting it.

Reputation and a clear involvement in nanoresearch were guidelines for the random selection out of the sample that fulfilled these criteria. By such a way, key informants were recruited, since the viewpoints of a sample that was made up in such a way provide maxims of action: For instance, if renowned scientists involved in nanoresearch had a detached position on nanotechnology and its meaning for their self-categorization, this is assumed to influence the whole group of scientists engaged in nanotechnology. A nanoscientist was identified as such if his or her self-description in university websites included a nanolabel. One category for sample groups was nationality, i.e., German vs. U.S. scientists. Single coordinators from nanocenters were also interviewed, since it was assumed that these might present additionally differing views on nanotechnology. In their case, a detached stance toward nanotechnology might interfere with their mission as coordinators. With that second sample group, a variation in the data thus might be detected. This was done to reflect the given institutional variance in higher education. The interviewees were mostly professors and doctoral students but also research scientists and coordinators to be able to delimit the field of nanotechnology actors. To this end, informants who worked in the institutional context, e.g. at a nanocenter, or ‘periphery’ of nanotechnology but explicitly rejected the self-definition of a nanotechnologist were also interviewed.

Single nanoresearchers at universities without any nanoinstitute affiliation were interviewed next to researchers that were part of a German excellence cluster or competence center in Germany or the U.S. NNIN as well as researchers from university centers that were labeled with the prefix “nano.”

All researchers, except doctoral students, were full professors, i.e., incumbents of a university chair or W2/W3 professorships that were introduced only recently in Germany to unify professorships at universities of applied sciences and at research universities. Bearing in mind that individual actors exhibit structural shortsightedness when it comes to their own reasoning, maxims of actions, and interpretation of personal life courses, questions about the macro-level were explicitly asked in the interviews. These included for instance questions about higher education reforms (Bologna, 'Excellence Initiative') or federal grant policies (the NNI) and industry. Based on the interviews, findings establish assumptions on how researchers and their perceptions shape and are interrelated with the constitution of a nanotechnology field. It becomes clear that local knowledge is indispensable for an analysis of the inner life of nanotechnology at universities with regards to the involvement of local actors. Thus, it would be difficult to specify hypotheses for quantitative studies without exploring first the effects and relevance of local knowledge for individual actors and the institutional context, as done in the present study.

Overall, with comparably high response rates the recruitment process was not problematic. This might have been due to the openness and desirability to talk about nanotechnology in order to convey their opinions on such a "hot" topic in science and technology. Some cases had to be contacted again, e.g. when they responded that they did not consider themselves as 'a nanotechnologist.' In these cases, it could be clarified what their role in nanotechnology was and that they still are related to nanotechnology. With regards to gender, it proved right that also in nanoscience, there was a greater availability of women at the lower hierarchical level, here doctoral level. Once recruiting interviewees at the professoriate level, it became clear that the presence of female scientists was scarcer. All in all, there were three female professors in my sample and five female doctoral students.

Individual study and employment biographies were asked in the interviews. Four disciplines were integrated, namely chemistry, engineering, materials science, and physics (see Heinze, 2006a, pp. 109-110). Physics and chemistry were chosen because they are process-oriented, dynamic disciplines which have lost the least among all natural sciences (Gabler & Frank, 2005). Professors (from assistant to full professor in the U.S.; tenured professors in Germany), administrators within nanotechnology networks, and Ph.D. students were recruited either randomly or because they were very renowned in the field. Some professors and Ph.D. students were not directly involved in nanofabrication but were working either partially on the nanoscale or contributed to progress in nanoscience and –technology by doing research in MEMS (microelectromechanical systems). These individuals were included in the sample to get an idea of the boundaries of the field of nanotechnology and to see how researchers who were not directly participating in nanotechnology viewed the development in this field. As Meyer (2006, p. 1659) suggests the patterns of researchers still have to be explored who contribute to emerging fields, such as nanoscience and –technology, and who combine several areas of knowledge without considering themselves as being part of the field. This is why in the sample of this study researchers working at the periphery of nanoscience were included.

The data gathered for the analysis of the meso- and micro-level theories result from interviews done with researchers (professors, research scientists not on tenure-track, Ph.D. students, and administrators) in the U.S. and Germany. Table 4 and Table 5 provide an overview of the names (kept anonymous for reasons of confidentiality and named in the study hereinafter by the given codes), the position within university, the disciplinary background, the affiliation, and the date of the interview. In the U.S., seven professors (on tenure-track), seven Ph.D. students, three administrators, and one research engineer (adjunct faculty) were interviewed.

Name	Position & Disciplinary Background	Institution	Date of Interview
Mr. A1	Professor, Chemistry	Mellon College of Science, Carnegie Mellon University, Pittsburgh, PA, USA	March 1, 2010
Mrs. A2	Ph.D. Student, Chemistry, Research Group A1		
Mr. A3	Ph.D. Student, Chemistry, Research Group A1		
Mr. B1	Administrator, (Electrical) Engineering	Georgia Institute of Technology and Georgia Tech Research Institute, Atlanta, GA, USA	Feb 25, 2010
Mr. B2	Senior Research Scientist, Chemistry/Biophysics		
Mr. B3	Research Scientist, Adjunct Faculty, Engineering		
Mr. C1	Professor, Chemistry	Massachusetts Institute of Technology, Boston, MA, USA	Mar 9, 2010
Mr. C2	Ph.D. Student, Chemistry		
Mr. D1	Administrator, Professor, Microelectronics/Physics	Center for Nanotechnology Education and Utilization, Pennsylvania State University, University Park, PA, USA	Mar 2, 2010
Mr. D2	Administrator, (Ceramic) Engineering		
Mrs. E1	Professor, Chemistry	Santa Clara University, Santa Clara, CA, USA	Nov 10, 2009
Mr. F1	Professor, Physics	Electrical and Computer Engineering, Texas Tech University, Lubbock, TX, USA	Oct 14, 2009
Mr. F2	Ph.D. Student, Engineering, Research Group F1		Oct 16, 2009
Mrs. G1	Professor, Biomedical Engineering	Department of Bioengineering and Therapeutic Sciences, University of California San Francisco/ Berkeley	Apr 15, 2010
Mrs. G2	Ph.D. Student, Engineering, Research Group G1		Apr 14, 2010
Mr. H1	Professor, Materials Science	Baskin School of Engineering, University of California Santa Cruz	Nov 9, 2009

Table 4: Overview U.S. Interview Partners; Own Source

Name	Position & Disciplinary Background	Institution	Date of Interview
Mr. J1	Professor, Chemistry	University of Erlangen, Bavaria, Germany	Jun 22, 2010
Mr. J2	Doctoral Student, (Ceramic) Engineering/ Materials Science, Research Group J1		
Mr. K1	Professor, Physics	University of Applied Sciences Munich, Bavaria, Germany	Jun 28, 2010
Mr. K2	Doctoral Student, Biomedical Engineering, Research Group K1		
Mrs. L1	Doctoral Student, Chemistry	Center for Functional Nanostructures, Karlsruhe Institute of Technology, Technical University of Karlsruhe	Jul 9, 2010
Mrs. M1	Professor, Chemistry	University of Münster	Jul 22, 2010

Mr. M2	Administrator, Chemistry	CeNTech	
Mr. N1	Administrator, Social Sciences	VDI (“Verein Deutscher Ingenieure e.V.”; Association of German Engineers)	Jul 15, 2010
Mr. O1	Professor, Chemistry	University of Bayreuth	Jul 23, 2010
Mrs. O2	Doctoral Student, Chemistry		
Mrs. P1	Professor, Physics	Technical University Berlin	Jul 27, 2010
Mr. P2	Doctoral Student, Physics, Research Group P1		
Mr. Q1	Professor, Physics	Ludwig-Maximilians-Universität Munich	Jul 16, 2009
Mr. R1	Professor, Physics	University of Hamburg	Sep 08, 2010
Mr. S1	Professor, Physics	University of Kassel, CINSaT	Sep 22, 2010
Mr. S2	Doctoral Student, Physics, Research Group S1	University of Kassel	
Mr. S3	Doctoral Student, Physics, Research Group S1		

Table 5: Overview German Interview Partners; Own Source

Implicitly, patterns of interpretations influence how nanoscientists deal with the term nanotechnology in everyday research within their research group and toward external institutions and persons (including the interviewer) and how they act upon it. The semi-structured interviews were coded according to meanings, definitions, and self-categorization with regards to nanotechnology and according to modes of knowledge production, such as research cooperation forms or application-orientation. Meanings, in particular, constitute elements that researchers act upon and are constitutive for organizational fields (Scott, 2004, p. 58). After coding, the interview answers were then compared individually and nationally.

4.3.2 Levels of Comparison

Levels of comparison are the national level, i.e., Germany and the U.S., the hierarchical/institutional positions the interviewees were in, and disciplinary differences (in section 7.1 on the meanings of nanotechnology). The national levels are considered highly relevant as the different systems of higher education and different market systems suggest a different institutionalization and diffusion of nanotechnology. As mentioned above, the institutional settings academic researchers work in are different from each other. Differing funding structures and organizational flexibilities in doing research greatly affect the diffusion of new research areas, such as nanotechnology and its acceptance, so the assumption in this paper.

In addition, as shown in the overview above, informants had different positions. They were professors (mostly full professors, i.e., the highest position a professor on tenure-track can obtain), administrators, or Ph.D. students. It is assumed that there are differences in attitudes toward nanotechnology depending on hierarchical positions. Professors were expected to have a more detached stance toward nanotechnology that spilled over to their Ph.D. students whose attitude is certainly influenced by the PI-culture, i.e., by the PI they work with. It is further presumed that administrators take nanotechnology for granted meaning that they do not question nanotechnology as a high-technology as much as professors. Their job in managerial positions is to promote nanotechnology and establish outreach to industry, other universities, and/or government. If they did not embrace nanotechnology positively, this would reflect badly on their work performance.

To sum up, the national organizational and individual levels of comparison must be kept in mind since they frame the following analysis. In the chapter of analysis, the national levels will be discussed separately when comparing German and U.S. researchers. The hierarchical positions do not stand out as explicitly as the national level. However, the positions are always mentioned and compared to each other when theoretically analyzing the responses and examining in particular the respective professional identities and attitudes toward nanoscience and nanotechnology. In this study, Ph.D. students are ascribed professional identities as well as they are technically part of the labor market. If they had not decided to continue academia, they would work in industry. They have all completed their studies and count as employees in their universities as they are paid by university budgets or, less often, grants from industry.

4.4 Research-up

The feelings of fear or inferiority usually arises with individuals that obtain an hierarchically superior position within an organization, such as executives do, since their work is more hectic, less structured, and less planned (Warneken & Wittel, 1997, pp. 7-8, 10). The same can be said about doing interviews with professors as a Ph.D. student. Professors are experts in their fields as a researcher is in his or her field. Thus, a researcher’s interview with an executive or professor who is as educated and knowledgeable as the researcher him- or herself adds to the feeling of being inferior and vulnerable and having to defend one’s own competency in the field of research (Warneken & Wittel, 1997, pp. 5-6). Another factor is that as a researcher, one is “pre-sensitized:” One expects professors to be busier than other employee ranks and to symbolically express their power within university.

Overall, the interviews went quite smoothly with no major interruptions or unforeseen occurrences despite telephone calls, individuals stopping by or interviewees answering short messages. As mentioned above, no interview had an ‘unbearable’ dynamic resulting from too short answers or unwillingness to participate forcing me to terminate the interview. No interviewee ended the conversation before answering all my questions or was reluctant to answer a question. In two interviews, the informants were quite self-confident, if not arrogant, and put forward their opinions in a very resolute manner. This happened in particular but not exclusively when the interviewer, i.e., the author of this study, confronted the interviewees with quotes from previous interviews or from the media. Most of the times, the author was asked at the beginning of the interview what her purpose was. If not asked by an informant, the author herself made sure to explain shortly what her project was about. This was indispensable for the interviewees to be prepared and to know what the author was interested in so that they can mentally prepare themselves. It was also necessary to show competence in her research area and in interviewing. Having an interview guide and a recording device also helped in demonstrating that it was a professional interview. Still, although no resistance was shown to the author and her topic was not put into question or declared as irrelevant, one must be aware that the informants were all natural scientists and not familiar with qualitative sociological methods, except through spouses (for example J1’s wife) that had a similar academic background to the author. Despite explaining her research questions to the interview partners, the author still had the feeling with some interviewees that they were constantly wondering which kind of data the author was gathering and how these data were going to be analyzed. The author sensed that they could not bridge the gap between their research and hers and what direction her research was going. For instance, asking about their biographies was certainly for some individuals not comprehensible as to what extent this information could be integrated in a doctoral thesis and to what extent this was important for gaining new insights. Nevertheless, the author felt that by explaining what she was doing and which questions she was interested in, she could foster the understanding and openness of the interviewees. The openness of some professors can certainly be explained in some cases with the fact that they were used to giving interviews. This could also elucidate the fact that Ph.D. students were more doubtful about the author’s research as they were not used to giving interviews and presenting their work to somebody with no natural science background.

One German professor demanded more effort from the interviewer. He had clear opinions that he stated rigorously when thinking that they were opposed to the author's although, naturally, the author asked questions neutrally and did not face him with any personal opinion. In this situation, it helped to stay friendly and encouraging by saying "this is interesting, can you tell me more?" This way, the dynamic of the interview could be preserved, and the professor went on giving more elaborate answers.

To prepare for the interviews, the author had to gain knowledge about nanoscience and nanotechnology. This is certainly an ambitious endeavor but it is not impossible. As a social scientist doing research in an area different from my own, the immersion into unfamiliar knowledge areas is essential, not least because it fosters the acceptance of the informants if a social scientist shows that she made the effort to inform herself about nanotechnology. It was vital for demonstrating my competence in research because not only the competence in the author's own field was demonstrated (something the interviewees could not verify themselves) but also the familiarity with a field that was not her actual field of study.

5. The German and U.S. Education Systems: A Comparison

Having outlined the methods applied in this study, now, the German and U.S.-American higher education systems are compared and analyzed with regards to the implementation of nanotechnology. One might ask due to the availability of an abundance of comparisons why such a comparison Germany and U.S. is relevant. There are contemporary issues and reforms, such as the Bologna process in higher education, the 'Excellence Initiative' at German universities and the Copenhagen process on vocational training (see J. J. W. Powell, 2009) that make it necessary to reconsider several comparative aspects. These aspects include the transition from tertiary education to the labor market, paramount institutional features of universities and their relation to technology. By looking at the example of nanotechnology, this study argues that the way higher education systems in Germany and the U.S. are set up influences how innovative technological research is done and how high-technologies are incorporated into higher education systems and curricula.

Although the U.S. graduate system was modeled on the German academic system of the 19th century, the higher education systems of both countries have developed differently due to different national contexts. With the global paradigms of economic growth and international competitiveness, the focus of higher education has been directed toward high-technologies as drivers of growth. As nanoscience and technology are successful in both countries, it is examined how higher education systems have reacted to public funding of nanotechnology and to higher education reforms in the face of the promises of high-technologies for national progress. The comparison becomes even more relevant in Germany as the European Bologna process has remarkably changed the higher education landscape. Germany also offers a bachelor and master system now (see e.g. Nida-Rümelin, 2009), which remains contentious as student protests in German cities from 2009 showed. In the following analysis, the German and U.S. national systems are compared based on the transition to the labor market, institutional diversity and the relation of education to practice.

Education systems are embedded into societies that focus on technologies, knowledge, and innovations nowadays more than ever (Edler, 2003; Etzkowitz, 2003). When technological innovations change, the changes are supposed to be absorbed by education systems according to political agendas. Innovation and technology can thus be seen as rationalized "powerful myths" (J. W. Meyer & Rowan, 1977) that "infuse and diffuse [contemporary societies and their] organizational worlds" (Djelic, 2010, p. 25). Institutions, as mentioned in the introductory chapter, are defined by both structural and cultural elements that guide social behavior by virtue of rules, norms and beliefs (Djelic, 2010, pp. 26, 29). In the present case study, the emphasis is on the institutional structure of the national education systems and their rules that affect the implementation of nanotechnology as a politically pushed and highly funded field of research. It is important to see technology 'as material culture' and 'a socially embedded process, not as an exogenous factor affecting society' (Castells, 2000, p. 693). Forces and manifestations of social change are information technologies, globalization, the end of a sovereign nation state and 'progress in scientific knowledge, and the use of science to correct its own one-sided development' (Castells, 2000, p. 694).

Higher education structures suggest that the training of a workforce is tightly linked to the development of nanotechnology and its promises and is subject to reforms that influence the implementation of technologies. In the educational field of today, Bologna is perhaps the most striking European reform and force seeking to create the European Higher Education Area. The Bologna process will make academic degree standards and quality assurance standards more comparable across Europe (Federal Ministry of Education and Research (German)). These circumstances, the study argues, affect how technology-related contents, such as nanoskills, are transmitted at universities as college-educated employees are needed in the economy.

Nanotechnology is an instructive example to demonstrate this study's argument because it is one of the most rapidly developing technologies and one of the advanced technologies that are heavily funded by the German and U.S. government. Further, the countries compared are worldwide leaders in nanotechnology. What makes the comparison even more interesting is that Germany, being a CME, is not regarded as a country where high-technologies based on radical innovations can take hold, whereas the U.S., being an LME, favors radically innovative technologies (Hall & Soskice, 2001a).

In light of the VoC approach the hypothesis is that in the CME of Germany, facilitated by the Bologna reform, a number of new study programs have been created keeping intact institutional factors with regards to a more rigid education and training system as well as a more regulated labor market (see section 5.1). In the LME of the U.S., however, a focus on large-scale and high-risk research is expected without an effort of the state to regulate the nanotechnology education and training system or labor market. The study confirms the hypothesis based on the VoC approach although the success of nanotechnology in Germany being a CME is not explained by this theoretical concept.

This analytical case study deals with the higher education systems in Germany and the U.S.. A historical overview on nanotechnology has already been provided in chapter 2. It is assumed that both countries find themselves in a process of ongoing change by way of new political agendas and reforms. Because of already existing comparative literature on higher education (Altbach, 1998, p. 32; Clark, 1995; Windolf, 1997), the subsequent paragraphs are limited to those points of comparison relevant for high-technologies whose development is dependent on, including how students are trained. These points are the transition from education systems to the labor market, diversity, and university education and its relation to practice and profession. The study compares how these higher education systems relate to nanotechnology and implement this high-technology. Significantly, nanotechnology is a politically prominent technology, the examination of which is useful to observe the present political and technological changes. Advanced technologies and their national contexts must be understood first before they can be adequately promoted. To increase this understanding is the goal of this chapter.

5.1 Transition to the Labor Market

In Germany, education systems are supposed to prepare students for qualified participation in the labor market. The assumption is that in the labor market, there is a constant but cyclical demand for a certain number of jobs depending on the economic situation and a certain level of qualification (which is of different quality in the post-industrial society than in the industrial one). Education systems thus need to train and qualify students accordingly. Moreover, in Germany a discrepancy exists between the belief in talents of a few and the societal need of qualifications on the one hand and the actual development in higher education after Bologna on the other. Here, the principles of selection and exclusion contradict the goal of integration of a mass of students by giving equal chances to everybody. In the U.S., by contrast, there is no idea of a general demand of qualification by the labor market asking for specific job profiles (Ravitch, 2001). Qualifications are seen as civic virtues, as individual qualities that are indispensable for a democratic society, not as technical, commercial or agricultural skills (Lenhardt, 2005, pp. 47, 217, 230-231). In sum, technological innovations, such as in the field of nanotechnology, force societies, including politics, to react and implement these new skills into curricula and study programs. This is true for both countries where different answers, however, are provided to the incorporation of nanotechnology.

Higher education and labor market structures are tightly coupled in Germany, loosely tied in the U.S. (Allmendinger, 1989, p. 241). The German labor market is a 'qualification' market with an emphasis on skills and vocational training, whereas the U.S. labor market can be entitled an 'organizational and seniority labor market system' (Allmendinger, 1989, p. 242) with an emphasis on employee flexibility and firm-specific skills that are adopted at the workplace rather than at school. Along with a loosely coupled educational system in the U.S., there are in contrast to Germany few national entities

which substantially shape U.S. education. (Garnier, 1980, pp. 92-93). Although there are indirect influences, such as standardized testing and national associations, individual institutions are largely autonomous.

The German vocational training system is dominated by an apprenticeship system or 'dual-system' which is standardized in contrast to the predominance of on-the-job training in the U.S.. On-the-job training in the U.S. is employer-specific and not regulated by a rigid curriculum. Apprenticeships and the education that takes place in them are formally integrated into tertiary education in the U.S.. In the 'dual-system,' apprentices attend public schools and are under contract with the employer. In a standardized labor market structure like the German one, employers can trust in the validity of standardized educational credentials. They do not need to assess and train the applicant before hiring him or her. (Allmendinger, 1989, p. 239) In the U.S., being a credential society, investments in skill formation rose after World War II (J. J. W. Powell, 2009, p. 1), and educational attainment is principally considered as an objective indicator of ability based on the assumption that schools are meritocratic institutions (Grubb & Lazerson, 1982, p. 123). The role of the dual-system in training individuals for positions in technology sectors, such as nanotechnology, is predicted to become even more important in the near future (Baron, Heybrock, & Korte, 2005; Baron & Schumann, 2009).

Jutta Allmendinger (1989, p. 240) concludes that 'labor market outcomes that result from stratified structures at the level of primary and secondary schooling reflect the matching of a differentiated school structure to a differentiated occupational structure'. This observation alludes to the existence of a 'qualification' labor market in the CME of Germany with specialized education at school and concrete career profiles. Whereas the German system is characterized by transparency and impermeability, i.e., difficulty in changing educational and job tracks, the U.S. system is permeable but opaque. This means that in the U.S., few concrete educational tracks are connected tightly to vocational careers, making it difficult to determine which training and skills are demanded to purse a specific career (Hamilton & Hurrelmann, 1994).

5.2 Institutional Diversity

The common tenor in literature is that diversity is a striking difference between the two national systems of education. Diversity is most evident in the number of different university institutions, in the departmental structure, and in professorial autonomy to be discussed in the following.

5.2.1 Diversity in Terms of Institutional Types of Universities

The U.S. education system is considered a more diverse system than the German one. It provides a higher diversity in tertiary education (research universities, undergraduate arts and sciences colleges (including liberal arts colleges), community colleges, and comprehensive colleges and universities) (Altbach, 1998, p. 55). Research universities, as the name conveys, or 'multiversities' (Kerr, 1995) cover a broad range of academic specialties and provide high research output and graduate education (Altbach, 1998, p. 60). They follow the unity of teaching and research, which is not self-evident in the U.S. higher education system, and include Master and Ph.D. programs (Lenhardt, 2005, pp. 133-134) . Undergraduate arts and sciences colleges represent a large number of colleges. They are diverse to some extent, but similar with regards to basic education in the liberal arts and in curricular orientation. There, after a year, students specialize in a field during the four-year curriculum. (Altbach, 1998, pp. 60-61) Liberal arts colleges provide general education. Graduates from these colleges obtain a bachelor degree, and most of them enter the labor market. Only a small number of students continue with graduate studies at other institutions. (see Lenhardt, 2005, pp. 126-127 on liberal arts colleges)

Community colleges feature large enrollments and two-year programs. They stress vocational and applied training and generally do not have entrance examinations. Burton R. Clark (1960) talks about 'open door' institutions. Their purpose is to ensure 'social and occupational mobility for segments of the population that have been disadvantaged' (Altbach, 1998, p. 61).

Steven Brint and Jerome Karabel (1991) analyze the institutional origins and the driving forces of change of American two-year community colleges. Their focal point was the ‘transformation of American community colleges from predominantly liberal arts to predominantly vocational training institutions’ (Brint & Karabel, 1991, p. 337), which is also shown by numbers of student enrollment. Because of lower prestige and competitiveness as well as ‘less advantaged, less able, and less mobile students’ (Brint & Karabel, 1991, p. 338), community colleges were looking for an alternative and, as a result, re-modeled themselves as vocational schools. The American Association of Junior Colleges (AAJC) was one of the main actors in the vocationalization of the community colleges, formerly called junior colleges. This movement started in California where it became strongest. In California, junior colleges were sponsored by four-year colleges and flourished because of favorable demographic and ecological circumstances. (Brint & Karabel, 1991, pp. 338-339) Apart from vocationalization, one must be aware that there is another trend of a proportion of U.S. students to continue their undergraduate studies at four-year colleges since community colleges are less expensive or less competitive in admission than four-year institutions.

To sum up, universities are deemed more favorable to the job chances graduates have than colleges with regards to money and prestige. In the U.S. with its more distinctive differentiation between public and private universities, it can be decisive for a student’s future career where he or she went to college in terms of the labor market chances the student has. Universities exhibit more research money and, in particular private research universities, do not depend on money from local government agencies. (Altbach, 1998, p. 61) Due to public funding, comprehensive colleges and universities as well as teacher colleges became research universities during the last decades and teaching loads were reduced for professors to accommodate their increased research responsibilities (Lenhardt, 2005, p. 137).

In Germany, there are basically three types of institutions in higher education: the (research) universities, universities of applied sciences (*Fachhochschulen*), and arts and music academies which are either public or recognized by the state ("Diploma Supplement [excerpt]," 2003). Teichler (Hochschulrektorenkonferenz, 2009, pp. 33-34) delivers an overview of the differences between universities and universities of applied sciences: The *Fachhochschulen* tend to offer rather vocational degree programs, whereas the universities have research as well as professionally oriented programs. Thus, the former are more practically oriented, the latter more theoretically oriented and focus toward general education and basic sciences, at least in particular disciplinary fields. To start a career as a researcher and scientist, one must attend a research university. There are varying principles: at research universities, skepticism and uncertainty out of research curiosity prevail, whereas at *Fachhochschulen*, ‘”rules” and “tools”’ are the focal points. The research university deals more with providing a professional foundation and basic sciences, the universities of applied sciences more with vocational education and applied sciences ("Diploma Supplement [excerpt]," 2003, p. 34). The diversity of U.S. universities must be set against the dual-system in Germany which also ensures diversity with regards to vocational education but which is not considered an element of tertiary education (Hochschulrektorenkonferenz, 2009, p. 18). In the U.S., by contrast, vocational education has been integrated more or less extensively into higher education depending on the type of university.

5.2.2 Departments as Basic Organizational Elements in U.S. Higher Education

Further, the U.S. departmental organizational structure provides for more diversity and autonomy by being less rigid in implementing new departments that are most often more specific–also in their naming–than German chairs. The U.S. department corresponds to the German chair and institute (Ben-David, 1984, p. 154). There is no fixed number of staff for each rank, including for professors, so that there is lower competition among staff. Departments can be added accordingly and more easily than in Germany (Altbach, 1998, p. 63). In Germany, the reason why no more specialized chairs have been founded since the end of the 19th century was due to organizational, traditional, and financial reasons: the power of German professors over their institutes, partly financial constraints of the state, and the traditional conception of ministries that a major discipline is supposed to be chaired by one full professor. Faculty could only be expanded for three reasons: a change in the delineation of an area, specialization of an area, and the establishment of a new discipline. (Clark, 1995, p. 35; Ringer, 1990, p. 53)

Therefore, adding new and/or more specialized departments or even new functions to extant universities is one source of change in American universities that is always locked between stability and change. One can rather speak of incremental change as whole institutions and departments are not commonly altered or renamed. If reform ideas and the subsequent requirements, however, are too far-reaching for existing universities, new institutions are established. Change, though being a constant influential factor, occurred mostly at the beginning of the 20th century till 1950 to 1970 when expansion was most extreme. (Altbach, 1998, pp. 59, 67-68) Clark (1995, p. 124) extends the period of basic changes in resources and expansion in faculty and students to the 1980s. This underlines the constant transformation of university education making it difficult to precisely confine periods of change.

To sum up, the implementation of new study programs and chairs in U.S.-American universities is expected. The greater flexibility and specialization at U.S. universities highlights the fact that specialized programs and chairs in nanotechnology are more easily established in the U.S. than in Germany, with its more rigid structure of chairs and with the larger responsibility over research and teaching areas of German professors, which leads to the next section. One observes the reverse case for nanotechnology: in Germany, there is as much change as in the U.S. with the latter having a greater focus on new institutes and the former emphasizing not only on new institutes but also new study programs facilitated by Bologna. These programs are facilitated by Bologna that serves as a ‘valve’ for the pressure for change in the German higher education landscape which is induced in turn by the political and also universities’ ambitions to provide career tracks for the training of nanotechnologists.

5.2.3 Professorial Autonomy and Institutional Functions

Another important issue which results from the departmental structure is the professor’s autonomy (Bourdieu & Passeron, 1971, p. 205), a principle which has been guaranteed in Germany from the beginning. German universities were assigned the ‘statutory right’ to ‘manage their own purely academic affairs,’ an autonomy which was mainly exercised by full professors (Ringer, 1990, p. 36). Joseph Ben-David (1984, p. 131) explains the resistance to the expansion of academic recognition to more specialized fields of research and the resistance to the introduction of new chairs by the remarkable power of the ‘ordinarius.’ Instead of becoming a chair or professor, new assistants are appointed to be in charge of new fields of research. This supports the fact that German chairs are less specialized than U.S. departments. German universities were opposed to or indifferent toward social movements at the end of the 19th century. This ‘noninvolvement’ had to do with the social standing of the professors who were attached to high civil servants, not to the upper middle class, as was the case in the U.S. (Ben-David, 1984, p. 136).

The professor’s autonomy in the U.S. is institutionalized in the form of departments. Since the 1950s, the departments control teaching and research and also staff policy. As professors acquire third-party funds, which they depend on because public funding is comparatively little compared to other countries (Clark, 1995, p. 128), they can dispose of these funds autonomously. (Lenhardt, 2005, pp. 139, 144)

To give an example, in terms of the formation of study programs, the autonomy of U.S. universities is revealed for instance in the fact that 75% of all U.S. colleges set up the programs themselves (Lenhardt, 2005, p. 138). At first, U.S. curricula were defined according to traditional values (Lenhardt, 2005, p. 139). The curricula were first oriented toward religious, humanistic, and scientific education before the process of secularization set in (Lenhardt, 2005, p. 127). When there was no consensus on these values any more, university presidents developed the programs. Then, the professors took over the task and, thus, strengthened their autonomy as from then on, the curricula could only be assessed by the professors themselves (Lenhardt, 2005, p. 139).

With the process of ‘scientification of education’ parallel to the curriculum reforms, the range of topics to be taught was enlarged and, hereby, the students’ freedom of choice (Lenhardt, 2005, p. 147). An elective system was developed for students, marked by the freedom to select courses and the juxtaposition of old and new ideas of education. Education became interdisciplinary and problem-oriented as it was supposed to prepare for life outside the university. In particular land-grant colleges had a vocational focus. Further, as tertiary education became more and more favorable for the labor market, liberal arts were linked to vocational education, too. (Lenhardt, 2005, pp. 127-128)

To understand current changes, in particular in Germany after launching the Bologna reform, the above mentioned autonomy must be set against the principle of accountability in the U.S.. Both principles need to be put into equilibrium: autonomy in research as the professor’s right indispensable in order to fulfill her role as a scientist and accountability because public funds are received, which makes universities responsive to society and the public (Altbach, 1998, p. 66).

Another source of tension is academic freedom and the higher education system with its rigid structure by trend (Altbach, 1998, p. 62). Although the U.S. system is regarded as more flexible than the German one, critics also mention the rigidity of the U.S. system as a hindrance for change. Clark (1995, pp. 122, 155), however, concludes that departments are more flexible and expandable as the professors do not obtain a hegemonic position, such as professors in Germany do. Departments feature a better allocation of resources (i.e., faculty time). For instance, money from many more undergraduate students than graduate students can be used for graduates and research funding. Therefore, departments with two levels–the graduate and undergraduate level–turned out to be most productive (Clark, 1995, p. 122) This form of reallocation promises to be especially supportive for the implementation and funding of nanotechnology.

In the U.S., university presidents function as employers (Lenhardt, 2005, p. 138). Having first been like an ‘autocrat, statesman, and entrepreneur’ (Ben-David, 1984, p. 154), the presidents of today are less powerful: They must report to the board and are supported by administrative staff, such as provosts and deans. In Germany, administration and research at chairs are combined (Lenhardt, 2005, p. 138). The curriculum historically depended on the professors’ inquiries and the students’ research topics as a consequence of the Humboldtian ideal of freedom of teaching and learning. The idea was to connect research with curricula. Institutes and seminars were directly responsible to the state, whereas today, the President of a German university has a stronger position. (Clark, 1995, p. 28) The ‘freedom of learning’, however, was impacted by the governments’ attempts to obtain practical gains from financing universities. German institutions in higher education were not totally spared bureaucratic interference. Yet, there was no greater concern about this issue because of the assumption that ‘pure’ learning could not be impacted by a ‘worldly setting,’ such as the state government’s actions. (Ringer, 1990, p. 112)

5.2.4 The Bologna Process: Quality Assurance in Focus

Numerous descriptive studies are available on the state of development of the Bologna process in the frame of higher education policy and the noticeable or potential problems of implementation in selected countries, e.g. Germany (Eckardt, 2005; Lenhardt, 2005; Ostermann, 2002). An external view is adopted by Johanna Kimler (2007) and Kristina Gensch (2008). While Kimler asks about the acceptance of bachelor- and master-degrees in the labor market, Gensch analyzes the practical skills bachelor students at Bavarian universities of applied sciences have obtained after completing a vocational semester or other practical elements within their study program. The effects of the Bologna process are examined by Richard Münch (2010) who points to the changes in the German tradition of the transition between education and the labor market. His hypothesis is that a ‘closed’ labor market marked by a differentiated job system based on the dual system and academic education will be transformed into an open, flexible labor market, such as Great Britain and the U.S. already have. In the context of nanotechnology, it is evident that by virtue of the Bologna process, the implementation of new study programs and research foci has become easier and thus accelerates the diffusion of cutting edge technologies like nanotechnology within the educational system. Thus, it is not only the interest of employers that pushed the creation of nanotechnology study programs, but also the restructuring process because of the Bologna reform.

With the economic paradigm of the European higher education policy, another constitutive element has become crucial within the Bologna process: quality assurance and accreditation of study programs (Petzina, 2005, p. 23). Accreditation must be differentiated from evaluation: The former evaluates a study program before its implementation, the latter after it has been started. Accreditation of study programs is aimed at evaluating a concept of study by competent reviewers according to its content, to its compatibility with set study goals, if it is well-suited for studying, to its occupational orientation, personal and material resources, and measures for quality assurance within universities. (Petzina, 2005, p. 28)

An ‘Americanization’ of the European higher education system due to the introduction of a bachelor and master structure is often discussed. This might not be a correct conclusion when the whole higher education system is taken into account. As Julian Nida-Rümelin (2009) points out, because German (Prussian) universities served as the model for U.S.-American institutions (at least until 1914, (J. J. W. Powell, 2009, p. 2)) they valued academic learning and freedom. According to Nida-Rümelin, these circumstances were disregarded in the reform by following a false conception of U.S. bachelor programs as ‘school-oriented,’ i.e., high-school based and rigid, programs. However, the U.S. accreditation often serves as an undisputed model in European discussions on quality assurance (Richter, 2002), certainly because quality assessment is a new measure of the legitimization of research and teaching in a traditionally bureaucratic-oriented institutional system.

The U.S. system is outlined only briefly here. Roland Richter (2002, pp. 22-23) remarks that despite the notable increasing influence of the state in the U.S., the role of the state is nevertheless still subordinated to the role of the accreditation agencies and their procedures. This is contrary to the German system where the state and the agencies together with their competencies are less transparent. Until today, there is no central federal institution responsible for accreditation and quality assurance in the U.S.. In the late19th century, several regional institutions founded six accreditation agencies that have been in since charge with the accreditation of institutions as a whole (Richter, 2002, p. 7). During the 20th century, many professional associations and science foundations founded further accreditation agencies. Nowadays, there are eleven national accreditation agencies which accredit institutions and/or only selected study programs. There are 50 agencies which are only committed to specialized, professional accreditation, i.e., with a focus on occupation relevant skills. (Richter, 2002, pp. 7-8) The goals of non-state accreditation (private accreditation) initiated by universities, professional associations, and science foundations are stated by the ‘Council for Higher Education Accreditation’ (CHEA):

> ‘”the assurance of quality of institutions and programs; the improvement of institutions or programs that have already met basic standards through increased focus on goals and achievements and the public certification of institutional or program sufficiency to enable programs or institutions to receive public funds, meet legal requirements for licensure, and provide, in part, a basis for decisions about the transfer of credit.”’

However, as Kathia Serrano-Velarde (2008, pp. 30-31) asserts, the quality assurance procedures and systems in the Anglo-American countries must be set against the European ones: The introduction of quality assurance agencies does not always involve the retreat of the state, and the Bologna process is distinctly characterized by a multilevel policy governance (national, intergovernmental, and supranational).

Quality assurance became a central goal of Bologna next to the introduction of the bachelor and master system, student mobility and internationalization, the European Credit Transfer System, the central role of universities, student involvement, Lifelong Learning, a common and national frame of qualifications, employability, etc. (Sandfuchs, 2008, pp. 62-63). In 1999, when the European ministers of education met in Bologna, they declared that the coordination of measures to reach the goals in short term was agreed upon. Among the agreements was European cooperation in the field of quality assurance (Sandfuchs, 2008, p. 61). In Prague in 2001, further measures were set, such as the improvement of global understanding and comparability of European graduate degrees by developing a common frame of qualifications and mechanisms for quality assurance, accreditation and certification (Sandfuchs, 2008, p. 61). At the Berlin conference in 2003, the ministers of education decided that quality assurance is one of the three most important reform paradigms of the Bologna process (Serrano-Velarde, 2008, p. 33) and that the main responsibility for quality assurance lies upon the universities themselves. At the conference in London in 2007, the ministers stated that the implementation of the 'Standards and Guidelines for Quality Assurance in the European Higher Education Area' (ESG), in particular external quality assurance, has developed well. Again, the responsibility of the universities for quality is emphasized (Sandfuchs, 2008, p. 62).

In Germany, a two-fold accreditation system has emerged consisting of the accreditation council functioning as a supervisory board and the accreditation agencies which conduct the accreditation procedures and compete with each other. This way, supervisory and operative functions are kept separate. Accreditation agencies are supposed to be institutionally independent and not profit-oriented. (Petzina, 2005, pp. 26-27) Problems of the accreditation procedure in Germany include: the unequal competencies of the neutral agencies and the partial 'Standing Conference of State Education Ministers', which is much stronger than the agencies, the slowness of the accreditation procedures, the difficulty to find adequate reviewers as they are not remunerated, the co-existence of state-accreditation of curricula, the selective and restricted admission to master programs which runs counter to the intended international expansion of study programs, and the taking over of costs by the universities themselves without subsidization (Kehm, 2007, pp. 88-91).

5.3 University Education and its Relation to Practice and Profession

Having discussed the relationship of higher education systems with labor market economies, the relationship of university education with vocational issues and practice is outlined. Basically, both German and U.S. universities are independent from practical, purposeful issues. However, the orientation of universities toward research or applied issues has been changed over time. First of all, there was a focus on empirical research, in the U.S. earlier than in Germany (Lenhardt, 2005, p. 226). In Germany, science (the *Wissenschaft*) was generally defined as 'abstraction' and 'theory' (Ringer, 1990, p. 111). At the U.S. graduate level for instance, there is a transition from general to special skills. This is manifested in the same or even higher number of courses offered at this level compared to the undergraduate level. Full specialization therefore takes place after the undergraduate college. (Clark, 1995, p. 155)

Vocational education at universities has become an integral element of general schooling only in the U.S.. Yet, it is not very specialized and does not generally prepare students for a concrete career, at least not at the undergraduate level. U.S. students often switch disciplines when entering graduate studies. This has been enabled by the traditional bachelor/master structure in the U.S., which has existed in Germany only for ten years now. In addition to academic study, on-the-job training provides the necessary specific skills for a job position in the U.S.. Vocational programs are found more often in the community colleges than in four-year colleges and universities (Brint & Karabel, 1991).

By contrast, vocational schools in Germany are technical schools where middle school graduates (from *Realschulen*) are admitted (Allmendinger, 1989, p. 238). The only form of vocational training that takes place at German universities has been the preparation of students for state examinations in teaching, law, and medicine which also impacted the curricula (Ringer, 1990, p. 105). Meanwhile, vocational education and 'employability' have become a much debated issue in Germany in the wake of the Bologna process and the reform of study programs. Teichler (Hochschulrektorenkonferenz, 2009, pp. 42, 195-196) criticizes the use of the term employability as it is defined differently in the context of the Bologna reform. Employability in the original Anglo-American sense of the term refers to youth who have difficulty finding employment for in the labor market. He suggests speaking instead of *berufliche Relevanz*, a term which cannot be translated satisfactorily in English encompassing all its aspects. One translation would be vocational or, in Teichler's opinion, 'professional relevance.' In Germany, study programs are supposed to enable students to participate in the labor market and to pursue a *Beruf*, an occupation/vocation (Hochschulrektorenkonferenz, 2009, p. 195). Consequently, German universities are not supposed to focus on the success of graduates in the labor market but on the more general vocational and social achievements of their graduates (Hochschulrektorenkonferenz, 2009, p. 196). To promote 'employability,' the German *Wissenschaftsrat* ('German Council of Science and Humanities') demanded in 1999 the establishment of career centers, a university service which had been already offered in Great Britain and the U.S. for a long time (Hochschulrektorenkonferenz, 2009, p. 177). Greater permeability and competition between (research) universities and universities of applied sciences are expected due to shorter study periods that allow an earlier and easier entrance into the labor market or facilitate the transfer between academic institutions (Mayer, Müller, & Pollak, 2003, p. 30). Shorter periods, in addition to a more practical orientation and lower risks and investments, might even lead to more graduates with a working class background enrolling at *Fachhochschulen* and thus increase access to previous socially disadvantaged groups (Mayer et al., 2003, p. 38). In conclusion, one can say that, given the different national histories, U.S. universities are more oriented toward the transmission of applied sciences than German ones.

The issue of applicability of practice in tertiary education suggests that in order to find qualified employees for the labor market, it must be communicated to educational institutes which qualifications are needed. This process is going on right now in nanotechnology. Study programs at universities, universities of applied sciences, and apprenticeships with a focus on nanotechnology have been established in Germany (Baron et al., 2005). In the U.S., the pace has also increased remarkably within the last ten years with regards of the creation of nanotechnology study programs both at the undergraduate, graduate, and Ph.D. level. Discussions arise with regards to how nano-scale science and technology should be included both in undergraduate and graduate curricula to prepare for the need to create a nanotechnology-skilled workforce. So far, agreement has been reached that nanotechnology is included into teaching with a focus on the interdisciplinary character of nanotechnology. It is not, however, to be considered a separate discipline (Healy, 2009, p. 7; Sweeney, 2009; Vogel & Campbell, 2002, p. 498).

5.4 Nanotechnology: How National Higher Education Systems Lead to Different Kinds of Implementation

With these findings in mind, it is comprehensible that reactions to the political push for nanotechnology have been different. Analyzing government documents, homepages, and print material, the following can be concluded for Germany and the U.S.: Unlike a previous conclusion from section 4.2.2, Germany exhibits structures not as rigid as suggested in the literature. For the U.S., funding of nanoinstitutes has been fostered; in Germany, next to nanocenters, the integration of nanotechnology in the form of new programs at universities has been encouraged by virtue of the Bologna process. Professors and university administration used the Bologna process as an opportunity for institutional change and innovative programs. In both countries, nanotechnology represents a fundamental element of governmental science and technology policy. In terms of economic growth and international competitiveness, innovative technologies, including nanotechnology, are seen as one component of national frameworks of policy (Edler, 2003; VDI Technologiezentrum e.V., 2009).

Implementation Strategies of Nanotechnology at Universities

Overall, the U.S. as an LME favoring radical innovations and Germany as a CME propitious for incremental innovations have been both successful in nanotechnology. There are institutions specifically dedicated to nanotechnology and initiated by states or the government, such as the National Nanotechnology Infrastructure Network in the U.S. or the 'Cluster NanoMikro+Werkstoffe.NRW,' in the German state of North-Rhine Westphalia. At universities, single labs are dedicated to nanofabrication, such as at University of Berkeley in cooperation with University of San Francisco, Georgia Tech University or the Center for Functional Nanostructures at Karlsruhe Institute of Technology. Therefore, nanotechnology has become highly institutionally visible in the diversified research landscape. This institutional visibility can be traced back to state funding, both in the U.S. and in Germany where the governments have great interest in funding advanced technologies with nanotechnology being one of the most important. It is appropriate to remark here that, as has been noticed in former national policy contexts, the "state is not, and has never been, a neutral funder of science. It is able to exert considerable power by choosing to fund particular areas while neglecting others" (Windrum & Birchenhall, 1998, p. 185). Issues of national prestige and defense are mentioned in this policy context, while one must add national competitiveness (for an institutionalist analysis see Pedersen, 2010; Schaper-Rinkel, 2010b) and economic growth as salient features of state funding decisions. The state has an interest in "producing" graduates that have acquired nanotechnological skills and techniques applicable in nanotechnology industry.

Yet, the approaches are different in the U.S. and in Germany signaling different stances toward how individuals are adequately prepared for practice. In both U.S. research and German higher education, nanotechnology has been institutionalized successfully. In the U.S., more and more nanocourses have been offered over the last decade, however slowly (Stephan et al., 2007). There are singular associate degree, bachelor and PhD programs. The dominant trend is toward immersion of nanocourses and nanocontent into existing programs, e.g. at PSU where nanocourses are part of associate and bachelor degrees in the (natural) sciences. Several reasons, such as higher efficiency and viability, speak for the immersion of nanotechnology into existing programs. In a highly diversified university structure, such as the U.S. represent, integration into existing programs appears to be the most practical realization of the transmission of nanoskills.

In Germany with its more unified university landscape, by contrast, many more, largely new programs, centers, and chairs are established. The thesis is that Bologna and the 'Excellence Initiative' do not merely imply a trend toward more third-party funding but also incited more 'flexibility' into the chair structure by inducing researchers to create degree programs or focal point programs. These reforms have no equivalent in the U.S., although the need for reforms is acknowledged by the U.S. government in policy documents, such as in the COSEPUP report from 1995 (Bartelse, Beerkens, & Maassen, 2000, p. 289), yet without having the same effect that Bologna and the 'Excellence Initiative' have had on Europe. In Germany, there are more bachelor programs in nanotechnology than in the U.S. (Nanowerk, 2010b). This evidently reflects the high autonomy German professors have to induce institutional change at universities by using the opportunity of Bologna. The number of degree programs in Germany has grown fast due to the attachment of new programs (master and bachelor programs in the verge of the Bologna process) and graduate colleges to existing universities. With respect to national size, Germany provides comparatively more programs, in particular at the bachelor level (Nanowerk, 2010b). In the U.S., in particular the creation of associate degrees has been accelerated lately (see an overview in Bradley, 2011).

What is to be noticed is that out of the U.S. programs, only some have a 'concentration' or 'specialization' on nanotechnology. Thus, nanotechnology does not represent the main track but students are trained in main disciplines, such as physics and engineering, first. The fact that Germany has more bachelor programs confirms Germany's focus on undergraduate training and on an early specialization. The fact that there is a higher number of PhD programs in the U.S. confirms that specialization in the U.S. takes place at a higher level of education. (Nanowerk, 2010b)

Summary and Outlook on Nanotechnology

To sum up, it can be noticed that nanoscience and -technology are more anchored in research in the U.S. than in Germany due to the more comprehensive government initiatives, namely the NNI and the NNIN. In Germany, there are single nanocenters but they are not as interconnected and ubiquitous as the NNIN for instance. What adds to the greater engagement of the U.S. in nanoscience is the higher interaction with companies and start-ups. In Germany, on the other hand, the traditional focus on (higher) education and the early specialization of students is pursued. The idea of training interdisciplinary-oriented but specialized nanotechnologists is pervasive in Germany, in particular in politics, whereas in the U.S., the degree programs are still kept more general. Specialization in nanofields is possible in the U.S., too. However, compared to Germany, U.S. universities are less likely to create whole new degree programs, as an overview of the number of nanodegree programs suggests (Nanowerk, 2010b). As the example of PSU shows, the immersion of nanoeducation into existing programs dominates the education strategy in the U.S.. In terms of interdisciplinarity, interdisciplinarity is institutionally favored in Germany in the form of new degree programs in nanoscience and -technology that are established. This leads to interdisciplinary, mixed research groups in Germany. In the U.S., interdisciplinarity occurs mainly through the creation of interdisciplinary research centers, such as the Georgia Tech Research Institute, or through students who collaborate with other departments. Institutionally, cooperation between departments opens intellectual space for interdisciplinarity in U.S. higher education systems.

Overall, nanotechnology has a fixed position in the academic landscape and in national technology and innovation policies both in Germany and the U.S.. Whereas the U.S. focuses on large-scale research, Germany focuses more intensely on the visible institutionalization of nanotechnology in the form of undergraduate and graduate programs. This follows the VoC hypotheses: to have institutional complementarities, Germany as a CME follows its focus on education and vocational training to create nanotechnologists whereas the U.S. follow its concentration on large-scale research in national research institutes as well as start-up companies.

Nanoscience and -technology have been institutionalized over the last 20 years in Germany and the U.S. in a remarkable pace. It has not replaced or dominated the 'big sciences' but, being a cross-disciplinary technology, it has been absorbed as a specialty and technology across the main disciplines of chemistry, engineering, materials science, and physics. While the success of nanotechnology is not surprising in the LME of the U.S., the CME of Germany is a more interesting case as nanotechnology is a high-risk technology. Of course, as an innovative technology, it remains to be seen if nanotechnology will be established on the long-term horizon in German academe and industry.

5.5 Tentative Summary and Conclusion

As shown by the comparison of the German and U.S. higher education system, there are basic institutional and functional differences between these two national systems. Different roles of professors in existing university structures as well as different degrees of autonomy and funding structures influence the way research is done and evaluated. Current reforms affect institutional structures and processes as well. The Bologna reform for instance has been changing the role of professors and their autonomy and has intervened into the way how German universities have been changed institutionally and with regards to the content of degree programs.

Furthermore, different national educational systems lead to respective implications for labor markets. Thus, for example, the fact that there is a well-functioning dual system in Germany not integrated into higher education provides for a completely different career track and qualification profiles industry can take advantage from than the more 'integrative' U.S. tertiary system. This goes along with the VoC approach that hypothesizes that in the CME of Germany a more regulated labor market demands a clear career track for nanotechnologists whereas in a more flexible labor market, such as the one the U.S. provide, study profiles and job opportunities in nanotechnology are loosely coupled (see section 5.1). Despite the integration of vocational education in the U.S., the implementation of nanotechnology degrees at community colleges for instance has been slower than in Germany. In Germany, with less diversification, at technical universities, universities of applied sciences, and research universities at the same time, nanoprograms have been established side by side with less applied and technologically oriented programs and combined with basic research that applies nanotechnology and, simultaneously, looks at the further development of nanotechnology tools of analysis and microscopy or spectroscopy. In other words, whereas with higher diversification in the U.S. there is a danger of confining nanotechnology education to less research oriented colleges by leaving high-profile nanotechnology research to renowned research universities, both areas are fruitfully combined in German universities. This, however, does not suggest which research system might be more successful in nanotechnology research. Yet, it suggests how different national structures of higher education deal with high-technology implementation and how these structures provide different answers to that.

If one looks at the rapidly developing field of nanotechnology for example, it is considered a fact that, with increasing production and services in nanotechnology, both college- and dual system-educated graduates are needed, i.e., also employees with a more technical and practical educational background (Baron et al., 2005, p. 65). With regards to the transition to the labor market, nanotechnologists are trained in vocational schools and undergraduate programs in Germany. In the U.S., associate degrees provide largely technical workers, for instance at technical or community colleges (for an overview see Bradley, 2011) whereas students at the graduate/doctoral level are provided with nanocourses and specialization certificates. On-the-job training will become more and more important in German companies that depend on skills in nanotechnology (Baron & Schumann, 2009, p. A12). Nanotechnology careers in Germany occur in academia, extra-university institutes, such as the Fraunhofer Institutes, and in industry. In the U.S., careers are to be found in academia, university-affiliated institutes, such as those participating in the NNIN, and in industry. These institutional settings arise partly because of the different set-ups of educational institutions and educational tracks that channel into the structures of career paths in the labor market.

In short, it is important to be aware of the similarities and differences in higher education as they influence innovative and knowledge-related processes and dynamics and vice versa. In the case of nanotechnology, it has been demonstrated that differing national systems in higher education have resulted in differing implementations of nanotechnology education: The U.S. have immersed nanotechnology research into existing curricula and doctoral programs or departmental research groups. Germany, by contrast, has installed a number of bachelor and master programs as a reaction to the European Bologna process. This reaction incited institutional change in the form of new degrees at universities. It provided answers to the implementation of nanotechnology that fit properly with the German institutional structure in higher education where engineering e.g. and other more applied study programs are installed closer to basic research than it seems to be the case in the more diversified U.S. education system. With the reform then, not only existing programs have been reorganized and transformed into bachelor and master programs, but also new programs have been added to the existing German university landscape. Together with Germany’s focus on education and training as a CME, these programs promise to be helpful in the delineation of nanotechnology as a profession, although this future development cannot be answered yet with certainty. With the U.S. having a partly different approach to the institutionalization of nanotechnology, the professionalization of nanotechnology appears to remain of lower priority.

With regards to future research, the findings are instructive for innovative processes in a society marked by technological revolutions. How research is done in educational arrangements and students are prepared for the labor market affects innovations. Innovations, in turn, affect the conception of which skills are indispensable for the education and the creation of a much-needed workforce. Thus, when questions arise as to the prevalence of certain technologies in a country, looking at tertiary systems reveals societal conceptions of what is assumed to foster innovative technologies that are promising for economic growth. Also crucial is the understanding of which institutional implementation is conceived adequate for educating a workforce to work in these fields of high-technology.

In terms of policy, one can see from the development of nanotechnology so far that policy is only able to influence advanced technologies in a limited way, namely within the given institutional structures of a nation. In both Germany and the U.S., the institutional structures provided indeed opportunities for the incorporation of nanotechnology, which made both countries leading nations within the realm of this technology. Therefore, policy must recognize existing institutional features of a country and develop strategies that take into account these national characteristics. For now one can conclude that nanotechnology policy, which is embedded in the general technology paradigm of public funding in Germany and the U.S., seems to be successfully docking technology funding to the national research systems. The latter hereby has not turned out to be too rigid in the institutional absorption of nanotechnology.

In this chapter, a background was provided on the different national higher education systems in Germany and the U.S.. This analytical comparison was necessary for the understanding of other chapters, in particular for chapter 7.3.1 where the institutional structures are discussed with a focus on interview data that have been gathered for this study. These interview data express the feelings and concepts of scientists with respect to nanotechnology that are mixed and not as straightforward as one might expect. It will be shown how the tension that arises due to the strong political support of nanotechnology and due to the scientists’ mixed feelings toward the integration of high-technology into higher education is resolved in different institutional structures. These structures channel nanotechnology research in partially differing national directions. The result of the incorporation of nanotechnology is the same if one looks at the fact that nanotechnology has a fixed place in both national research systems despite or maybe even because of the tension emerging with the different motivations of politics and scientists with regards to nanotechnology. From the view of professionalization, this process takes place predominantly in the economic labor market outside universities. In Germany and, less extensively in the U.S., this process is explicitly supported by providing career tracks on nanotechnology. Having delivered a rather broad perspective on national higher education systems and the incorporation of nanotechnology, it is time now to turn to the individual, i.e., micro-level, and meso-level respectively to examine diffusion of nanotechnology from the bottom-up, as done in the next chapter by looking at the emerging phenomena of individual research behavior.

6. Network Simulation Model[4]

6.1 Experimental Framework

The present study contributes to existing literature on scientists' networks and specialties at universities that has not simulated academic networks so far by using agent-based modeling. The simulation modeling approach is applied to trace the emergence of a new academic specialty, namely nanotechnology, focusing on the influence of public funding: Can the way of distribution of public funding steer the development of the number of nanoresearchers and thus the spread of a high-technology? The question is how a new (technological) specialty that is conceived of as a Mode 2 technology in politics emerges and meets academic Mode 1 criteria (Wald, 2007), such as discipline-oriented structures of knowledge production as well as scientists. Therefore, agent-based modeling delivers one methodical perspective on the field of nanotechnology next to the interviewing technique whose outcomes are presented in chapter seven. The model draws on criteria that are derived from and validated in empirical research: the role of public funding, the structure and size of research centers, the probability of disciplinary identity change or, in other words, perseverance of disciplinary structures (see Abbott, 2005; Czada, 2002; Hagstrom, 1970, p. 92), interdisciplinary cooperation as well as the production of graduates from degree programs, such as nano-specific studies, represent relevant modeling factors. Heterogeneous research centers and interdisciplinary cooperation are therefore two Mode 2-criteria that are looked at in the model.

In the model, the institutional and disciplinary development of the academic field of nanoscience is simulated and measured by the number of researchers that are active in nano-scale research or other specialties. The goal is to compare Germany and the U.S. based on their respective status quo of nanotechnology at universities. The basic question underlying the simulation then is: What happens if a new academic field, namely nanotechnology, is being funded in different ways among other specialties and disciplines by public agencies? How does the Mode 2 criterion interdisciplinarity influence the spread of nanotechnology? How does the openness of researchers affect its development given the perseverance of disciplinary structures at universities, as widely acknowledged in literature? These questions dovetail and at the same time upgrade the main research question in this study on how the political support via funding influences the field and its development and how this influence is evaluated by scientists working in the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) of higher education policy and academic research.

Nanotechnology is used here as an example of a high-technology specialty that has been supported increasingly by national governments since the late 1980s. However, this model, if extended and adapted, is also suited for the study of other specialties that might be of interest for policy research, higher education research or issues of technology diffusion. For instance, the proportion of funding going to nanotechnology that is used in the present case can be changed to the proportion of funding another high-technology under investigation receives or, if the proportion for nanotechnology alters e.g., then, too, this parameter can be modified.

Finally, the results indicate that network effects arise depicting non-linear distributions of the number of nanoresearchers, being the dependent variable, and thus also of the diffusion of nanoresearchers at universities. Non-linearities are regarded as emerging phenomena due to network effects that have already been analyzed e.g. in complex markets (Gilbert, Jager, Deffuant, & Adjali, 2007). Public funding as an independent variable can achieve only a limited role in fostering the emergence of nanotechnology in academia so that, in future research, a wider range of variables ought to be integrated when examining research networks and the development of new specialties therein.

6.1.1 Model Description

In the model, there are several theoretically based parameter and variable settings. These parameters and settings simulate a U.S.-American and a German model. The models are further based on the different size of the respective national research systems and on literature, for instance the study of nanoscience as a Mode 2 field (see Jansen et al., 2010). The independent variables are the spending of public money for disciplines and specialties, in particular nanotechnology, and the production of graduates from degree programs that are nano-specific (as often in Germany) or not. The focus on public funding is explained by the largest share that public funding provides for nanoscience and -technology at universities in both countries. The variation and calibration of a discipline-based change of one's (occupational and, more generally, social) identity, the probability for interdisciplinary cooperation, the social mechanisms for the likelihood of interaction provide control variables of the model. These mechanisms are interpersonal relationships and spatial proximity (Blau, 1977; Pattison & Robins, 2002; W. W. Powell et al., 2005; Schweinberger & Snijders, 2003), meaning that knowing each other and having short paths (distances) to other agents increase the probability of entering collaboration. Further mechanisms are the 'Matthew Effect' (on the unequal distribution of scientific papers see de Solla Price, 1965; Merton, 1968, pp. 511-512) and, more generally, 'Lotka's Law' (Lotka, 1926), which lead to scientists citing 'star scientists' and thus expressing an unequal distribution in science, not only of papers but also of citations. Finally, transitivity (Davis, 1970) holds, i.e., indirect relationships with agents acquainted with a specific other agent (node) who can only enter research or reference links (citations) with directly or indirectly known agents. Only when changing their disciplinary identities as a result of the application of the parameter of identity change, agents can merely choose among directly known agents. The latter rule accounts for the fact that change in identity is influenced by peers.

Parameters are varied to simulate real social networks and to generate artificial data. These data are analyzed by statistical methods (Kruskal-Wallis and Nemenyi tests) to detect if there are significant differences between the samples for the four funding strategies. These strategies are: the funding of 'star scientists', i.e., those with a maximum number of citations, 'core scientists', i.e., those who have a maximum number of research alliances, the random funding of 'any scientist' in the research networks, and the funding of 'research programs' in which two coordinators are involved and get funded. In addition, some empirical data have been included into the model. This does not make it a pure empirical network model, however, wherefore a real social network would have had to be measured. Yet, the empirical data included make the model more realistic in terms of the structural settings and size of the research networks. The simulation results show that nanotechnology emerges rather as a specialty, not as a discipline, and that network effects in research collaboration take hold.

These results will also be subject in the chapter on the analysis of interviews done with nanoresearchers that confirm the specialty character of nanotechnology and the importance of personal acquaintance with each other in academic research groups, in particular when recruiting doctoral students and going to conferences. As an abstract model, not all questions about the field of nanotechnology can be answered here. It delivers merely one central perspective on the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) that is under analysis in this dissertation. The model simulates individual researchers and their interaction in order to look at emerging phenomena that arise at the macro- and organizational level of national research systems. Questions arise with regards to how one can imagine the inner organizational life of the simulated research systems, how researchers cooperate with each other, how researchers interpret Mode 2 criteria, and how the different nation-

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[4] This chapter is partly derived from the following article and published with kind permission from Springer Science+Business Media: Computational and Mathematical Organization Theory, Public Funding in the Academic Field of Nanotechnology: a Multi-agent Based Model, 19, 2013, page 253, Nadine Hoser, figure numbers 12, 23, and 24, table numbers 6, 8, and 9.

al institutional structures of Germany and the U.S. affect the development of nanotechnology and the work of academic nanoresearchers. These issues will be explored and discussed in chapter 7 in that order.

6.1.2 Model: Setup and Agent Behavior

In the setup of the model (see Figure 13 and Figure 14), agents (96 in Germany, 408 in the U.S.) are distributed randomly over the number of research centers that are displayed in the grid of the model. The number of agents in both model settings is distributed equally over four scientific disciplines (chemistry, engineering, materials science, and physics), which participate in nanotechnology research. This way, there is no bias in the model toward one single discipline. The adoption of nanotechnology as the researcher's identity can only occur during the simulation rounds when the function 'funding of nanotechnology' is activated, as this is a condition for the spread of nanotechnology. The agent behavior is based on the fact that agents cooperate with and cite whom they know directly or indirectly (see 'transitivity' mentioned above). Directly known are, first of all, all agents that belong to one research center, which favors intradepartmental research alliances, as cooperation with a spatially close agent is preferred. Then, an agent knows directly those agents who graduated the same research center's study program and stay in the center. In addition, an agent knows its funding agencies which look for funding partners over all the existing research centers independently of the research center they are located in. As funding agencies are not bound to one research center, as agents are, funding agencies function as intermediaries between different research centers and their agents. It is via agencies that agents get to know indirectly researchers from other centers. There might be disadvantages to this kind of rule. However, this rule takes into account the importance of spatial proximity highlighting the centrality of research centers for research cooperation. The rule further stresses the role of agencies which link research centers and influence the researchers' perceptions with regards to which topics seem to be worth pursing and which are not.

An agent can have multiple research, reference and funding links. The number is not limited by an absolute number but by the rule that research and reference links end after a realistic period of time, namely the average duration of scientific research projects. This duration is implemented in the model by a probability that determines when a link is deleted. The number of research alliances and citations within the network depends on the probabilities for these links in any given simulation round (0.1 and 0.5 respectively). The probability for reference links is higher because a single agent can engage with research alliances less frequently than with citations due to their limited capacity concerning time and money. In each simulation round, a random probability is chosen between zero and one. If these randomly selected probabilities are lower than 0.1 or, in the case of citations, 0.5, a respective link emerges between two agents. Therefore, the number of links varies from one round to another. Concerning funding links, the number of links cannot exceed the budgets that are available for research grants. However, if an agent is already funded in one project by a funding agency, agencies do not give further grants for the same field of research to that particular agent.

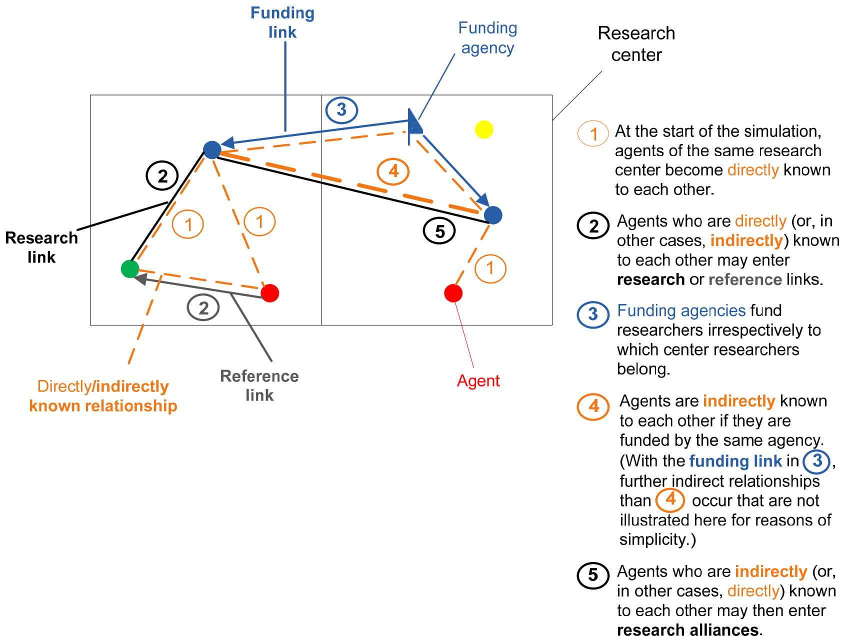
Furthermore, agents can be influenced in their research content by other agents' disciplines and research (visualized by the agents' color) by changing their 'color.' 'Color' of agents can only change by way of the probability of identity change where agents adopt the color of one of their funding agencies or one researcher that they know directly. They know other researchers whom they cite (but not by whom they are cited) or cooperate with and with whom they share a research center. This implies that nanotechnology can spread via funding agencies or via already existing nanoresearchers who are cited or who collaborate in research networks with others. The more nanoresearchers thus exist, the more additional nanotechnologists can emerge. Identity change therefore denotes the self-description of researchers with reference to their identity as a scientist. In addition, agents can be influenced by graduates from degree programs (depicted in the model snapshots by boxes) who, at least at the beginning, pursue research that is identical with their study programs. Thus, when researchers

cooperate with these graduates and happen to change their identities, already active researchers might be influenced by graduates or vice versa, if graduates change their identities themselves.

Creation of Links: Research, Reference, and Funding Links

The basic procedure is the creation of links between researchers from different (sub-) disciplines and specialties who know each other directly or indirectly through another researcher. There are three types of links: research, reference, and funding links, of which nanofunding links represent a special type.

Figure 12 illustrates a possible scenario of agent and agency behavior by pointing to a number of steps that can occur in a tick. It portrays the funding strategy of 'any scientist,' since two agents (in blue) from different research centers who are indirectly known to each other are funded randomly as they do not have a maximum number of research or reference links.



① At the start of the simulation, agents of the same research center become directly known to each other.

② Agents who are directly (or, in other cases, **indirectly**) known to each other may enter **research** or **reference** links.

③ Funding agencies fund researchers irrespectively to which center researchers belong.

④ Agents are **indirectly** known to each other if they are funded by the same agency. (With the **funding link** in ③, further indirect relationships than ④ occur that are not illustrated here for reasons of simplicity.)

⑤ Agents who are **indirectly** (or, in other cases, directly) known to each other may then enter **research alliances**.

Figure 12: Possible Scenario of Agent and Agency Behavior Illustrated in Steps 1 to 5; Own Source

Research alliances are formed between researchers whereby those who are spatially closer to one another are more probable to engage in collaboration: cooperation with a researcher from the same research center or from one research center in the vicinity of this center occurs more likely than cooperation with someone further away from the research center. Distance in the present model is a rather abstract measurement, as it solely refers to the distance between researchers in the grid of the model as to be seen in Figure 13 and Figure 14. Reference links emerge between researchers as well and represent citations. These links are not based on 'spatial proximity' but on the prominence of researchers due to citations that are measured by already extant references which are directed toward a researcher. This means that the more prominent a researcher is, the more probably that researcher is cited by somebody who knows that researcher directly or indirectly (by reading his or her research for example), but not necessarily by somebody who is already a research partner. This observation is similar to

Lotka's law (Lotka, 1926), whereas in the present case, the simulated mechanism does not denote publications but citations, as was studied by de Derek J. Solla Price (1965, pp. 511-512).

Degree centrality for research and reference links are the measure of prominence which is originally based on research collaborations or citations (Mutschke, 2010, p. 367). For reference links, the relative in-degree more precisely measures prominence in the present network. Degree centrality denotes the number of direct neighbors of a node i (here of a specific researcher on a specific position within one of the model's research centers) based on the number of links that connect node i with other nodes. The relative in-degree is central because it implies that reference links are directed toward a 'star scientist,' not directed away from a 'star scientist.' A 'star scientist' is a researcher who unites a maximum of citations of their publications (on the introduction of the term 'star scientist' see e.g. Zucker & Darby, 2001). Research links, however, are undirected, which means that they can be directed toward or away from a researcher. It remains to be noted that there is no coupled dynamics of reference or research links when taking into account the funding. In each round, i.e., after each 'tick,' which is the time unit of the model, a new randomized probability between 0 and 1 determines the establishment of research and reference links. This procedure takes place independently of what has happened in the previous round. It means that a different type of researcher is more or less probable of being funded dependent on the funding strategy that is used throughout the 100 runs of each of the four samples. Research links in the 'core scientists' strategy denote as much funding as reference links in the 'star scientists' strategy, for example. Just the fact who receives a budget differs due to a higher probability of the occurrence of reference links. In the case of research programs, however, two researchers at a time receive funding links and thus the same budget so that, overall, more budget is received for the same research project.

Funding agencies (represented by flags) establish directed funding links with researchers (illustrated by circles) who are not already being funded by that particular agency's program or specialty. The establishment of funding links depends on the budget available for the funding agencies, which is the same for each agency and depends on the size of the research system divided by the proportion of the overall budget that is designated for nanotechnology (which is higher in Germany than in the U.S.). A funding agency establishes one funding link with one researcher at a time. This is repeated so long as its budget, i.e., the size of its grant, allows. On the other hand, one researcher can have several funders at the same time. Furthermore, directed reference links are established from researchers to other researchers as well as undirected research links among researchers. Funding links always remain the same, i.e., they designate the same amount of money to each researcher. Funding agencies can also fund degree programs (represented by boxes in the middle of each grid unit) but only in the German model to account for the third-party funded bachelor and master degree programs in the sciences that have been established due to the European Bologna reform.

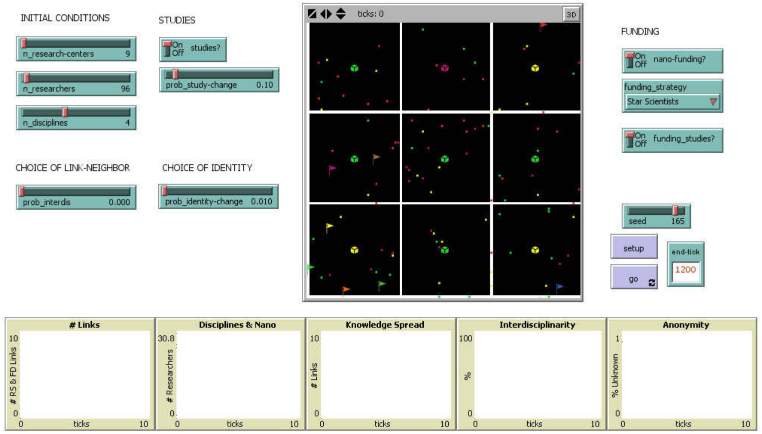
Nanofunding links stand out as a special type of funding because it is of interest here how nanoscience and -technology develop by being funded as a separate program. If the function 'nanofunding?' is activated on the interface, then one funding agency is colored blue, i.e., funds nanotechnology. Funding agencies in this model can thus fund disciplines and specialties, with nanotechnology being but one example. The funding link's color is dependent on the 'color,' i.e., research emphasis the respective agency program has. The funding links namely are colored according to the funding agency's color to denote the project content that is funded by the agency. Research and reference links each have a separate color so that they are to be distinguished on the interface.

Furthermore, in both models, the creation of degree programs and the influence of researchers on degree programs is depicted by a constant probability of 'study change' ensuring that degree programs do not stay the same but are subject to the influence of researchers who are responsible for lecture content or for their creation in the first place. There is one study/degree program with a particular focus on a single discipline or on nanotechnology for each research center. Researchers belonging to that research center influence the content of the study program.

The function 'funding of studies' is only activated in the German model since, due to the relatively recent reforms of the 'Excellence Initiative' (and Bologna), new degree programs in the form of bachelor/master programs as well as doctoral graduate colleges have been created to raise third-party funding. Thus, public money in the form of third-party funding flows into degree programs as well, in particular into master programs in the natural sciences, i.e., the relevant disciplines in the context of nanotechnology (Hüning & Langer, 2006, p. 22). By way of funding, these degree programs are influenced not only by researchers (via the probability for study change in the model) but also by the funding agency itself that gives money due to a particular intention for the content of that program (depicted by the funding link directed to studies). These reforms have not occurred in the U.S. so that the U.S. model lacks the 'funding studies'-option.

One must bear this national distinction in the model setup in mind since it indicates a major difference between Germany and the U.S. from the view of the VoC approach: the focus on institutional education and training systems and specific skills in CMEs like Germany (Streeck & Thelen, 2001; Thelen, 2004) is taken into consideration in the model by the 'funding studies'-option. This option includes the establishment of institutional complementarities in the German political economy by providing education in specific skills through nanotechnology study programs. This way, the importance of education and vocational systems in a CME is taken into account, whereas an LME like the U.S. continues to pursue its focus on large national research systems and institutes as well as more general skills acquired in education (Thelen, 2004).

The interaction of researchers in the form of intra- and interorganizational research links, i.e., within and between research centers, is also illustrated and accounts for a 'knowledge spread' within and between these centers. Thus, researchers do not only influence the study program of their research center but also other researchers of their own or from another center by collaboration or by being cited. These processes then cause an endogenous dynamic depicting knowledge and technology spread, in our case knowledge related to nanotechnology. Next to knowledge spread (third from left diagram in Figure 13 and Figure 14 at the bottom), the absolute number of research (gray), reference (black), funding (cyan), and nanofunding (blue) links (first from left diagram in Figure 13 and Figure 14) are delineated, the absolute number of researchers belonging to a certain discipline or specialty (second from left diagram in Figure 13 and Figure 14), the percentage of interdisciplinary links out of all research links (fourth from left diagram in Figure 13 and Figure 14), and anonymity (fifth from left diagram in Figure 13 and Figure 14). Anonymity depicts the percentage of interconnectedness between the researchers or, in other words, how connected the network is, i.e., how many researchers are linked to other researchers and how many remain isolated. Naturally, this value approaches zero the longer the simulation run has advanced, as more and more links are created over time. The diagrams at the bottom of the model setup always run over the period of 1200 ticks in diagrams.



ticks: 0

n_research-centers 9

n_researchers 96

n_disciplines 4

studies?

prob_study-change 0.10

prob_interdis 0.000

prob_identity-change 0.010

nano-funding?

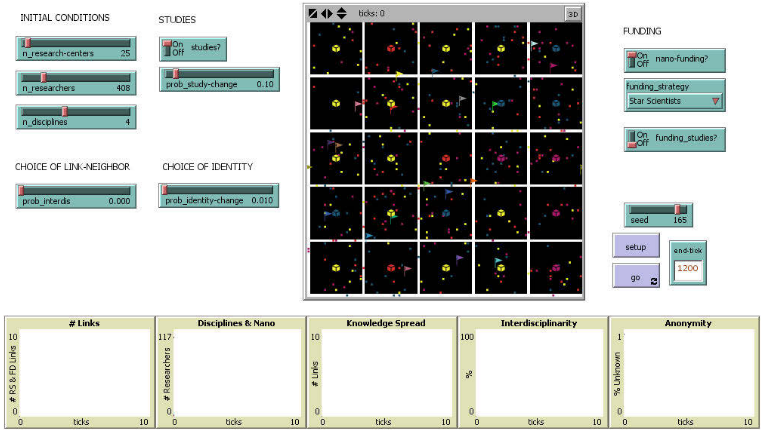
funding_strategy: Star Scientists

funding_studies?

seed 165

end-tick 1200

Figure 13: German Model–Setup: Probability for Interdisciplinarity 0.00 and for Identity Change 0.01; Own Source



ticks: 0

n_research-centers 25

n_researchers 408

n_disciplines 4

studies?

prob_study-change 0.10

prob_interdis 0.000

prob_identity-change 0.010

nano-funding?

funding_strategy: Star Scientists

funding_studies?

seed 165

end-tick 1200

Figure 14: U.S. Model–Setup: Probability for Interdisciplinarity 0.00 and for Identity Change 0.01; Own Source

The main question examined here is: what happens to research networks if not only a new specialty is funded but also if public money is distributed in different ways and thus allocated in various ways to researchers in nanoscience and -technology? In general, what happens if differing funding strategies for money allocation are applied? To analyze money allocation based on different foci, four possible, logically derived strategies of funding for nanoscience are applied that might turn out to be influential in the diffusion of nanotechnology within the simulated scientific community: funding of 'star scientists,' of 'core scientists,' of 'research programs,' and of 'any scientist.' The funding of nano-'star scientists' is based on the maximum number of citations a researcher has, which increases the chance of being funded. The funding of 'core scientists' depends on the maximum number of a researcher's research links, which increases the chance of being funded. In other words, those who have a maximum number of (outgoing) research links are the first ones to engage in collaboration or to be chosen as co-operators. One might object that prominence in terms of the number of cooperation relationships with other researchers is rather a secondary criterion resulting from high reputation due to citations. Yet, here, the logical possibility of the network to fund researchers with a high number of research links was regarded to be worth a separate analysis, as it might indicate an additional importance of research alliances for the funding of nanotechnology as opposed to the importance of citations within the network alone. The funding of nano-'research programs' describes the funding of a group of researchers who are already partners and known to each other, such as German 'excellence clusters' or U.S. research groups headed by several PIs, e.g. department/research center collaboration. Hereby, as long as grants are available, one funding agency supports a maximum of two researchers at a time, one with a maximum number of partners and one of his or her partners. A funding agency cannot fund a researcher who is already receiving a grant from that same agency. With the 'research programs' strategy, public money is distributed over several agents and lessens the influence of a central position that one researcher might obtain within the network in the course of the funding process simulation. The funding of 'any scientist' refers to nanoresearch performed by a single researcher without having a high reputation in nanotechnology, be it with regards to citations or research alliances, but who nevertheless has a chance of obtaining grants by way of submitting proposals. In other words, the structural position within the simulated research network does not have any influence on whether a respective researcher gets funded or not in the case that the strategy of 'any scientist' is applied. This differentiation between strategies only applies when the procedure 'nanofunding' is activated, which is done here for both cases, Germany and the U.S., as in both countries nanotechnology is publicly funded. Otherwise, i.e., in a model setting where nanotechnology would not be fostered, research disciplines are funded in a random way. This would be equivalent to the funding type of 'any scientist.'

The two models are true to scale when it comes to the following aspects: the number of agents (96 in Germany (based on Jansen et al., 2010), 408 in the U.S.), research centers (represented by grid units), the relation of nanofunding links to all other funding links, which is the proportion of nanofunding in national R&D budgets in 2007 (Bundesministerium für Bildung und Forschung (BMBF), 2009, p. 124; National Nanotechnology Coordination Office, 2010; National Science Foundation (NSF), 2008, 2010; VDI Technologiezentrum e.V., 2009), and, finally, the number of disciplines. These disciplines are related to nanoscience but remain structurally separate from nanotechnology since they merely implement this technology but do not base their identity on that specialty. The disciplines compete for funding links as well.

Several other factors and parameters are true to scale as well. This is the approximate duration of research projects, i.e., the duration of research and funding links, and the size of the average research networks that determines the probability for establishing research alliances between simulated researchers (Jansen et al., 2010). Furthermore, one tick (i.e., step of the model runtime) equals one month. This is relevant for the implemented 'renewal' of agents, i.e., the production of a new generation of scientists, because researchers are not doing science perennially but for a limited period of, as in the present model, around 40 years. This is an approximation used here and means that researchers enter the field at the age of 25 and leave at the age of 65, meaning that they vanish from the nanofield that is simulated. Altogether, the maximum number of ticks is 1200, representing a period of 100 years, i.e., nearly three generations. The empirically-based values for the parameters are recalculated to fit the time unit of months.

6.1.3 Variables and Parameters

The final simulation results in the form of numbers of nanoresearchers represent analytical results derived from 'abduction' (Squazzoni, 2010), not from empirical results by deduction or induction. Thus, they would need to be externally validated with empirical data to be used for inference on populations. Simulation models aim at understanding processes and mechanisms based on the simplicity of the model. They represent a heuristic toward understanding, not a proof of theories via statistically measurable correlations.

Validation implies that the simulation is a plausible model for the different strategies of public funding of a new technology. Validation occurs if empirical results are available and can be compared to the model results to check if there is a correspondence of the behavior of the target to the behavior of the model. (Gilbert & Troitzsch, 1999b, p. 18) Structures and budget proportions are empirically validated by using data from 2007 to calculate the proportions that national nanobudgets have out of the total BMBF/National Science Foundation (NSF) budgets. However, this is not the case for all of the parameters in the present model. Rather, assumptions and mechanisms are taken over to simulate social reality, such as the above mentioned 'spatial proximity.' Instead of using numerical empirical data, this model's focus lies on empirical observation asking: what can be seen that happens? Furthermore, as previously stated, the aim of this model is to understand the mechanisms of four different funding strategies and their effect on the dynamics of the field of nanotechnology. The effect is measured by looking at the spread of the number of nanoresearchers. Hereby, the study takes into account the degree of perseverance of researchers with regards to their disciplinary self-categorization. This is evaluated first by looking at the degree of variance due to the effect of public funding and second by integrating the Mode 2 criterion of interdisciplinarity and the probability for scientists' identity change together with their effect on the dependent variable, the number of nanoresearchers. The model is thought of as a help to analyze in an explorative way these processes to see what would happen if funding strategies varied, given the initial conditions of size, interdisciplinarity, identity change, and funding of studies. Therefore, rather than feeding a list of numerical data into the model, mechanisms and structures have been simulated to compare two different national contexts that differ in their size of research systems, the number of agents, the number of research centers, and the proportion of federal grants available for nanotechnology research.

The model is set up in a way to observe what happens when a new sub-discipline, nanotechnology, is funded by public funding agencies. This is illustrated by the 'blue flag.' Nanoresearchers are represented by blue points. Nano-degree programs are marked by 'blue boxes.' The observations are based on several parameters and variables. The following factors are recognized as influential for research collaboration: interdisciplinarity and identity change (referring to the degree of openness to change ones disciplinary/professional identity). Identity change varies in each country setting between the two previously mentioned values, whereas the respective probability of interdisciplinarity takes the value of zero and one (i.e., interdisciplinarity funding yes/no) for each country. Further differences are: the number of research centers and researchers as well as the proportion of nanofunding in the national government budgets, which are all higher for the U.S., the funding of studies occurring only in Germany. An overview of all parameters is given as follows:

- *n_research-centers*: This value indicates the number of research centers that are extant in the respective national setting. The value, which differs for Germany and the U.S., represents the relative number of nano-related research units attached to universities compared to the whole number of research institutes specialized in nanotechnology.
- *n_researchers*: This number depicts the relative number of nanoresearchers in Germany and the U.S. respectively compared to the estimated total number of nanoresearchers.
- *n_disciplines*: N_disciplines shows the number of main disciplines that form the (natural) sciences. The number is always four to represent physics, chemistry, materials sciences, and engineering.
- *studies?*: This switch enables to create course programs of different specialty and disciplines that produce graduates from the respective specialty and discipline respectively.
- *prob_study-change*: This parameter assures that nano-degree programs change slowly over time to represent influence by the creators of courses, course catalogues, whole programs, and lectures.
- *prob_identity change*: This variable represents the probability that researchers change their professional disciplinary identity, i.e., their color, randomly. The color blue stands for nanotechnology, i.e., for researchers who report that they are involved with nanotechnology. Other colors stand for academic disciplines and specialties. Researchers when changing their identity do not adopt a random specialty or discipline as their identity but orient themselves toward one of their funding agencies or toward the identity of somebody they already know by virtue of collaboration or citation.
- *prob_interdis*: This parameter reports if researchers from different disciplines, i.e., different colors, start interdisciplinary research collaboration by choosing randomly a partner of a different color or not.
- *nano-funding?*: This switch tells if nanotechnology as an academic specialty is funded or not. For the analysis here, funding of nanotechnology is always applied, as it is of interest how this specialty develops.
- *funding_strategy*: This variable applies, one at a time, the four strategies of funding 'core scientists,' 'star scientists', 'any scientist' or complete 'research programs' that have to do with nanotechnology.
- *funding_studies?*: This switch indicates if degree programs are funded (as in the German model) or not (as in the U.S. model). Studies furthermore adopt the funding agency's color while they are funded to indicate the changes in study content that go along with external funding and/or accreditation of study programs.

6.2 Simulation Setup

Running the model demonstrates the development of the field of nanotechnology delineated by the establishment of links. The parameter and variable settings are based on empirical results wherever appropriate and feasible as well as on more extreme values for interdisciplinarity and identity change to test the implications of high or low levels of these parameters in an ideal way. There are two national model setups (see Figure 14 and Figure 14) and further constellations with regards to interdisciplinarity, identity change, and funding strategy.

For each of the four funding strategies, 100 simulation runs were conducted, which leads to 2 (two values for identity change, 0.00 and 0.01) * 400 (4 strategies * 100) runs * 2 (two values for interdisciplinarity) for each country. This totals 1,600 runs. Measures of one run are averaged using arithmetic means. Therefore, one receives one mean for one run for the respective model setting. There are 100 values for 'random seed' ranging from 67 to 166. This function is included to ensure that random sample variances are identical, i.e., imply the same variations attributable to random variables ('noise') over the whole 100 runs per funding strategy. Random variables refer to the potential values of an exogenous variable whose value is uncertain. With random seed, these values are kept constant over all runs but they are not reduced to zero. Thus, one can safely say that the observed differences, and similarities, in the model can be traced back to the different types of funding strategies and the different values for identity change and interdisciplinarity, which makes the single runs comparable to each other. This is also crucial for the robustness of the model: One can be confident that the differences observed between the runs are due to the different parameter settings, not to random variables. Thus, there is high reliability in the obtained results based on the parameter settings.

The data set resulting from the simulations was analyzed doing a Kruskal-Wallis test (Kruskal-Wallis one-way analysis of variance). It computes the differences in variance and in sample medians to see if the numbers of nanoresearchers of the four samples (the four strategies) differ statistically significantly from each other. A non-parametric test was used because of the violation of the normality assumption of ANOVA, the parametric one-way analysis of variance. To see which funding strategy samples differ significantly from each other, which happens in the case of significant Kruskal-Wallis results, the post hoc Nemenyi test was used for multiple comparisons being the non-parametric correspondent for the Tukey test, i.e., the post hoc test for ANOVA. It is important to note here that this chapter does not develop a stochastic model for the networks generated in the simulation and testing structural features, such as transitivity.

6.3 Simulation Results

6.3.1 Snapshots on One Run for Each Model Setting

First, it is looked at one run out of 100 for each interdisciplinarity and identity change setting for Germany and the U.S. with regards to only one funding strategy for reasons of straightforwardness and simplicity. As these snapshots are not representative, the focus here lies not on presenting an exhaustive overview but on presenting single snapshots for reasons of illustration. This way, one can get an idea of how different values for identity change can affect the outcome of nanoresearchers. The following charts show the preliminary results of one run (1200 ticks) of the German and the U.S. models with the funding strategy being ‘any scientist,’ i.e., a random allocation of funding links. The first two of each national model have a value of 0.00 for interdisciplinarity and the two values for identity change, the second two of each national model a value of 1.00 for interdisciplinarity and also the two values for identity change. Nanotechnology (blue) and funding links (cyan) to be seen with the first diagram from the left at the bottom of the interface from Figure 15 to Figure 22 remain constant in all runs for both Germany and the U.S., as the number of links in these cases are fixed at the beginning due to stable government budgets for research projects in all topics.

The snapshots all show that the percentages for interdisciplinarity, which denote the proportion of research links between researchers from different disciplines, depend on the value for identity change varying between zero and one and that anonymity falls down to almost 0% and levels off more or less regularly. In the case of interdisciplinarity and identity change values of 0, the percentage of anonymity even increases to about 50%, meaning that 50% of researchers do not know each other.

Taking further into account the diagram on knowledge spread, one might conjecture that, the same way as *inter*organizational links decrease to half of all *inter*organizational links, anonymity increases as well as links occur more frequently within centers and not between centers. Anonymity in the U.S. stays higher than in some snapshots of Germany ostensibly due to the fact that the number of U.S. researchers is almost five times as much as the number of German researchers. *Intra*organizational links increase exponentially at the beginning and then level off. *Inter*organizational links increase more exponentially than *intra*organizational links, then drop down to almost a half of all the *inter*organizational links to subsequently fluctuate irregularly (except for the interdisciplinarity and identity change value of 0 where the numbers do not fluctuate as heavily as with the other parameter settings). The distribution of *intra*organizational links is relatively stable at a level of about one fourth to one fifth of *inter*organizational links. The *inter*organizational distribution reveals that rather nonlinear effects come into play in research networks and organizational links over which knowledge can diffuse by communication and interaction between researchers. Principal differences between the national models are to be detected in terms of the number of researchers in the single disciplines and in nanotechnology.

German Model Snapshots

Research and reference links in the German simulations reach a maximum of up to 767, i.e., one researcher can be linked to several nodes (to several funding agencies and/or researchers by way of citing or cooperating), as the research and reference links are higher than the actual number of researchers.

Overall, in the German snapshots, nanotechnology could establish itself only sporadically as a main discipline but stays most of the time in the lower half of the diagram compared to main disciplines (red, green, and yellow curves). Other disciplines, such as the one colored yellow, experienced a decrease and then, near the end, an increase in some snapshots. Nanotechnology nevertheless becomes a visible specialty and, literally, a sub-discipline, and experiences ups and downs in the number of nanoresearchers.

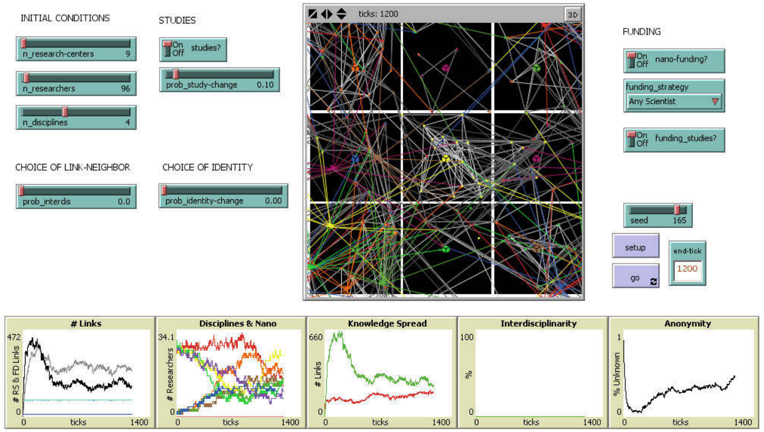

INITIAL CONDITIONS
n_research-centers 9
n_researchers 96
n_disciplines 4
STUDIES
studies? On Off
prob_study-change 0.10
CHOICE OF LINK-NEIGHBOR
prob_interdis 0.0
CHOICE OF IDENTITY
prob_identity-change 0.00
ticks: 1200
FUNDING
nano-funding? On Off
funding_strategy Any Scientist
funding_studies? On Off
seed 165
end-tick 1200

Figure 15: German Model, Interdisciplinarity 0, Identity Change 0.00, One Run; Own Source

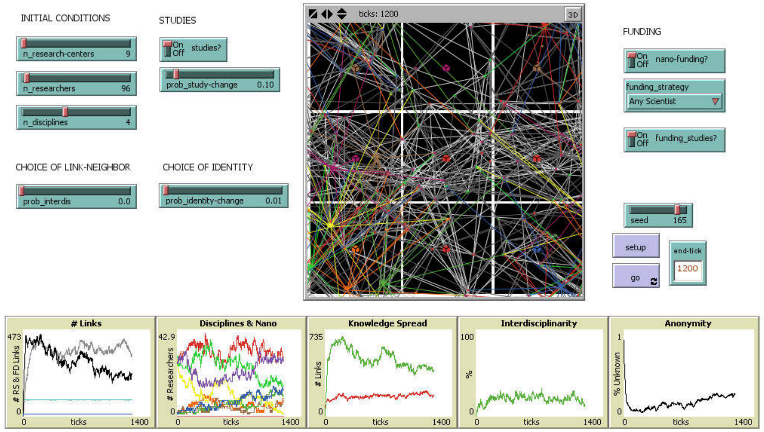
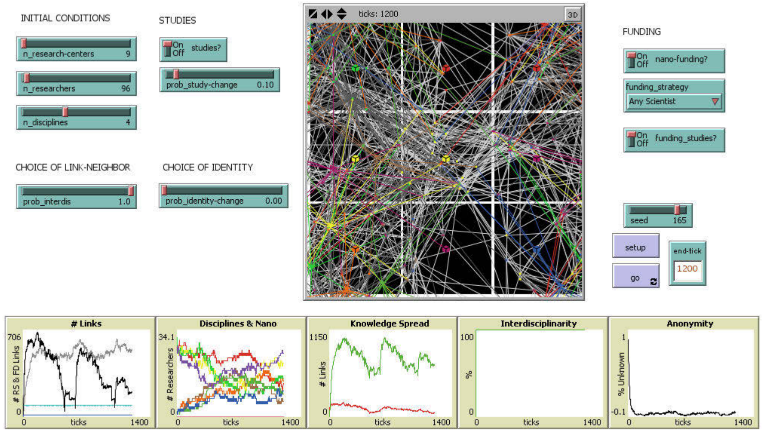

INITIAL CONDITIONS
n_research-centers 9
n_researchers 96
n_disciplines 4
STUDIES
studies? On Off
prob_study-change 0.10
CHOICE OF LINK-NEIGHBOR
prob_interdis 0.0
CHOICE OF IDENTITY
prob_identity-change 0.01
ticks: 1200
FUNDING
nano-funding? On Off
funding_strategy Any Scientist
funding_studies? On Off
seed 165
end-tick 1200

Figure 16: German Model, Interdisciplinarity 0, Identity Change 0.01, One Run; Own Source

The next two charts have a value of 1 for interdisciplinarity. Which differences from the first two charts on Germany can be detected? The graphs on knowledge spread and anonymity are fairly equal with the number of *intra*organizational links being always a smaller proportion of the *inter*organizational links, since single research centers are always smaller than the whole research system, and anonymity approaching 0%. The percentages for interdisciplinarity are, unsurprisingly, 100% for the value of 1 and 0% for the value of 0.0 given an identity change value of 0.0. With the identity change value of 0.01, percentages for interdisciplinary cooperation reach one-third with an interdisciplinarity probability of 0. This demonstrates that interdisciplinary cooperation can also happen merely due to researchers that change their identity: as researchers change their identities, interdisciplinary cooperation can set in once researchers involved a single discipline-project change their identity and turn the alliance automatically into an interdisciplinary one. The higher the identity values are, the higher is the percentage of interdisciplinary cooperation links. By contrast, with the probability for interdisciplinarity being 1 and with an identity change value of 0.01, interdisciplinary links become smaller with higher identity change values whereby interdisciplinary cooperation reaches between 90 and 100% of all cooperation links. In that case, interdisciplinarity demand has a negative effect on the percentage of interdisciplinary links.



ticks: 1200

n_research-centers 9

n_researchers 96

n_disciplines 4

studies? On Off

prob_study-change 0.10

prob_interdis 1.0

prob_identity-change 0.00

nano-funding? On Off

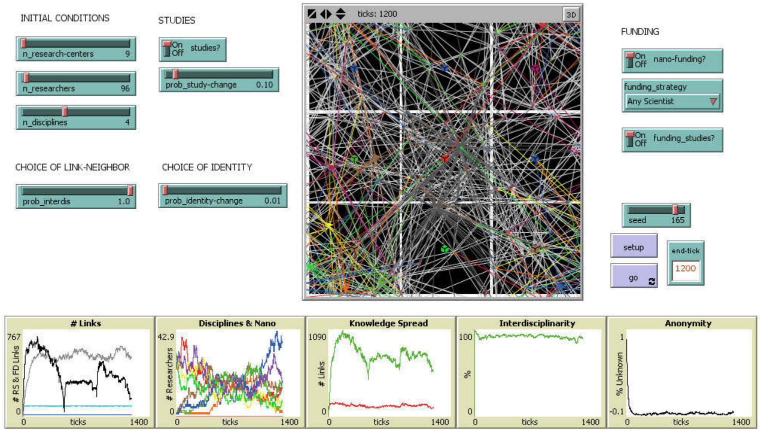
funding_strategy Any Scientist

funding_studies? On Off

seed 165

end-tick 1200

Figure 17: German Model, Interdisciplinarity 1, Identity Change 0.00, One Run; Own Source



ticks: 1200

n_research-centers 9

n_researchers 96

n_disciplines 4

studies? On Off

prob_study-change 0.10

prob_interdis 1.0

prob_identity-change 0.01

nano-funding? On Off

funding_strategy Any Scientist

funding_studies? On Off

seed 165

end-tick 1200

Figure 18: German Model, Interdisciplinarity 1, Identity Change 0.01, One Run; Own Source

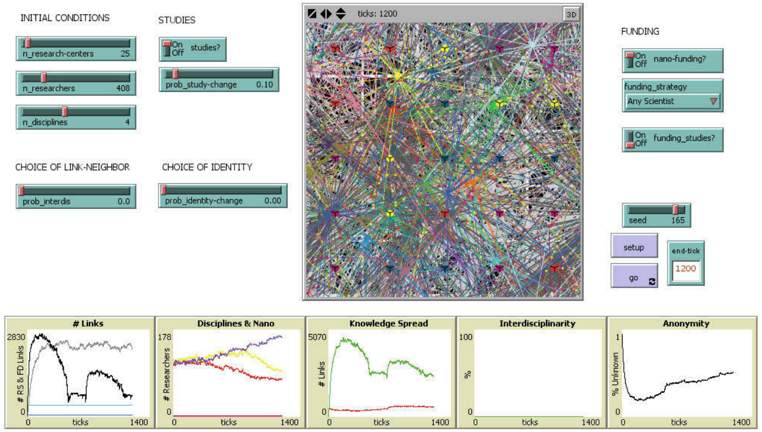
In addition, the distribution of nanoresearchers in Figure 18 for instance looks very interesting, although if repeated with a different seed value this run does not always exhibit such a unique distribution with such a high peak of the number of nanoresearchers. This indicates that the spread of a new specialty cannot be predicted exactly; rather it depends on the constant random influence that the network experiences. Thus, it becomes clear that a large enough number of runs must be simulated to obtain a representative average sample where random influences are controlled. Therefore, also the range of seed (66 to 167) for the 100 runs for each sample is kept constant.

In sum, what do the different curves and their parameter settings tell us? First, identity change and interdisciplinarity do matter, as the curves for the number of nanoresearchers do not resemble each other exactly in the selected identity value and interdisciplinarity settings. Second, there are different dynamics following roughly an inverted parabola, a more or less steadily increasing linear curve or a wave-shaped curve respectively. The dynamics of the development of the number of nanoresearchers is so irregular that no pattern can be detected that might be related to the variables of identity change, interdisciplinarity or funding strategy. This dynamic speaks for emerging phenomena, as the snapshot results and curves are not to be predicted based on the initial model setting and the individual agent behavior, but only if interactions between agents are taken into account.

U.S. Model Snapshots

The U.S. model snapshots show following features: as in the German model, nano- and the remaining funding links are constant and form a pre-set proportion of the total of funding links. The maximum number of research and reference links does not differ greatly between values of identity change. It ranges between 2830 and 3810 and increases with increasing interdisciplinarity and identity change values. This is not surprising, as higher probability values imply much more dynamics of interaction between agents.

The distribution curves here are nonlinear as well. The outcome for the number of nanoresearchers is around zero except for the identity change value of 0.01 (combined with an interdisciplinarity value of zero). This might indicate that openness of researchers is indispensable for a new community to emerge.



ticks: 1200

n_research-centers 25

n_researchers 408

n_disciplines 4

studies? On Off

prob_study-change 0.10

prob_interdis 0.0

prob_identity-change 0.00

nano-funding? On Off

funding_strategy Any Scientist

funding_studies? On Off

seed 165

end-tick 1200

Figure 19: U.S. Model, Interdisciplinarity 0, Identity Change 0.00, One Run; Own Source

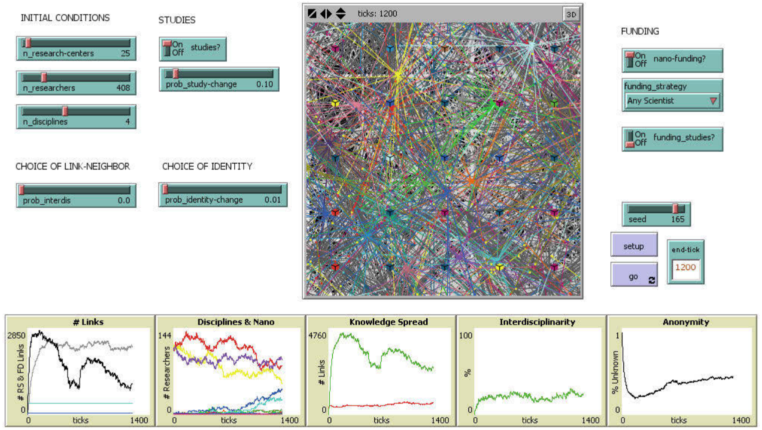

INITIAL CONDITIONS
n_research-centers 25
n_researchers 408
n_disciplines 4
STUDIES
On Off studies?
prob_study-change 0.10
CHOICE OF LINK-NEIGHBOR
prob_interdis 0.0
CHOICE OF IDENTITY
prob_identity-change 0.01
ticks: 1200
FUNDING
On Off nano-funding?
funding_strategy Any Scientist
On Off funding_studies?
seed 165
end-tick 1200

Figure 20: U.S. Model, Interdisciplinarity 0, Identity Change 0.01, One Run; Own Source

The patterns for interdisciplinarity and anonymity are similar to the German patterns. Yet, the values for anonymity do not quite peter out, such as the German values do. Anonymity in the U.S. always remains higher certainly due to the larger size of the research system. Furthermore, with smaller identity change values, percentages of researchers that do not know each other rise again after plummeting at the beginning. The pattern still stays the same since with a rapid increase of research, reference and funding links at the beginning researchers get to know each other very fast.

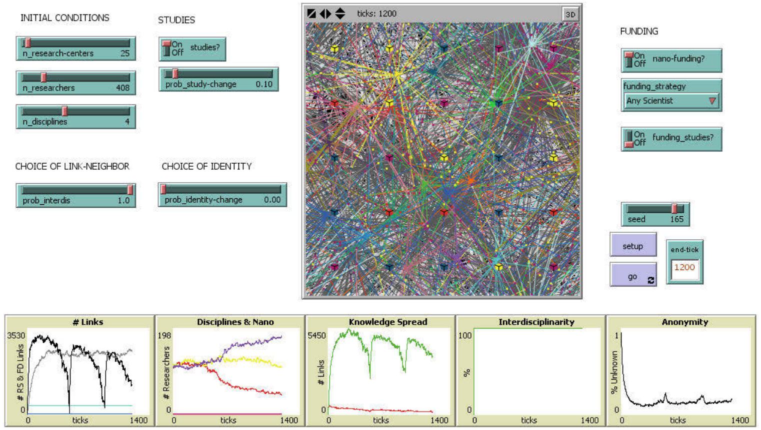

INITIAL CONDITIONS
n_research-centers 25
n_researchers 408
n_disciplines 4
STUDIES
On Off studies?
prob_study-change 0.10
CHOICE OF LINK-NEIGHBOR
prob_interdis 1.0
CHOICE OF IDENTITY
prob_identity-change 0.00
ticks: 1200
FUNDING
On Off nano-funding?
funding_strategy Any Scientist
On Off funding_studies?
seed 165
end-tick 1200

Figure 21: U.S. Model, Interdisciplinarity 1, Identity Change 0.00, One Run; Own Source

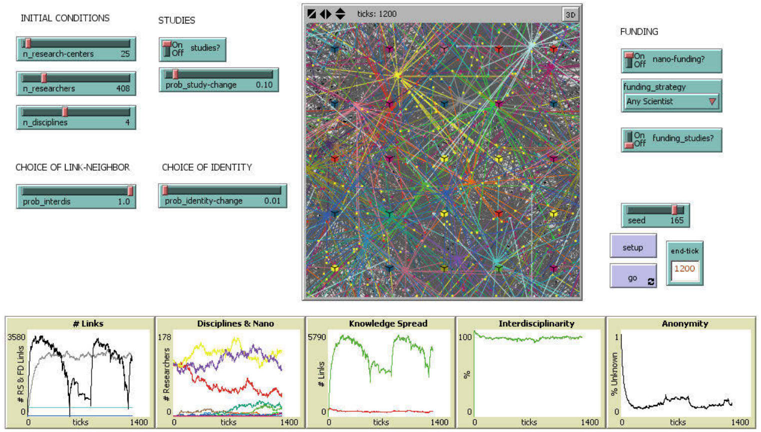

INITIAL CONDITIONS
n_research-centers 25
n_researchers 408
n_disciplines 4
STUDIES
On Off studies?
prob_study-change 0.10
CHOICE OF LINK-NEIGHBOR
prob_interdis 1.0
CHOICE OF IDENTITY
prob_identity-change 0.01
ticks: 1200
FUNDING
On Off nano-funding?
funding_strategy Any Scientist
On Off funding_studies?
seed 165
end-tick 1200

Figure 22: U.S. Model, Interdisciplinarity 1, Identity Change 0.01, One Run; Own Source

The number of *inter*organizational links in U.S. model snapshots is naturally bigger than in the German snapshots. Numbers reach 4760 links (interdisciplinarity value of zero and identity change of 0.01) to 5790 links (interdisciplinarity value of one and identity change of 0.01). Thus, the pattern is not quite the same as in the German model with a clear direct proportionality of interdisciplinarity/identity change values and the number of research and reference links. *Intra*organizational links occur in a far less number and in a linear way parallel to the x-axis as a result of the smaller size of research centers compared to the number of external nanoscientists. The shapes of the distributions are similar for *inter*organizational links in all cases: there is an exponential increase, then a drop in a quite volatile way, and finally, a leveling off of the number of *inter*organizational links. This finding supports the notion that knowledge spread in the form of organizational links takes place in a nonlinear way.

The U.S. models that imply a greater number of research institutes, researchers, and funding agencies, show the same pattern for interdisciplinary links, as described in the German model snapshots above, but higher proportions of anonymity and lower proportions of *intra*organizational links. Both are certainly to be traced back to the fact that the U.S. system is much larger than the German system and also of a different institutional kind. For U.S. professors, it is more difficult to cooperate or cite all researchers in the field. Furthermore, there is a ‘gap’ to be assumed in social reality between research universities, including elite universities, and state universities that are more engaged in teaching.

In the U.S., the number of nanoresearchers in some snapshots is invisible and hardly increases to give nanotechnology the status of a discipline or even small scientific community. In others with an identity change value not being zero, the number of nanoresearchers can experience an irregular development that can reach fairly high numbers but only temporarily. This supports the notion of a reluctance of researchers to define themselves as nanotechnologists that is certainly a factor for nanotechnology not establishing itself within the portrayed one hundred years as a stable and main discipline. Nanoresearchers who are trained in another, established academic discipline shun away from adopting the nanolabel as a marker of professional identity, both in the U.S. and in Germany, which is consistent with literature on academic disciplines (Abbott, 2005; Czada, 2002). However, nanotechnology when being funded can establish itself within academia, not as a leading discipline but as a force to be reckoned with.

With regards to the number of nanoresearchers, this number seems to depend not only on the funding strategies, but also on other parameters, in particular interdisciplinarity and identity change but also size of the research system. As already mentioned, these snapshots must not be seen as representative for all 100 runs. They only give us an ad-hoc insight into which pattern of distribution the dependent variable can produce and how other parameters develop over the simulated time. Whereas in the German model, numbers for nanoresearchers always reach a certain level in the snapshots and can even overrun numbers of researchers from disciplines, in the U.S. model, nanotechnology does not always establish itself as a visible specialty. Therefore, it must be noted that in the U.S. models, nanotechnology naturally cannot establish itself as visibly as in the German models because of the size of the U.S. research system that is comparatively of greater size than the German system. In the U.S., it can be far more difficult to establish a new specialty in the long term and as a ‘serious’ field next to main disciplines, such as physics or chemistry. This is one reason why the absolute numbers of nanoresearchers must be looked at and evaluated after repeating the simulation runs. In both countries, however, it can be seen that some disciplines become main disciplines and dominate. Examples would be the natural sciences and big specialties, such as experimental physics or organic chemistry, under which nano-S&T tends to be subsumed because of its cross-technological character and the lack of joint fields of application. Still, nano-S&T represent distinct specialties.

Most importantly, one must be aware that these are all preliminary results of just one snapshot, i.e., one run, and thus not representative for all simulation results. However, they do give an insight into the dynamics of the development of a specialty. In the German snapshots, the dynamic of the number of nanoresearchers is much more irregular than in the U.S. snapshots. Whereas the number of nanoresearchers in the U.S. model is always negligibly small it seems as nanotechnology never appears to seriously ‘compete’ with established disciplines, the development of nanotechnology is much more dynamic and seems to assign nanotechnology the role of a serious specialty next to main disciplines in the German model snapshots. To have more valid results, one must look at all of the 100 runs. Still, the irregular distributions of the number of nanoresearchers imply nonlinear network effects at work that arise when researchers form cooperative relations and funding relations to funding agencies. This observation strongly underlines the conclusion that public funding has only limited impact on the establishment of academic disciplines and scientific communities due to the lack of linear relationships of public funding and the number of nanoresearchers. What can certainly be conjectured is that values for interdisciplinarity and identity change affect the network dynamic and thus influence the spread of nanotechnology being a newly funded academic specialty. The higher the number of interdisciplinarity and identity change, the more ‘intensely’ the network reacts and builds up a new structure without being too volatile to detect any regular pattern between the simulated parameters, as already mentioned. This, on the other hand, does not mean that the curves for the outcomes are regular or linear: one can detect inverted parabolas, exponential distribution, and ‘waves’ in the distribution outcomes.

What can be said about the curves in terms of the development of invisible colleges into specialties is that the curves do not seem to support Diana Crane’s theory of invisible colleges and the organization of specialties in science. She found that specialties follow a logistic, sigmoid-shaped curve, showing “low levels of communication and few links among researchers” at the beginning of the growth of a specialty, an increase of communication links along with the growth of the specialty forming a “highly coherent group,” and finally, a slow-down of growth with different outcomes concerning the state of the specialty near the end, be it a loose network or a polarization into schools (Crane, 1972, p. 76; Griffith & Miller, 1970, p. 137). The issue of communication links among nanoscientists and their distribution has, to the knowledge of the author, not yet been studied. Thus, the analysis of the organization of nano-S&T as a research specialty, as pursued by Crane for other specialties, ought to be addressed in future research.

6.3.2 Descriptive Sample Statistics

Table 6 presents descriptive sample statistics giving the means, medians, standard deviations, and the value for skewness for the four funding strategy samples for Germany and the U.S.. The numbers in Table 6 refer to the number of nanoresearchers that emerge when nanotechnology is funded by public agencies. Therefore, the numbers would have to be brought down to a round number since researchers can only be natural numbers.

Country	**Inter-disci-plinarity**	**Identity Change Value**	**Funding Strategy**	**Mean**	**Median**	**SD**	**Skew-ness**	**Kur-tosis**
Germany	0	0.0	Core Scientists	12.88	12.0	5.12	0.54	0.58
Germany	0	0.0	Star Scientists	13.48	13.0	4.61	0.24	-0.46
Germany	0	0.0	Any Scientist	13.44	13.0	4.66	0.50	0.58
Germany	0	0.0	Research Programs	13.40	13.0	4.77	0.51	-0.37
U.S.	0	0.0	Core Scientists	2	2	0	n/a	n/a
U.S.	0	0.0	Star Scientists	2	2	0	n/a	n/a
U.S.	0	0.0	Any Scientist	2	2	0	n/a	n/a
U.S.	0	0.0	Research Programs	2	2	0	n/a	n/a
Germany	0	0.01	Core Scientists	12.03	10.0	7.73	1.19	1.37
Germany	0	0.01	Star Scientists	12.02	10.0	7.42	1.24	2.63
Germany	0	0.01	Any Scientist	13.15	12.0	7.08	0.60	-0.06
Germany	0	0.01	Research Programs	11.2	9.0	6.89	0.88	0.15
U.S.	0	0.01	Core Scientists	7.34	6.0	6.12	3.44	20.69
U.S.	0	0.01	Star Scientists	62.55	45.0	60.30	1.31	1.42
U.S.	0	0.01	Any Scientist	9.54	7.0	8.15	1.83	3.59
U.S.	0	0.01	Research Programs	6.98	4.0	6.74	2.14	4.82
Germany	1	0.0	Core Scientists	14.06	14.0	4.97	0.74	1.25
Germany	1	0.0	Star Scientists	13.88	14.0	4.40	0.30	-0.46
Germany	1	0.0	Any Scientist	13.61	13.0	4.83	0.49	-0.25
Germany	1	0.0	Research Programs	13.95	13.5	4.78	0.46	0.05
U.S.	1	0.0	Core Scientists	2	2	0	n/a	n/a

Country	Inter-disci-plinari-ty	Identity Change Value	Funding Strategy	Mean	Median	SD	Skew-ness	Kur-tosis
U.S.	1	0.0	Star Scientists	2	2	0	n/a	n/a
U.S.	1	0.0	Any Scientist	2	2	0	n/a	n/a
U.S.	1	0.0	Research Programs	2	2	0	n/a	n/a
Germany	1	0.01	Core Scientists	12.28	11.0	7.13	1.06	1.39
Germany	1	0.01	Star Scientists	13.62	13.0	7.21	0.59	-0.05
Germany	1	0.01	Any Scientist	13.91	13.0	8.53	0.80	0.12
Germany	1	0.01	Research Programs	13.06	12.0	7.71	1.08	1.68
U.S.	1	0.01	Core Scientists	17.02	10.0	16.84	1.85	4.49
U.S.	1	0.01	Star Scientists	71.50	72.0	43.57	0.36	-0.72
U.S.	1	0.01	Any Scientist	20.18	12.5	18.54	1.62	3.18
U.S.	1	0.01	Research Programs	16.45	10.0	17.50	1.88	3.51

Table 6: Descriptive Statistics for Four Funding Strategies with Two Values for Identity Change and Two Values for Interdisciplinarity, Germany and the U.S.; Own Source

For the German model, the (weighted) *means* of the number of nanoresearchers vary from 11.2 ('research programs;' interdisciplinarity zero; identity change 0.01) to 14.06 ('core scientists;' interdisciplinarity 0; identity change 0.0) nanoresearchers. For the U.S. models, the means range from 2.0 for the identity change value of 0.0 in both interdisciplinarity settings and from 6.98 to 71.5 nanoresearchers for the identity change value of 0.01. Thus, the means are higher than for the German values. Outliers like the mean value of 71.5 for the U.S. indicate that extreme numbers are more probable in the U.S. setting where dynamic effects are more probable due to the greater size of the research system.

The *median* of German nanoresearchers ranges from 9.0 to 14.0 nanoresearchers. The strategy of 'core scientists' and 'star scientists' for values of interdisciplinarity of 1 and identity change of zero produces the highest median of nanoresearchers, 14.0, which is, however. The lowest medians of 9.0 have been brought about by 'any scientist' with values of zero for interdisciplinarity and 0.01 for identity change. The medians for the U.S. samples have a greater range overall: from 2.0 to 72.0 whereby the samples for an identity change value of 0.01 produce higher maximum medians (from 4.0 to 72.0) than the samples for a value of 0.0, which results in the same value for all runs (2.0).

Standard deviation values, measuring statistical variability by using the mean as the central tendency and based on the sample means, vary from 4.4 to 8.53 in the German model. With increasing identity change values, standard deviations increase with both interdisciplinarity values but more drastically with an interdisciplinarity value of 0. The U.S. values for standard deviation range from 0 to 60.3. Therefore, standard deviations are more than three times higher than the German means, whereby the deviations are about similar to the means in the case of the U.S. values. The values show that the data vary greatly supporting the notion that there are non-linear effects and non-normal distributions in the simulation data.

Skewness greater than 0 implies right-skewed data; a value of 0 would mean that the data are distributed symmetrically. Thus, skewness gives preliminary insights into how data (the number of nanoresearchers) are distributed. Lack of skewness does imply normality but not alone: data can be symmetrically distributed (having a value of 0 for skewness) but still not be normally distributed, for instance when data mirror each other by forming an inverted parabola. Positive skewness values signify that the data distributions are right-skewed, i.e., concentrated to the left of the center of the normal distribution. The distribution 'tail' thus points to the right of the distribution of the collected data. At first glance, one can notice that the U.S. samples are more highly asymmetrically distributed than the German samples. This could mean that in the U.S., network effects are stronger, as distributions are right-skewed and even less normally distributed. The lowest skewness value is 0.24 for 'star scientists' in the German model with interdisciplinarity and identity change values of 0.0 indicating a very slight right-skewed distribution for this sample. With 3.44, the highest value is obtained by the strategy 'core scientists' in the U.S. model with the identity change value of 0.01 and an interdisciplinarity value of 0.0 indicating the greatest asymmetry of the right-skewed data in that sample.

Overall, the skewness values differ from 0 and therefore indicate a non-symmetrical distribution of the data. This suggests network effects that point to non-linear relationships between funding strategy and the number of nanoresearchers that emerge due to public funding of nanotechnology. To conclude, the descriptive statistics, above all the standard deviations, as well as kurtosis and skewness values, support the fact that there are non-linear effects that emerge in the research networks that were simulated.

Figure 23 to Figure 26 give the distribution of selected sample data in the form of histograms illustrating the non-normal distribution they exhibit (with the normal distribution given in colored lines). The value for interdisciplinarity for the following histograms is always zero, which gives an adequate and insightful overview of the way how the data are distributed. The bars depict the frequency of the occurrence of the number of nanoresearchers, as shown on the x-axis. The colored lines show what the distribution would be like if normal distribution was given. As to be noticed with an identity value of 0.0 for the U.S. model, the output values are all the same; thus, the distribution in the histogram shows that all 200 output values of two nanoresearchers are the same.

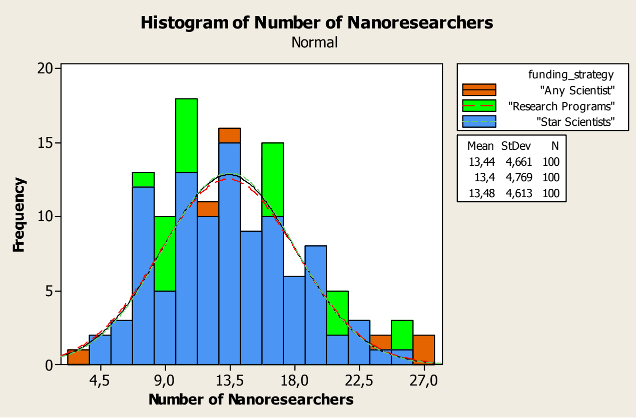


Figure 23: Histogram for Germany with Identity Change Value 0.00 Grouped according to Funding Strategies; Groups Compared to Normal Distribution (See Lines); Own Source

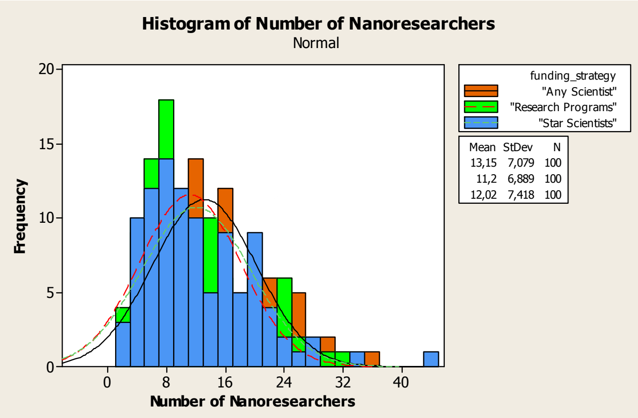


Figure 24: Histogram for Germany with Identity Change Value 0.01 Grouped according to Funding Strategies; Groups Compared to Normal Distribution (See Lines); Own Source

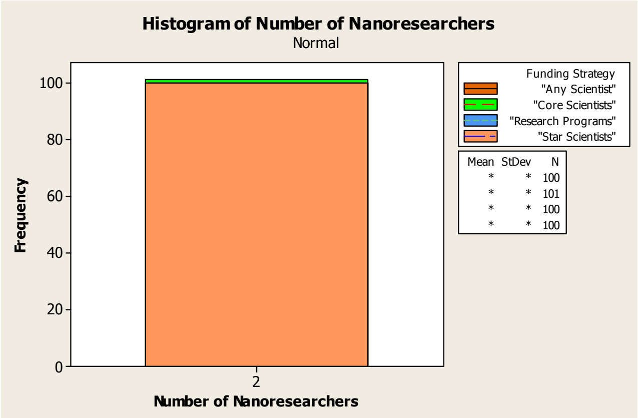


Figure 25: Histogram for the U.S. with Identity Change Value 0.00 Grouped according to Funding Strategies; Groups Compared to Normal Distribution (See Lines); Own Source

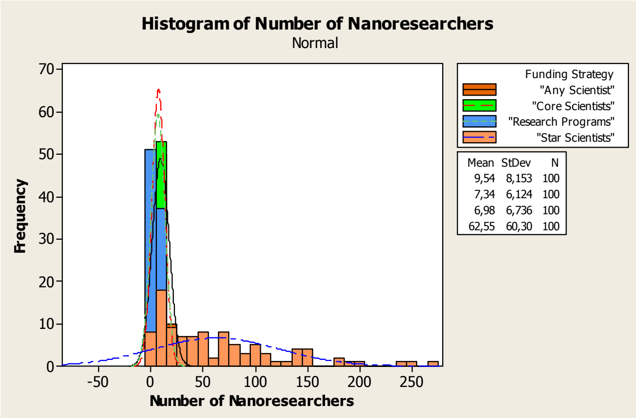


Figure 26: Histogram for the U.S. with Identity Change Value 0.01 Grouped according to Funding Strategies; Groups Compared to Normal Distribution (See Lines); Own Source

6.3.3 On the Influence of Public Funding–Summary and Interpretation of Results

It is checked if the differences in median numbers of nanoresearchers between the four samples are significant or not compared to the funding strategies applied. Finally, the model results must be interpreted. The first check was done with the Kruskal-Wallis test, a one-way analysis of variance. This analysis checks for variances between and within samples. With the Nemenyi test, it is examined which samples differ significantly from each other. Non-parametric tests were used because the ANOVA normality assumption is not given. Table 7 gives an overview of which value constellations yield significantly different results and which do not.

Parameter Values	**Identity Change Values**	
Interdisciplinarity	**0.0**	**0.01**
0		U.S.
1		U.S.

Table 7: Kruskal-Wallis Results for All Parameter Constellations according to Country; Own Source

The result for all the German models is that there were no significant differences in the four sample medians. Therefore, the null-hypothesis that the expected values in the four groups of funding strategies differ is confirmed.

For the U.S., significant results between the four funding strategy samples were given by the Kruskal-Wallis test for the identity change value of 0.01 with both interdisciplinarity values. With an identity change value of 0.01 and an interdisciplinarity value of 0, the results are strongly significant at the 5% and 1% level (see Table 8 below). The strategy ‘star scientists’ yields higher medians of the number of nanoresearchers that are significantly different from the strategies of ‘core scientists,’ ‘any scientist,’ and ‘research programs’ on a 1% significance-level. The strategy ‘research programs’ yields a significantly higher number of nanoresearchers compared to ‘core scientists’ at the 5% significance-level (see Table 8 below). With an interdisciplinarity value of 1, the strategy ‘star scientists’ yields significantly higher numbers of nanoresearchers than all the remaining funding strategies on a 1% significance level given an identity change value of 0.01 (see Table 9 below).

Funding Strategy	-----------------	Any Scientist	Research Programs	Star Scientists
--------------------	**Rank Sums**	16,283	18,727	30,807.5
Core Scientists	14,382.5	1,900.5	4,344.5*	16,425**
Any Scientist	16,283	-----------------	2,444	14,524.5**
Research Programs	18,727	-----------------	-----------------------	12,080.5**

Table 8: Nemenyi Test Results for U.S., Interdisciplinarity Value 0, Identity Change Value 0.01: Rank Sum Differences Given for Funding Strategies; Own Source
Significance-level: * 5% (Critical Value of 4,254.6), ** 1% (Critical Value of 5,202.6)

Funding Strategy	-----------------	Any Scientist	Research Programs	Star Scientists
--------------------	**Rank Sums**	15,773.5	17,862	31,517.5
Core Scientists	15,047	726.5	2,815	16,470.5**
Any Scientist	15,773.5	-----------------	2,088.5	15,744**
Research Programs	17,862	-----------------	-----------------------	13,655.5**

Table 9: Nemenyi Test Results for U.S., Interdisciplinarity Value 1, Identity Change Value 0.01: Rank Sum Differences Given for Funding Strategies; Own Source
Significance-level: * 5% (Critical Value of 4,254.6), ** 1% (Critical Value of 5,202.6)

The identity change value of 0, however, results in very interesting findings compared to Germany: There is a constant output of two nanoresearchers in each run irrespective of the value of interdisciplinarity and a standard deviation of zero and no skewness/kurtosis values available. This forecloses the finding of 1.0 that is given by the Kruskal-Wallis test, meaning that the variance between the four sample values is zero or, in other words, the sample distributions equal each other 100%. This means that if two researchers are funded as a research alliance, a constant output of nanoresearchers on the macro-level is obtained, but only in the bigger academic system of the U.S.. The finding suggests that if there is no openness of researchers to adopt a new disciplinary identity, even the funding of two researchers at a time does not induce dynamic network effects but leads to a stagnant number of nanoresearchers. In sum, the strategy of 'star scientists' still turns out more effective in producing nanoresearchers and yields a significantly higher number of nanoresearchers compared to 'research programs,' as Table 8 and Table 9 show.

The findings from above on the snapshots of single runs for each parameter setting cannot be replicated naturally one-to-one on the aggregated level. Now that the different model settings have been simulated, it is to be noted that there is one noticeable overlap with regards to the observations from the model snapshots: the way of public funding distribution that has great interest in promoting innovative technologies has only fairly limited impact in Germany on the creation and fostering of academic disciplines and scientific communities, although the numbers of nanoresearchers reach a fairly high level, yet not in a stable way. The number always declines near the end of the simulation time.

In the U.S., significantly different medians have been yielded with identity value being 0.01. In addition, the arithmetic means of nanoresearchers are higher than for Germany (two to 71 compared to 11 to 14). Therefore, asymmetrical distributions, indicated in the non-normal distribution of the data and the large number of outliers, in particular but not only for the U.S. results, suggest the hypothesis that funding strategies alone do not significantly influence the number of nanoscientists. Still, in both countries, the makeup of funding policies seem indeed to be able to influence to some degree the diffusion of a high-technology in terms of the number of researchers that adopt the nano-label. Mass effects, to be seen in the U.S. setting, play a role for diffusion. What funding strategies in our model do not support are policy directions that assume a positive linear relationship between public spending and the establishment and/or enlargement of an academic specialty given the non-normal data distribution. As the model is not validated with empirical data, the model rather represents a descriptive, abstract model that shows that influence can take place but not in a linear, causal way with funding incentives being the single instrument to encourage the diffusion of nanotechnology.

Overall, it is to be stated here that the U.S. produce a higher number of nanoresearchers throughout the simulation runs than Germany. This, however, is not surprising due to the larger research systems simulated in the U.S. model. In relative numbers, Germany is not too disadvantaged in spreading nanotechnology when comparing the number of nanoreseachers with the absolute numbers of researchers which is about four times less than the U.S. system. With four times the number of nanoresearchers in Germany, Germany reaches numbers larger than most U.S. output values and close to the maximum value of 71 for the U.S.. This finding from the simulation confirms the observation made on the nanoeducation at universities and thus validates the model that has been created here: In Germany along with a more favorable institutional higher education structure for professional education (Streeck & Thelen, 2001), nanotechnology is established more strongly than in the U.S. in terms of the number of nano-degree programs, just as the number of nanoresearchers in the model is also higher for Germany than for the U.S.. In other words, there is congruence between the empirical observation that Germany is much more 'active' in the creation of nano-degree programs than the U.S. and the simulation result that Germany is more effective in producing higher numbers of nanoresearchers than the U.S.. This then speaks for the realistic setup of the model.

Normality and Network Effects

Before turning to the closing section on the summary and the interpretation of the simulation results presented above, normality and network effects are discussed shortly. In normality tests, non-normal distribution was confirmed for all samples. The fact that these tests gave a p-value of less than 0.010 for all the model samples alludes to network dynamics that are effective in scientific communities. This observation also explains why nanotechnology, in the model being funded just like any other discipline, cannot get 'a hold' in the scientific community. Nanotechnology does not become a stable main discipline within the simulation run time that equals 100 years.

A central role is performed by 'star scientists,' as the results demonstrate. The highly referenced scientists ensure knowledge spread, as in the case of nanoscience and -technology, by being cited by other known or unknown researchers who are in turn influenced in their research by the knowledge they absorb from other 'star scientists.' This endogenous dynamic process reflects the influence scientists have on research in the form of citations and on the research directions that are taken by other scientists. In the model, this behavior is reflected by the probability of change of discipline and specialty resulting from citing scientists of a different 'color.'

Knowledge spread also occurs due to intra- and interorganizational links. The former links are more likely to occur because researchers of one research center rather engage in collaboration first with a scientist from the same research center. The dynamic in the snapshots shows that knowledge, for instance in nanotechnology, in the form of research collaboration spreads within the center and to other centers in quite differing ways. As research centers are limited in size, knowledge spreads in a constant linear way within the center reaching only small numbers of research collaboration. Interorganizational links, however, spread much more dynamically with a steep increase at the beginning reaching higher numbers of research links throughout one simulation run. Therefore, interorganizational links are crucial in spreading knowledge to other centers because this way, research findings have the chance to influence other centers after being absorbed, usually in the form of citations, in other research projects. Naturally, influence is a rather general term here. Research results can be absorbed critically, negatively or positively by other scientists or only mentioned in a footnote. This occurrence, however, has not been taken into consideration here.

One often-mentioned example of non-normal distributions are power-law distributions that are indeed not the only form of distribution found in the model snapshots in this study but that are common in network analyses, as the overview article of Claudio Cioffi-Revilla (2010, p. 262) suggests.

James Moody (2004) detected clustering phenomena in scientific communities and that there is a power-law distribution in social science scientific communities constructed through preferential attachment where "stars will act as 'area authorities' with respect to particular theoretical or empirical claims. … However, competition for status within the discipline will likely revolve around stars who generate new ideas at the intersection of different research specialties" (Moody, 2004). In other words, there is an inequality in returns on research with 'stars' gaining more prestige and being more attractive collaborators than others. In Moody's case, power-law distribution is consistent with preferential attachment (also known as 'Matthew Effect' based on Robert K. Merton (1968)). With the funding strategy of 'star scientists,' i.e., highly cited researchers, the preferential attachment process is implied.

In the present study, however, for the funding strategy of 'star scientists,' the only precondition was the number of reference links. Dimensions of status, such as awards or the amount of acquired third-party funding, are excluded. It is not measured through network analysis if the actual 'star scientists' funded are responsible for connecting the network or not (Moody, 2004, p. 216).

Next to 'star scientists,' the remaining funding strategies are non-normally distributed as well. Therefore, network and mass effects seem persistent over all strategies, not only with 'star scientists'. This supports the conclusion that non-normal distributions also apply to other conditional variables, not only to star networks. Overall, the both high and low values of kurtosis, as to be seen in the descriptive statistics section, underline that non-normal distributions prevail in all model settings, namely leptokurtic and platykurtic distributions respectively (with the former having a higher peak around the mean and fatter tails and the latter having a lower and broader peak around the mean of the distribution). Normal distribution cannot be assumed in these kinds of models and thus prevent using statistical tests that require normal distribution. Whereas for the German model data no pattern can be discerned in their asymmetric distribution, the U.S. data exhibit an exponential distribution of the data (see Figure 23 to Figure 26 in 6.3.2).

Overview of Results

Let us now turn to the summary of the simulation results. Overall, the findings demonstrate that nanotechnology emerges as a specialty, not as a main discipline. Furthermore, network effects in research collaboration are noticeable. Hereby, 'star scientists,' i.e., highly cited and thus prominent researchers, turn out to be crucial in terms of fostering the emergence of a distinctive and a strong specialty at universities. This demonstrates the still important role of Lotka's Law (Lotka, 1926) and, more precisely, of the unequal distribution of citations (de Solla Price, 1965).

Going into more detail, one can note more model-specific observations. With the four funding strategies being taken as independent variables for the outcome of the number of nanoresearchers, we get the following results: The data for the U.S. models result in significant differences in the median numbers of nanoresearchers. These median numbers correlate with, but are not caused by, the four different strategies due to the low variance explanation level of the model that includes relatively few variables. The strategies of 'star scientists' in the model setting with an identity change value of 0.01 and interdisciplinarity values of 0 and 1 turn out to differ significantly from all the remaining strategies on a 1% significance-level. On a 5% significance-level, 'research programs' significantly differs from the number of nanoresearchers of 'core scientists,' yet only with an interdisciplinarity value of 0. For Germany, however, the sample medians are not significantly different in all model settings. The reason for insignificance in the German model is traced back to structural differences with lower number of research centers and researchers in the German higher education and research system.

The U.S. finding suggests that 'star scientists' who are mostly cited are most central and, to degrees, influential in the proliferation of nanotechnology. With regards to the control variables, interdisciplinary cooperation does not influence the outcome. However, a relatively high value of identity change, here 0.01, is needed to obtain significantly different results. The Kruskal-Wallis told us that for Germany, the numbers do not differ significantly from each other in the context of different funding strategies. This result signifies that the way how public funding is distributed in a research network, here in particular by focusing on 'star scientists' and on 'research programs,' is not as influenceable as in the U.S. model setting.

6.4 Discussion and Conclusion

First, it must be remarked that an interpretation of the obtained results must be done very carefully having in mind the limited number of the parameters which are empirically validated from literature and the high degree of abstraction. The presented model is abstract, as it concentrates only on the variables and parameters described above. Still, trends can be extrapolated that ought to be singularly examined more deeply in future research. This future exploration can be done by an extension of the model setting, by simulating the model using empirical data or by the gathering of further realistic parameter values and data. The model setting can be extended by an additional interorganizational level, meaning that the reputation of universities and research centers respectively is simulated as another influential factor for the distribution of federal grants. In addition, scientific success of single researchers, in the form of research cooperation projects or citations, could be accumulated from run to run to account for a coupled dynamic of academic prestige within the network. These researchers then would be able to build on success they achieved in previous rounds. Researchers could also move from center to center to see what happens when, as in reality, researchers change universities and take their networks with them. As this model, however, wanted to examine only relationships between public funding and networks where researchers have different positions in term of citations, research cooperation, disciplines, and relationships, the model was kept simple but realistic to be able to understand more clearly how the interactions within the network take place and which parameters are at work.

In short, the country that produces significantly different medians and higher means in the number of nanoresearchers is the U.S.. How are the chosen parameters related to each other? Interdisciplinarity does not influence the test results in any particular in the chosen parameter settings. Important are the size of a system with its network of researchers and identity change, if interpreted as more or less and existing or non-existing openness respectively. In the present study, only plausible and varying parameter settings have been chosen. The fact that Germany does not provide significant results does not mean that there is a range of identity change values that does not come up with significantly different medians. These findings deserve further scrutiny.

Second, emerging phenomena come into play in the form of those funding strategies that yield significantly different numbers of nanoresearchers. Quite interestingly, the strategy of 'star scientists' and, in just one specific case, 'research programs,' turn out to be most effective. 'Star scientists' is the mechanism for funding those researchers with the maximum of citations. This mechanism only considers the maximum of links irrespective of the number of links. Therefore, it is not important how many citations a researcher receives but if he or she dominates the citation landscape. Mass effects come into play with regards to the 'research programs' strategy since in that strategy several researchers are funded at once and thus become known to each other increasing the probability to adopt the nanolabel. The finding that the 'core scientists' strategy has yielded insignificant results can be interpreted in such a way that reputation in terms of citations indeed appears to be a primary criterion with research cooperation being of secondary importance.

Given that Germany yields insignificant differences in sample medians, what is decisive for significant differences is the fact that the network of researchers is larger in the U.S. in terms of the number of research centers and researchers. The larger size and differing institutional structure of the U.S. research system increases the probability to obtain significant differences in the number of nanoresearchers due to different funding strategies. This means, the effect of different strategies can increase in a non-linear and dynamic way and thus significantly alter the number of nanoresearchers due to network effects. This is underlined by the fact that all data follow a non-normal leptokurtic or platykurtic distribution. Germany's insignificant differences do not mean, however, that there is no model setting that might lead to significantly different sample medians. As the U.S. results imply, network size and the degree of identity change, i.e., openness, play a role when it comes to significant differences.

Third, based on the fact that no causal relationships can be obtained, other variables that are not included in the abstract model presented here would explain more comprehensively the distribution of the data. Ostensibly, the structural conditions at universities must play a role, namely conditions that create differing opportunities for researchers to implement nanotechnology or not. There is a range of other variables that influence the development of the number of nanoresearchers at research institutes and that might not only correlate with but present causes for the obtained number of nanoresearchers. These reasons can be departmental and faculty structures that facilitate nanotechnology or not, laboratory structures, communication networks and interdisciplinary cooperation.

Fourth, in the case of nanotechnology, the structural issue would have to be examined more closely in further research. Hereby, the approach of Blau (1994) seems adequate to address the issue not from a micro-sociological view but from a macro-sociological view: For a change in occupations or other social groups, structural opportunities must be created first that can be filled by individuals according to their probabilistic chances to fill that vacant position. In the networks, too, the bigger a center, the more positions it can offer for nanoscientists. Given the concept of structural opportunities, one might conjecture in the present case that a larger structure in terms of the number of positions produces a higher number of nanoresearchers. This is true, since the U.S. data show higher output values for the mean numbers of nanoresearchers.

Fifth, due to the fact that little variance can be explained by the examined independent variable (limited) to funding strategies, one can conclude for public policy that public funding has limited impact on the creation and fostering of academic disciplines and scientific communities and is, if at all, only correlated with the spread of a high-technology research field. One explanation that is derived from the non-linear distributions in the simulation runs is based on network effects that emerge due to relational positions of researchers. These effects occur because 'star scientists,' 'core scientists' or researchers that either know each other or are spatially near to each other have a higher probability of being cited or being chosen as collaborators. These researchers then obtain a position that is increasingly influential in the make-up of the research network. The effects lead to a dynamic that cannot be explained naturally by public spending or identity change alone and that does not follow a linear distribution (as made evident by the absence of linear relationships between the observed variables). The U.S. yielded significantly different sample medians with an identity value of 0.01. Thus, openness of researchers is central for the spread of nanotechnology and the influence of the way how funding is distributed. What the U.S. government in short can influence in the model is their choice of funding strategy and with that how to produce more nanoresearchers.

Consequently, a range of other variables must be included in future research to give safe and comprehensive answers on the emergence of a research specialty in higher education. Yet, the result complies with another result on the limited influence of government funding, namely in the creation of biotechnology as an industrial sector: there is only very moderate "evidence that governments can orchestrate the construction of science-based industries, such as biotechnology, particularly within coordinated market economies" (Casper, 2009, p. 214), such as Germany is. As made evident in the models, Germany as a CME has indeed more limited means in creating a stable academic nanocommunity than the U.S.. This is contrary to Etzkowitz's finding on Europe and the U.S. that the U.S. government has fewer means of influencing the development of technology (Etzkowitz, 2003, p. 58). Yet, Etzkowitz observed the influence of governments on technology as a whole and did not focus academia. So, there is a hint that the emergence of a field must be looked at from different angles, be it with a focus on academia, industry or society, which underlines the contribution of this study that concentrates on the university sector.

The findings discussed above are confirmed and extended in chapter seven since they raise further questions on the inner life of research networks at the example of nanotechnology. The importance of social contacts, nurtured at conferences and in cooperation alliances, the limited influence of funding on the diffusion of nanotechnology, and the limited influence of funding on identity construction and professionalization will be discussed from multiple perspectives based on interview data. The interviews demonstrate how complex the field of nanotechnology is, even if only the academic sector is focused.

7. Interview Analysis: Nanoresearchers' Meaningful Interactions in German and U.S. University Institutions

In simulation models, meanings of relationships that are the basis for social interactions are not examined, but must be explored separately for a method has only limited means of addressing a particular kind of research questions. Meanings, as several papers elucidate (Fine & Kleinman, 1983; Fuhse, 2009), are the basis and recurrently changing constituting elements, motivations or constraints, of social relationships (Fine & Kleinman, 1983, p. 100). Thus, meanings are crucial for the understanding of social order and corresponding networks with "the social network [being] .. a negotiated, meaningful cognitive resource for interaction" (Fine & Kleinman, 1983, p. 103). After providing a network of researchers in the previous chapter, this chapter turns to the meaningful units of nanoresearchers' work lives at universities.

The previously discussed static 'Model of Intervening Mechanisms' from section 1.2 serves as the starting point for this discussion. The model compares, chronologically, the transition of individuals from education systems to the labor market and specifies the institutional elements of higher education systems and of the labor market. On a synchronic level, the influence of professional associations and the market is included into the analysis of nanotechnology as a field. The intervening mechanisms model focuses on the structural level rather than on the processes and interactions that create the working culture at the individual and organizational level. Furthermore, as education and (academic) employment systems are decisive in the diffusion of innovations, this study is constrained to these two systems but delivers reference points for further research. This means that the view of researchers, professors and Ph.D./doctoral students, are explored to see how nano-S&T were established in higher education with higher education being the link between the education of a workforce and the market as illustrated in the 'Model of Intervening Mechanisms.' Since the static model ignores the interactions and interests of individuals and organizations, these levels in the nanotechnology field ought to be inserted into a more comprehensive analysis of the working culture at universities. Universities therefore represent institutions that incorporate "structure and culture" (Djelic, 2010, p. 29) including rules and beliefs that guide social actions. Institutional rules include institutional factors of LMEs and CMEs as known from the VoC approach, the reproduction of research groups that form an organizational unit of faculties, departments and colleges, departmental structures or professorial autonomy, which is an essential attribute of the roles of PIs. Beliefs are expressed by nanoresearchers in the form of meanings, evaluations, and their notion of nanotechnology.

Both structural and cultural factors enrich the chronological level by encompassing more detailed descriptions and insights into 'work activities.' This way, working cultures in both countries, including the emerging tension among actors but also between actors' interests and institutional or environmental pressures, can be delineated and explained using the 'Model of Intervening Mechanisms.' The result of this tension is a field that emerges due to scientists' and political interests which meet in the academic sector. Thus, the focus is on the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) between the two systems of politics and university and their policies and interests rather than the market and academia. This tension is, on the one hand, solved by the common interest of the promotion of nanotechnology. Even though professionalization in nanotechnology has not taken hold in academe, this process is 'outsourced' to the market economy, since companies have the chance to hire nanotechnologists that were educated in programs dedicated explicitly to nanotechnology. On the other hand, the tension contributes to the construction of the field because it constantly makes actors negotiate the borders of the field and the meaning of nanotechnology. Consequently, the tension keeps the social construction of the field's borders alive. This observation, finally, becomes evident in the interviews.

For now, it has been demonstrated that, on a macro- and structural level, the VoC approach with its distinction between liberal and coordinated market economies cannot properly explain the diffusion, status quo, and progress nanotechnology experiences both in Germany and the U.S.. The categorization of Germany as a CME and the U.S. as an LME does not hold in the case of nanotechnology as both countries are successful competitors. This is why it is assumed in this study that one must leave the structural level and look more closely to the ongoing processes in academia at a meso- and micro-level respectively in order to elaborate similarities and differences. The simulation model shows that differences in funding can be effective, however, only in a very limited way. There is no 1:1-translation of public funding into academic fields and the formation of new specialties: The simulation results hint to the fact that the rise of a new specialty in academe is influenced by a myriad of variables, not only by the prevalence of public third-party money. Although this observation might not be new, this study provides insight into the field from several perspectives. Therefore, to account for this observation, a more detailed perspective is used to look 'inside' the field of nanotechnology in academe by asking how scientists are actually affected in their everyday lives by the rise of a newly funded specialty.

In the following, nanotechnology is thus introduced as an organizational field by looking at nanotechnology in a multi-faceted approach from three different theoretical perspectives: sociological neoinstitutionalism in order to establish characteristics of the academic field of nanotechnology (7.1) and Mode 2 knowledge production to find out about scientists' concepts of policy-related Mode 2 criteria (7.2) on a meso-level, and the theories of professions at the micro-level (7.5). Processes, as Abbott (1988) emphasized in his theory of professions, are at the center, not structures, to find out how knowledge is produced and organized with regards to nano-S&T. All these theories serve as ways of analyzing data gathered in semi-structured interviews with German and U.S. researchers in academia, i.e., with single actors who function as intermediaries between the micro- and macro-level (Koch, 2005, p. 11). Before turning to the issue of professionalization of nanotechnology, the interview findings are compared on a structural and individual level as well (7.3.1 and 7.3.2). The latter sections deliver additional findings on similarities and differences with regards to interdisciplinarity, departmental and personnel structures, the role of PIs, funding and publication patterns of informants, the standing of nanotechnology within the academic disciplinary structure, the applicability, individual life courses, and identity change, individual interests, and PI–student relationships. Sections 7.4 and 7.5 deal with two institutional processes, the creation of scientific communities through identity construction and professionalization. Therefore, these two processes complement the structural analysis of the German and the U.S. higher education systems from section 7.3.

Researchers as Actors of Cultural Change and Identity Construction within Institutions

Privileged positions and their incumbents (in academia professors, research assistants, graduate students) are responsible for change, in particular cultural change (Koch, 2005, p. 22), whereby in this study, the focus lies on institutional change in the field of nanotechnology, change of professions and professional identities. It is assumed that this form of change does not leave untouched the working culture of nanoresearchers. Therefore, it is not only asked for the characteristics of the field, but also for the way the scientific community of nanotechnologists is constructed. To do this, social, historical and cognitive identities, as demonstrated for sociology, are seen as an essential framework for analysis (Lepenies, 1981). These identities become also evident for core technologies. For instance, the field of artificial intelligence has survived as a separate research area despite its complexity and heterogeneity (Koch, 2005, p. 225). Personal contacts, openness and lack of rigidity, eccentrics, and job positions are indicators and incorporations of the respective social and historic identity present in this field (Koch, 2005, p. 225). In the present study, scientific identities developed by looking at professional identities, which are part of scientists' social identities, are combined with historical and cognitive identities (7.4). Processes of institutionalization that help stabilizing a discipline as an organization are delineated next to historical reconstructions of nanotechnology as an innovative core technology as well as field-specific orientations, paradigms, problems and methods. In particular, the cognitive identity of nanoscientists turns out to be problematic due to the lack of a common problem or theory and the cross-disciplinary character of nanotechnology. In this context, it is crucial to differentiate between the production of meanings and identities that occur due to social circumstances, such as through institutionalization, and the production of meanings and identities that come about due to cultural processes. (Koch, 2005, p. 24) In nanotechnology at academia, it becomes evident that the two forms of production, cultural (on the basis of meanings) and social forms (i.e., networks and PI–student relationships), are responsible for the construction of identities, above all professional identities of scientists.

In industrialized, knowledge based nations, science and technology are prevalent social and economically important areas (Wullweber, 2010, p. 232). By taking actor-centered perspectives in relation to social contexts, traditions are elucidated that lead to cultural change within institutions. Cultural change in a broader sense includes the social construction of identities that university actors are involved. In addition, one can see how individuals create these changes through their actions (Koch, 2005, p. 335), but also in expressions of individual concepts and meanings that indicate (hidden) values and norms. By living these values, norms, and systems of meaning that are reified in technical artifacts and brought into social discourses by scientists with more or less power, they function as factors of change in existing cultural systems of meaning and practice (Koch, 2005, p. 336).

As the definition of institutions here is based on John W. Meyer, W. Richard Scott, Paul J. DiMaggio, and Walter W. Powell (Nee, 2005, p. 49) who consider institutions and cultural beliefs as influential factors on human behavior, institutional change also implies cultural change along with the change of beliefs that become manifest in individual voices. From the perspective of social constructivism, these beliefs are expressed in internalized meanings and evaluations that actors express. Actors, at the same time, are also embedded into social contexts that shape actors' (professional) identities. Thus, interviews are most promising in detecting the meanings that actors act upon. The interviews disclose what happens when nanotechnology that is conceived of as a Mode 2 technology, in particular by politics (see Wullweber, 2010, p. 232), meets a predominantly Mode 1 field in the academic sciences. The theoretical concept of Mode 2 knowledge production is extended by looking at 'work activities' which are decoupled from 'formal structures' of institutions, as sociological neoinstitutionalism argues. This extension is promising because a close look at 'work activities' gives insights into the way knowledge is produced, i.e., in which setting of actors' meanings, research groups, and work environment nanotechnology is applied and nurtured. This conceptual extension consequently represents the integration of the concept of 'work activities' as an 'empirical tool' into Mode 2 knowledge production, since this sociological concept allows an empirical analysis of Mode 2. According to the different national contexts, researchers react differently to the imposition of nanotechnology on universities for reasons that are of a different kind in politics than they are in academia.

In short, this study looks at the culturally based meanings, definitions, and evaluations of scientists. It combines them with the institutional setting in which these actors are situated, where they act based upon the evaluations they have, and where they interact with the institutions they find and exert influence upon. The institutions, in turn, provide opportunities for scientists and their actions. In other words, culture, with its meanings and evaluations, interacts with institutions and vice versa, following Martina Merz (2010, p. 17) who advocates a combination of studies on scientific communities with local practices of knowledge production.

The social constructivist perspective is used as a frame for the meanings that are uttered with respect to nanotechnology and professional identities which are responsible for the social construction of the identity of nanotechnology. Yet, it is also used with regards to terms that are prominent in Mode 2 knowledge production and in politics: interdisciplinarity and application are the most central terms that nanoscientists are confronted with and to which they lend meaning. It is these meanings that they act upon which are expressed in the interviews. The next section examines meanings expressed as beliefs and logics, which are used by nanoactors who are responsible for the delineation of nanotechnology as an organizational field on the one hand, but which are also the driving force behind a dreaded destabilization of the field with blurred boundaries on the other. With the Bologna process and other governmental grant policies (NNI or the German Action Plan Nanotechnology) providing favorable opportunities or, more figuratively expressed, a 'valve' for the pressure for change, the delineation of nanotechnology as a field in the academic sector has taken hold. Scientists obtain funding directed to nano-S&T projects, degree programs in nanotechnology are created to produce nanotechnology graduates, and research institutes for nanotechnology are founded. Scientists' and political interests must be balanced and coordinated. The partially differing interests meet, however, in the circumstance that funding nanotechnology entails advantages for political promises of economic growth and international competitiveness and advantages for scientists that are enabled to pursue their research interests by receiving nanotechnology grants (J. W. Meyer & Ramirez, 2009, p. 216; Schaper-Rinkel, 2006, p. 484).

To conclude, the tension produced in the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) between politics and academia creates forces that construct the identity of nanotechnology which is marked by successful institutionalization in both Germany and the U.S., but at the same time by ambiguity and reluctance based on the importance of traditional academic disciplines within the university working culture that slow down the rapid development of nanotechnology to become an autonomous discipline or a visible profession. This might seem contradictory at first glance. This chapter, however, will show how these two strands are to be found in the field of nanotechnology and are not mutually exclusive, but contribute to a unique identity of a specialty that has become a firm part of the present academic working life.

7.1 Nanotechnology as an Organizational Field

This study is about nanotechnology as an organizational field in academia. Fields are socially constructed through the interaction of interests pursued by actors, such as politics. Scientists interact due to the nanotechnology funding policies in the U.S. and Germany. In the U.S., there is a focus on institutes and centers engaged in nanotechnology with the goal to establish a nationwide infrastructure supporting nanotechnology (National Nanotechnology Coordination Office, 2010); in Germany, with a lower governmental nanotechnology budget (VDI Technologiezentrum e.V., 2009), there is an additional implementation of nanotechnology study programs in reaction to the Bologna reform, which provides a favorable condition for change. These rule-based interactions of national higher education structures with state politics of technology funding, which have been simulated using agent-based modeling, imply institutional and innovative mechanisms, such as reproduction or layering (Streeck & Thelen, 2001). In the simulation model, the German and U.S. national organizational fields of nanotechnology at academia and the diffusion of nanotechnology within research centers have been modeled according to certain selected criteria. At the center of the analysis are scientists who are embedded in national research systems with universities combining teaching and research. It is asked how they experience and how they fulfill their role in the organizational setting of nanotechnology in academe. In that respect, this study argues that nanotechnology is an organizational field with specific characteristics when looking at the field from the perspective of scientists including their beliefs, i.e., evaluations and meanings with respect to nanotechnology. These characteristics are the constant negotiation of its borders through evaluative discussions among scientists about the definition of nanotechnology and the recurring but temporary participation of university scientists in the organizational field of nanotechnology by performing several roles that allow the entering of the field but also the 'opting out' of the field.

In the following, it will be shown how nanoscientists view nanotechnology, how they are reluctant to internalize nanotechnology as a self-categorizing element, how social, and in particular in this context, professional identities are built and how the training and reproduction of new scientists fosters the decoupling of 'formal structures' from ongoing research activities in nanotechnology as participating in an organizational field where traditional disciplines dominate. As can be seen, structural and cultural elements matter and are investigated. Whereas structure is focused in the previous chapter on research networks as well as in the following sections 7.3 and 7.5, culture plays a more pivotal role in sections 7.1, 7.2, and 7.4.

7.1.1 Nanotechnology: Definition of Size versus Blurred Meaning?

Several studies (Grodal, 2007; Selin, 2007) have engaged in an institutional analysis of nanotechnology and looked at the emergence of nanotechnology as a high-technology field. What is problematic with the term nanotechnology, as mentioned by Petra Schaper-Rinkel (2010b, pp. 43-44) and confirmed in the interviews, is its breadth and blurred boundary due to the fact that, primarily in politics, merely size (1 to 100 nm) is used to define the boundaries of nanotechnology. Nanotechnology accordingly comprises

> "the total of procedures and processes that deal with the controlled production, analysis and application of structures and materials on the scale between 1 and 100 nanometers. On this scale there are in part drastic changes of properties of materials and components that are used in nanotechnology for a controlled functional optimization of technological components." (VDI Technologiezentrum e.V., 2009, p. 4)

This definition turns out to be a hardly applicable definition for scientists. In research funding organizations, the 'core' notion of nanotechnology is also a scale-based definition of nanotechnology that entails various factors:

> "It starts with the nanoscale, points out that unknown phenomena occur at that scale, and continues that this requires basic research to understand them and/or that the phenomena provide opportunities for innovation. In addition to this core a number of often mentioned aspects can be identified: the bandwidth of the nanoscale, nanotechnology vs microtechnology, nanoscience versus nanotechnology, nanotechnology's interdisciplinary character, top-down versus bottom-up nanotechnology, and the number of spatial dimensions." (van der Most, 2009, p. 66)

Within the NNI, a longer definition is given (National Science Foundation (NSF), 2000) where the scale of nanotechnology depends on the newly found properties. This scale can vary according to the area of research. Coming back to research studies, Grodal (2007) analyzes the emergence of the field of nanotechnology in a comprehensive context by including more types of actors in the field than it is done in this study, which focuses on the academic sector. Grodal also refers to the role of meaning of nanotechnology, pointing to Scott's (2004, p. 58) argument on the importance of meanings for the an organizational field. Thus, no matter if the meaning of nanotechnology is its being a tool, a specialty or sub-discipline, a device or cutting-edge technology, meaning is created and subsequently "socially negotiated" (Grodal, 2007, p. 171) at conferences, when applying for funds or when submitting papers at a nanotechnology journal (or not).

The noticeable social negotiations manifest that nanotechnology is an organizational field. On the individual level, however, the interview partners adopt the "field's label" (Grodal, 2007, p. 171), in a multi-faceted and often contradictory way. What makes the organizational field of nanotechnology so peculiar is that negotiations are still going on due to definitions of nanotechnology that are incongruent. There is no broad consensus as to where nanotechnology starts and where it ends (except for the size of 1 to 100 nm). But even the definition of size is disputed when scientists consider 90 nm too large for nanotechnology. This goes along with the notion of J1who defines 20 to 30 nm as the scale of nanotechnology, rejecting anything bigger than 30 nm to be 'real nanotechnology.' One important factor is that the field of nanotechnology was constituted by politics focusing on the range of 1 to 100 nm, not by scientists themselves (Schaper-Rinkel, 2010b). To scientists who are actors in the field of nanotechnology, this definition is often not transferable to their research, since it is too broad and comprising for research with particles of the size that falls within that range.

The central questions in the semi-structured interviews were the meaning of nanotechnology for the individual's research, the definition of nanotechnology and the question if the interviewees saw themselves as nanotechnologists. In the interviews, all elements of the above-mentioned scale-based definition were alluded to. Yet, although nanoscientists were aware of the 'political' definition of nanotechnology, it also asserted that politically based definitions need further clarification, as not everybody who deals with atoms and molecules of nanometer size considers herself a nanotechnologist. From that perspective, the definition captures important features of nanotechnology: the change of properties and functional optimization. Applicability is another feature, not explicitly mentioned in the interviews but raised as a characteristic of nanotechnology separating nanotechnology from molecule and atomic physics. The fact that in the German nano.DE-Report from 2009 (VDI Technologiezentrum e.V., 2009) the commercial significance of nanotechnology is mentioned brings the applicability of nanotechnology back into focus: "The commercial realization and use of nanotechnological effects and principals for innovative and competitive products represent an important task with regards to the long-term protection of the technological and economic location of Germany" (VDI Technologiezentrum e.V., 2009, p. 5).

Thus, there are undisputed and elaborate definitions of nanotechnology rather in politics than in academe. However, the popular use of nanotechnology and a possible bandwagon effect led to a detached view of nanotechnology. The interviews reveal that nanotechnology cannot be delineated for scientific practice as easily as in politics. In the interviews, it is not technical definitions that are given but notions and meanings of nanotechnology. Individual concepts of nanotechnology must be separated from technical definitions of nanotechnology that turn out to be impractical in researchers' everyday work and were quickly left behind in the interview talks due to their rigidity and impracticability when talking about 'real nanotechnology.'

Interviewees struggled with the question if they call themselves a nanotechnologist or used the label nanotechnology as a way of identification. This is similar to Gertraud Koch's (2005, p. 324) micro-analysis results about artificial intelligence, where protagonists had a detached stance regarding "radical" interpretations of the label of artificial intelligence, i.e., equalizing computer and human intelligence. In the interviews, it became clear that nanotechnology implied vagueness when it comes to self-labeling and socially relevant interpretations about its applicability and significance. This was the case despite the existence of a precise (technical) definition based on scale. This vagueness creates additional 'reputational pressure,' since one's self-presentation in the scientific community influences one's reputation, the acquisition of social capital, i.e., collaboration, and finally, legitimacy. Frank van der Most (2009) explains this phenomenon as follows:

> "Researchers perform boundary work: they outline a particular field of research and attribute characteristics to it, in order to mobilize resources for the field, which they then will be able to profit from since the definition favors what they want to do themselves. This is a general strategy, also visible in the struggle for industry standards in a sector of industry. The variety of local and national resource contexts thus feeds the variety of definitions of nanotechnology, and makes it difficult for a shared and authoritative definition to emerge." (p. 176)

Thus, despite precise political definitions of nanotechnology and the ability to acquire resources for nanoresearch, ambiguity arises in the practical work of nanotechnologists maybe concisely because of doing "boundary work" (van der Most, 2009, p. 176). The term spreads and is widely used so that the niche in which nanotechnologists perform research becomes permeated by popular conceptions. There is a danger and fear that researchers 'jump on the nanotruck' without actually doing nanotechnology and so inflate the use of the term.

In sum, what the present study looks at is the academic side of the nanotechnology field within the context of public funding. Several factors speak for an existing field of nanotechnology in academia, such as conferences, nanotechnology journals, nanotechnology degree programs, in particular in Germany, and nanoinstitutes. Further, the fact that nanotechnology has a fixed place on national funding agendas makes researchers react and embrace the nanolabel, at least in terms of acquiring third-party funding. By this embracement, the field of nanotechnology is made "vulnerable to external interventions" (Granqvist & Laurila, 2011, p. 275), such as from politics, since the 'stories' attached to nanotechnology continue to exist and impede uncontested delineations of nanotechnology. The emphasis in this study is on funding sources and institutional change at universities due to the necessity of acquiring third-party funding for research from the state and industry. The focus is on the state and the influence of government initiatives, such as the U.S. NNI or the 'Nano-Action Plan' and the Bologna process in Germany. Hereby, institutional change has become part of researchers' everyday work lives. In a nutshell, this change comprises, theoretically expressed, the inner life of organizations that reveals mechanisms of innovations in the tradition of historical institutionalism and decoupling of 'formal structures' from 'work activities' and organizational practices.

7.1.2 Notions and Evaluations of Nanotechnology from Scientists

Drawing on the belief-based creation of meaning and the nanotechnology definition based on scale, the interviews indeed addressed several concepts of nanotechnology. For researchers in academia, the interviews showed, nanotechnology represented a range of meanings, independent of their specific research field: nanotechnology was a tool and device for F1, G2, A3, and D1. In addition, nanotechnology was understood as nanoparticles that were indispensable in fostering issues, such as energy, environment, and drug therapy or general biological processes for G1, A1, A2, C1, and H1. Contradictory notions arose when some interviewees talked about the breadth and depth of nanotechnology. To some, nanotechnology was too broad (B1, F2, C1, G2, A1, and H1). To others, it was too specific (C3 and A3); and to some even both at a time (C1, F2, and G1).

Informants most often gave a narrow definition of nanotechnology compared to the political one. For interview partners such as F1 and G2 who looked at nanotechnology mainly as a tool or a device, nanotechnology was not a field, let alone an organizational field. To them, nanotechnology was used when appropriate for research interests. Another interview partner, C1, avoided the word nanotechnology and preferred nanoscience because "nanotechnology doesn't really have a market or a field" (Interview C1, p. 7). Nanotechnology then would always be part of another higher-level technology or research topic, such as biotechnology. This reveals that there is a divide between basic research scientists and applied research scientists who might also cooperate with industry. Yet, there is also a gap between basic research scientists and politics, as the latter believes in an existing or at least future nanotechnology market (Hullmann, 2007, p. 741).

To G1 who was involved in drug therapy, i.e., a rather application-oriented field, nanotechnology was a tool. As a tool, it was applicable for the creation of a broad range of structures. With nanotechnology being solely an "approach," she suggested a rare and cautious use of the term:

> "I think we should be sparing in … thinking about how we use that word. Because it really is an approach that one can take and a platform that one can use to create structures that have unique properties. But it doesn't make you a micro-technologist or a macro-technologist. I think [a nanotechnologist] is somebody who's developing technologies that can be used for a whole range of things." (Interview G1, p. 9)

G1 referred to the technology aspect of nanotechnology. According to her, somebody who develops new technologies for any imaginable field of application might be a nanotechnologist but not someone who merely creates structures without new qualities. On the other hand, G1 described nanotechnology as too narrow when it comes to her self-categorization. She pointed to the problem of using size as a definition:

> "I would call myself .. first a bio-engineer that works in nanotechnology. I think nanotechnology is a little too narrow in that we are interested fundamentally in how structures affect biological processes and they happen to be that size-scale, but they also are larger and smaller." (Interview G1, p. 5)

F2 described the breadth of nanotechnology by comparing it to MEMS as follows:

> "Nanotechnology is a fairly broad term. It can encompass many scientific fields, or it can focus solely in one. For me however, it simply means working with devices or processes that fundamentally measure or produce nanoscale objects. This definition covers areas like nanocoatings (chemistry), transistor development (electrical engineering), lipid design (biology), polymer development (chemical engineering), etc. My experience however, has been in Micro Electrical Mechanical Systems (MEMS), usually developing actuators or sensors. Most of these had the goal of either manipulating nanoscale objects or measuring them." (Email Communication F2, Oct 30, 2009)

What is more, C1 like G1 and F2 mentioned both concepts of breadth and depth and applied them to nanotechnology, thus revealing an inner contradiction of their own evaluation of nanotechnology. This indicates a personally and 'socially negotiated' process (Grodal, 2007) that was in progress. Interviewees were still undecided if nanotechnology was either a broad or a very specific technology that comprised a large or, respectively, small community. Thus, discussions in the form of social negotiations still take place between nanoscientists with regards to the definition and meanings of nanotechnology. These discussions make the adoption of the nanolabel as a self-categorization unattractive due to its uncertainty. Within the nanocommunity, as the interviews reveal, there were for instance differing definitions that contended the nanoscale. As previously mentioned, to J1, for instance, molecules of the size close to 100 nm were too big for him to be considered nanotechnology.

With regards to occupational identities in the field of nanotechnology, scientists referred to traditional academic disciplines or undisputed, renowned specialties, such as bio-engineering and materials science. The latter naturally can also be fairly broad. Yet, the term materials science does not carry as many ambiguous notions and visions with it as nanotechnology does. On the whole, all interviewees except for B3 refused labeling themselves as nanotechnologists. B3 stated,

> "When someone asks me what I do, I say I work in nanotechnology, science with nanomaterials. … I use microscopes (both optical and electron microscopes) and other techniques to actually 'see' [emphasis in the original] what I'm doing. … I'm not specifically a metallurgist; I'm not specifically a ceramist. Even though I do work with metals and I do work with ceramics; I'm a nanotechnologist first." (Interview B3, p. 6)

B3 therefore represented one exception of all informants by pointing to the technology-aspect of nanotechnology, not to content or materials that he worked with. All the others were reluctant to see themselves as nanotechnologists, precisely because of the cross-technological, i.e., general-purpose, character of nanotechnology that hinders the demarcation of a field according to (disciplinary) content and topics. Cross-technology means "general-purpose technology" (Shapira & Youtie, 2008, p. 187) that allows the participation of scientific disciplines in nanotechnology. This makes a focus on the academic sector relevant for analysis: as a "general-purpose technology" (Shapira & Youtie, 2008, p. 187), nanotechnology can be used in the traditional scientific disciplines of physics, chemistry, materials sciences, and engineering. Its openness further complicates a precise demarcation of the field. G2, for instance, did not feel knowledgeable enough because in her studies the technology part was not stressed:

> "[N]anotechnology is such a wide field. I do have chemistry and physics backgrounds in straight up nanotechnology ... But I would not feel in any way qualified to work on a job where I was … modeling nanomaterials or something. Because that's not what I've been trained to do. So in some cases, I would have to parse through it." (Interview G2, p. 13)

Adding another aspect to the reasons for scientists' cautious attitude toward the nanolabel, A3 promoted the idea that, as a cross-technology, nanotechnology cannot be confined to only one field of application, discipline or content and thus makes identification with it problematic. A3 subsequently described his identity the following way:

> "I'm a chemist. I consider myself a chemist … because there's no use restricting yourself. That's one of the reasons I came here right after Amherst, because it's a polymer Ph.D. I wanted to do chemistry. … [T]echnically, I'm [at the] atom scale, because proteins are a tenth to the minus—they're really small. So it doesn't matter size, it matters what you do. So I don't make genetic nanoparticles …, but I can make nanoparticles that I try to find out the ability for. Because if you limit yourself [to calling yourself a nanotechnologist] at this point, then it can be really dangerous. …Closing your mind off to other ideas. I like working with the interfaces of technology. I do chemistry and biology, so I get to see different ideas and methodologies and new ways that they think. So I use nanotechnology, but I wouldn't say that I only do nanotechnology." (Interview A3, p. 8)

The meaning of breadth certainly comes from the integrative character and the combination of several disciplines that apply nanotechnology. The meaning of specificity comes from the notion that nanotechnology is one technology among others and that it can be detrimental for a researcher's reputation if one calls herself a nanotechnologist.

Nanotechnology as Hype

In addition, nanotechnology was evaluated as a current hype or buzzword (e.g. by B1, C1, C2, C3, F2, G1), i.e., not as a socially acceptable marker of professional identity. G1 like many other interviewees saw nanotechnology as hype and referred to the danger of inflation when it comes to the use of the term:

> "[It makes a difference] if you're just creating a nanoparticle for the sake of creating it versus you've really figured out some unique functionality of that nanostructure that cannot be achieved in any other way, or some properties of the actual structure are able to exhibit that can make an impact. I think when it first came out, anybody that could create a nanostructure would just get funded. I think we're realizing it's not enough to create one, but we're thinking about: what is it that this is really going to do and addressing anything important. … And it's really what we're doing. If I can say that it is the nanostructure that imparts this unique function, then I'm fine with using that [the term nanotechnology; author's note]. But you know, if I hear [about] another novel nanostructure or the fabrication of another nanostructure, I think, 'so what?' unless it really has some unique function." (Interview G1, p. 9)

F2 also regarded nanotechnology as a buzzword:

> "[T]he concept with that is that nanotechnology is the buzz-word. Society … always runs on buzz words. So, generally, when I refer to nanotechnology, I am specifically stating that this is technology; .. this is anything that is manufactured for specific purposes and is nanometers in size." (Interview F2, p. 12)

With regards to disciplinary differences, some variation can be detected. Nanotechnology definitions based on size are more complicated for chemists who have always been working at the molecular scale which often overlaps with the nanometer scale. For engineers (see B3), by contrast, it is easier to cope with a nanotechnology definition based on size or based on its character as a tool (see e.g. G1), since they link nanotechnology to the ability to visualize atoms on the nanoscale, which became possible with the scanning tunneling microscope.

The evident ambiguity of notions of nanotechnology alludes to John L. Campbell's conclusion about the complexity of institutions: the "meaning of an institution is always open to interpretation" (Campbell, 2010, p. 105). This is what happened in the interviews: Informants were asked about their interpretation of nanotechnology as well as its meaning for universities and their own research. These interpretations might change in interactions between policymakers and then reflected in the interpretations researchers give. However, due to the complexity of interests and interactions, policy interpretations are not translatable one to one to university researchers. Interpretations of politicians, coordinators, and researchers diverge: Coordinators or political representatives, such as the one from the Association of German Engineers interviewed for this study, saw nanotechnology as a factor of economic growth and a motor for job creation which individuals have to be trained for. Researchers, on the other hand, acknowledged the importance of nanotechnology, its potential for basic research, and its promise of applicability. Researchers did not, however, recognize nanotechnology as a category that dominates or even replaces disciplines for the sake of research progress.

With regards to the observable institutional change in nanotechnology, researchers carried on and did not impede the institutionalization of nano-related degree programs and research centers, as the institutionalization also served their own interests. With institutionalization, public funding became available that could be used for research. Nevertheless, scientists distanced themselves from nanotechnology quite decidedly. Their professional identities were more securely based on the legitimacy of renowned disciplines than in the uncertainty of nanotechnology (Selin, 2007, p. 213).

The technical definition of nanotechnology, grounded on scale and supported by politics, was the source of the controversial discussion among scientists. This discussion is still going on because academia is organized around theories, fields of application, disciplines, and schools, not around technologies and tools. Hereby, scientists are encouraged in using the term nanotechnology "sparing[ly]," as G1 (Interview G1, p. 9) remarked, in order not to succumb to the nanotechnology 'hype.'

On the other hand, the lack of a concise definition of nanotechnology might not be as harmful to nanoscientists as one might suspect. Scientists certainly profit from a broad conception of nanotechnology insofar as breadth eases the attainment of public funding that is available due to the perceived attractiveness of nanotechnology in politics. This favorable notion in politics enlarges the opportunities of funding and suggests an alternative interpretation of the statements above: the broader the definition, the more attractive nanotechnology is as a possible channel for public funding. The selective use of new funding channels also secures one's position in the case that a funding channel is redirected to other topics. Then, scientists can easily give up the 'nanolabel' they attached to their research when applying for funds and can tap into other funding opportunities. This strategic maxim of action clearly demonstrates the blurred boundary of the field of nanotechnology from where scientists can switch to other fields, disciplines, specialties or funding channels and, possibly, back.

Self-categorization represented a crucial theme in the interviews. In the study's context, ingroup-outgroup categorizations based on social similarities and differences between humans were prominent: physicists, chemists, or materials scientists versus other disciplinary groups or, nanotechnologists versus discipline-based categorizations. Normative influence is central here because this form of social influence on self-categorization implies the rewards and lower costs that are implied in a social categorization, here, in disciplinary categorizations versus nanotechnology-based categorizations. Naturally, as social identities are linked to the evaluative frame of a social group, members were motivated to evaluate their group (physicists, chemists, etc.) positively as opposed to nanotechnologists for instance. The attractiveness of a member depends on "their perceived prototypicality in comparison with other ingroup members" (Turner et al., 1987, p. 60). This circumstance even increases individuals' motivation toward positive evaluations of their own social groups.

Consequently, if the frame of reference changed and nanotechnology was integrated into the main frame of reference, then, nanotechnology would experience more positive evaluations. A nanotechnology group would emerge if individuals form and internalize self-defining social categorizations with regards to nanotechnology whereby identification or attraction of a corresponding frame of reference are needed. Thus, either members start to identify with nanotechnology or the nanotechnology label becomes more attractive. In particular the latter seems to fit nanotechnology for now at least for politicians, less for scientists though. An ingroup-outgroup categorization becomes salient in case of accessibility and fit between perceptions ("input" (Turner et al., 1987, p. 127)) and ("stored" (Turner et al., 1987, p. 127)) categorizations. 'Accessibility' is dependent on "recency and activation" or "emotional or value significance" (Turner et al., 1987, p. 129) whereas 'fit' is dependent on the perceived degree of differences and similarities in a given situation. In the context of this study, one can infer that, given the situation with a social scientist as the interviewer, the nanotechnology category was not seen as appropriate ('fit') for the interviewee and his or her work or, alternatively, the nanotechnology category was not available as a social category or seen as a valuable category for describing one's social identity and self-concept ('accessibility') in an academic context. (Turner et al., 1987, pp. 14, 27, 29, 35, 45, 54, 76, 129-131)

7.1.3 Collective Actors: Nanotechnology Institutes

Despite the vagueness of the definition of a nanotechnologist and the reluctance to define oneself as a nanotechnologist, there are, in academia, "collective actors who try to produce a system of domination in that space" (Fligstein, 2001, p. 15). Collective actors in nanotechnology are represented by interviewees and nanotechnology institutes. These institutes, with the support of politics, are highly visible in the institutional landscape and are supposedly aimed at dominating this field with regards to technological progress and reputation, also on an international level. D1 for instance compares the nanotechnology facility he coordinated to countries like Russia or Germany and pointed out the early development of a well-connected network of nanotechnology institutes, the NNIN. As we speak of an organizational field, we need to keep in mind that we look at nanotechnology in the context of several organizations and single nanoscientists, not at merely one organization that is dedicated to nanotechnology. One must draw a line between single researchers doing nanotechnology and using it as a tool and centers that promote nanoscience and nanotechnology. Nanotechnology centers are widely spread, in particular university centers funded by the government and/or third-parties, such as companies. These centers are crucial for the emergence of the field of nanotechnology because they create roles and positions that are adopted by professors, senior researchers, and coordinators in the name of nanotechnology. The fact that their actions were decoupled from these nanoinstitutes will be another story.

Subsequently, informants from nanocenters were recruited. These were the Nanotechnology Research Center at Georgia Institute of Technology and the Center for Nanotechnology Education and Utilization at Pennsylvania State University, both being institutions exclusively dedicated to nanotechnology. Talking to coordinators from these centers, it became clear that these representatives had a much clearer self-understanding of nanotechnology. They saw nanotechnology as 'a given,' an undoubted high-technology that must be fostered to stay competitive with other countries, to promote progress in areas, such as solid state physics or the environment, to enable companies to do nanoresearch, such as at Georgia Institute of Technology, or to institutionalize nanotechnology by offering courses at the associate degree level like at Penn State University. B1, who worked at the Nanotechnology Research Center at Georgia Institute of Technology, described his tasks as follows:

> "I graduated from here with my Ph.D. in 1996. I went to work with [a large computer company] and I stayed there 8 years. And I came back here in 2004. .. [M]y duties since then have been to recruit external users, whether they be [sic] from companies or other universities. Now, the reason they hired me to do that is that our NSF project, this NNIN project, is to recruit external users. So they basically wanted me to do that. So when I started, we had about 18 external users total. And now we are up to an annual user level of about 250 or so. … That's a lot for us considering our staff. Because external users require a lot of staff time. They need a lot of training. And sometimes we do a lot of work for them. So my job up to this point has been to recruit them, get them into the clean room, get them using the facility and work out projects with them, work out contracts with them, do the billing—make sure that they pay us, and then do all the reporting back to the NSF." (Interview B1, p. 3)

B2, who worked at the same institute as B1, delineated his responsibilities as follows:

> "I wear many hats here. I was hired really to do one thing … at the time that I was hired, about 2 ½ years ago, we had just recently joined a few years before the NNIN. So we joined NNIN in 2004. I started here in 2007. And part of NNIN's mandate, and this became really the mandate of our director, … is to increase the number of external users of the facility, .. external meaning non-Georgia Tech. So as part of NNIN, we open up our doors not only to Georgia Tech folks, but anybody that wants to come in and use the facilities. They just have to pay; we train them, we work with them to–and this is anybody from small colleges but also larger universities that don't have the equipment that we do, and also particular companies that don't have the facilities. … So at the time that I joined, that was what I was hired to do, .. basically bring in those outside people, … do marketing and sales, which is what I did and still do. At the same time, I was also hired for my expertise in working with biological material because … as part of NNIN, we are the lead institution for, I guess they call it biomedical and life sciences research. Really, it's the nanotechnology. And they knew this building was going up, and there was a strong component going in that was towards biomedical and life sciences, so they wanted people on staff." (Interview B2, pp. 2-3)

As one can see from the statements, nanoinstitutes do create new roles and positions. Both coordinators were committed to "bringing in .. outside people" (Interview B2, p. 2) and to promote the NNIN with its mission to "increase the number of external users of the facility" (Interview B2, p. 2). Both interviewees did not mention any doubt about the efficiency and usefulness of fostering nanotechnology. It was their strong attachment to the NNIN initiative and their job mandate that they did not question that nanotechnology institutes would be necessary in the future. Both informants had an academic background. They had Ph.Ds. in the natural sciences. This helped because NNIN institutes usually have a topical focus (Interview B2, pp. 2-3). M2 from CeNTech in Germany expressed enthusiasm about nanotechnology and its advantages, above all in terms of funding opportunities:

> "[As an analytical chemist I started my new position as Chief Scientific Officer [CSO] at the CeNTech GmbH in 2007,] being a 'nanotechnology-neutral' scientist without any experience in the nanosciences. In my new position, not the promotion of nanotechnology as such but rather the support and further development of Münster's innovative CeNTech structure was my main general objective when I accepted the responsibility of the new job. To decide whether I was able to master the challenge of the CSO position at CeNTech, I needed deeper insight into and a broader overview of nanotechnology in general. Very soon I noted that nanotechnology was a very interesting and highly promising .. field that really attracted me and opened great opportunities. Many different forces promote nanotechnology, and I understood that it was really great to be a part of this important and fast growing sector. Many sources of financial support for research, technology, and its transfer to industry make this .. field very attractive." (Interview M2, p. 5)

M2 emphasized the coordination and economic aspect of nanotechnology that he liked. In contrast to B1 and B2, M2 stressed policy involvement and the promotion of technology transfer, i.e., applicability, in nanotechnology where basic research had been prevailing at the time. He stated that central policy actors and networks must be actively coordinated for nanotechnology to be successful:

> "When I started, CeNTech participated in several EU-funded projects. One was called 'Nano2Life,' the first European Network of Excellence in nanobiotechnology. Another one was the 'Frontiers' project,

> also a European Network of Excellence bringing together European top organizations in nanotechnology research … Soon I was asked to participate in another approach for a new project within the European INTERREG IVc program. The CeNTech GmbH team succeeded in setting up an interregional project called 'nano4m' [nanotechnology for market] in which I still represent CeNTech with its modern transfer-stimulating research and technology center concept. Parts of this concept actually .. serve as a model for new similar structures that are planned in Asturias and Tuscany. At the European level four different regions, namely North-Rhine Westphalia, Tuscany, Asturias and Lorraine, are involved in the nano4m project. … We think about how his gap between science, scientific basic research, and … a … real economic product, … how this gap can be closed in nanotechnology." (Interview M2, pp. 2-3)

These centers are active in acquiring industry and public funding via collaboration projects. They sustain the organizational visibility of nanotechnology in public, at conferences or when cooperating with industry like the industry advisory board of Penn State University. Thus, even though for researchers nanotechnology was invisible as a dominating work principle because it was 'merely' seen as a device or hype, there are institutions showing that nanotechnology is a visible organizational field. These institutes and centers are designated with the nanolabel due to governmental support and thus legitimize these organizations as supposedly efficient 'formal structures.'

Therefore, one might speak of a bifurcation in the emergence of nanotechnology as an organizational field. To one group, it was subsumed under traditional academic disciplines, such as chemistry, engineering, materials sciences, and physics. To another group, it was a high-technology that promised to be fruitful for solutions in realms like energy, drug delivery, and transistors. This subsumption enables researchers to handle the legitimacy of research institutes that are dedicated to nanotechnology because the founding of institutes, attached to universities, 'outsources' the institutionalization of nanotechnology formally and does not force scientists to identify with the nanotechnology label.

Social relations consisted of cooperative relations in doctoral projects, as in the case of A2 and A3 who collaborated with the chemical and environmental engineering department and professors from Rutgers University and Duquesne University respectively. This was ensured by a local culture of cooperation, application-oriented research, i.e., doing basic research but usually with a possible application in mind, and a PI approach. The latter means that a professor is a supervisor of several Ph.D. projects and functions as a mentor and enabler of projects. Hierarchies were rather flat with regards to direct–usually weekly–interactions between PI and graduate student without any intermediaries between professor and student. However, if one considers the distribution of (administrative and teaching) tasks and the generation of new ideas and research lines, it becomes evident in the interviews that the professor has a powerful position within university structures. He or she does not only write proposals to acquire third-party funds, but also determines the direction of research and delegates research projects to graduate students (see also Jansen et al., 2010, pp. 58-59). In addition, he or she is responsible for recruiting graduate students and assistants. So, professors are responsible for the reputation of their research group and, with that, of the whole university:

> "[Doctoral students] normally apply … [We] have two ways to support financially their Ph.D. One is just on the basis of grants. In this case I interview the students personally. So they come to Münster and give a talk in front of the group, and we ask questions. .. I really interview them. And the second way is to recruit Ph.D. students through the graduate school. .. Also the graduate school is based on a system with interviews. So, all the students essentially are evaluated before they enter. And, this is very important for me. I would not hire a person without seeing him or her. .. [M]y group is great. .. I would like to keep this very nice atmosphere. .. I would not hire without knowing what type of personality the new member has." (Interview M1, p. 4)

Mechanisms of Innovation and their Role in Institutional Change

The bifurcation between nanotechnology as a high-technology and integrated into disciplinary structures entails institutional change that occurs due to governmental reforms and initiatives, i.e., exogenous key events. Having in mind that "actors actually determine what institutional changes to make" (Campbell, 2010, p. 92), universities in Germany and the U.S. decided for "translation" (Campbell, 2010, pp. 98-99) and "layering" (Streeck & Thelen, 2001). Bachelor/master programs were fused into, i.e., 'blended into' or 'layered onto' the existing organizational structure of universities, thus ensuring growth. Differential growth, the mechanism for layering, becomes manifest in the institutional change of the nanotechnology and university landscape: both German and U.S. universities change through new institutes and centers or chairs and study programs that are 'layered onto' or 'blended into' existing universities. However, the mere attachment of new institutional elements also reveals implicitly that they can possibly be removed again, if they become disused. These mechanisms can be quite fragile in terms of enduring change, especially if federal grants are channeled into other areas of research.

To give examples for the mechanisms of "layering" (Streeck & Thelen, 2001) and "translation" (Campbell, 2010, pp. 98-99), one can note: the number of degree programs in Germany has grown fast due to the attachment of new programs (master and bachelor studies in the verge of the Bologna process) and graduate colleges to existing universities. With respect to national size, Germany provides comparatively more programs, in particular at the bachelor level (Nanowerk, 2010b). Old diploma programs have been altered and remodeled into bachelor and master programs. In the U.S., in particular the creation of associate degrees has been accelerated lately (see an overview in Bradley, 2011).

Further change occurs when these bachelor and master programs are reinterpreted by professors who see them as an opportunity to recruit new students and insert new topics into degree programs. Therefore, the intention of politics to introduce uniform degrees for the creation of a unified European Higher Education Area as well as the goal to promote employability and internationalization are reinterpreted and given a new purpose. Recruiting students, to sustain the main disciplines of physics or engineering for instance, has become a new purpose:

> "[The newly created nanoprograms] have clearly evolved out of the physics degree program. … In the 1990s there was a decrease with regards to the number of applicants in physics. And so [universities] thought about how to make it more attractive and have created a separate degree program quite early." (Interview K1, p. 1)

This result does not imply that research identities are affected. Rather, the introduction of new programs is seen as a function for student recruitment along disciplinary lines. Students were needed in physics, not in nanotechnology. Nanotechnology solely provided an opportunity to make physics more attractive to students. If the establishment of nanotechnology programs does not influence researchers' identities, then, the dominant strategy of U.S. universities to immerse nanotechnology skills into existing programs is not expected to affect identities either. D1, who was convinced that nanotechnology would not become a separate college program, lists several reasons, including reasons of efficiency and viability, supporting the immersion of nanotechnology into existing programs. Here again, the cross-technological character comes into play: nanotechnology as a comprehensive technology combines scientific disciplines without dissolving them:

> "Here in Pennsylvania, we have schools that are offering a degree in physics with a concentration in nanotechnology … or a degree in chemistry with a concentration in nanotechnology, as well as many other science and technology options. We enable this cross-disciplinary diversity to occur. … I think, [nanotechnology] will always be subsumed in other programs because it's so pervasive and … concentrations are a very good idea. … Although I know some universities, I know some in Germany for example, are creating four-year degrees in nanotechnology …, I personally don't think that's the right way

> to go. ... I think this way for several reasons. …I think that the fundamentals don't change; it's just that you bring them all together in nanotechnology. … And the second reason … is that [immersion] helps us to keep the old courses ... I think economically it's viable. I don't think we can afford to have a whole series of new courses." (Interview D1, pp. 2-3)

Reinterpretation of national technology policy has also occurred. Economic growth and international competitiveness, which form central pillars of the German high tech strategy and the U.S. science and technology policy, are reinterpreted by scientists as opportunities for the acquisition of third-party funding. The strategic use of higher education policy, i.e., the orientation toward peer-reviewers in research proposals, in order to obtain funding is made explicit by J1:

> "It takes time to build the entire [university] infrastructure, but then, the Excellence Initiative of the German government came. .. [W]e got the excellence cluster in the second run, called Engineering of Advanced Materials where for instance nanoelectronics play a leading role. Or, alternative electronics where nanoparticular systems are an issue. This is the second pillar that I work on. [The 'Excellence Initiative' was used as a strategy to use nano.] … [Participation in this initiative] was consciously decided for reasons of strategy and was welcomed by peer-reviewers." (Interview J1, p. 5)

To conclude, creating new programs helps to support professorial interests, not only institutional and political interests. This shows that institutional change has been nurtured by the Bologna process in Germany. In the U.S. with the NNIN or the NNI, new centers on nanotechnology have been installed at university locations and attached to existing buildings, such as at Penn State University, or old institutes are restructured and entitled nanoinstitutes, such as at Georgia Institute of Technology.

In short, the U.S. university structure has changed as well due to the increasing support of nanotechnology by public funding agencies, however, in a different way than German universities have changed. The institutionalization of nanotechnology is naturally the result of a contingent process. Nanotechnology could have been integrated into universities in ways other than the creation of new institutes and programs. Therefore, the visible institutionalization of nanotechnology has signaling effects for other high-technology fields or academic research areas. The institutional facts or "powerful myths" (J. W. Meyer & Rowan, 1977, p. 340) with regards to nanotechnology specify one powerful form of incorporating a high-technology into research and teaching.

7.1.4 The Constitution of the Field: Reproduction of New Generations of Scientists and Professional Identities

The relationship between PIs and graduate students brings up the issue of recruiting students as a mechanism of reproduction of new generations of scientists and, along with it, the development of disciplinary-based professional identities. In Germany, master's programs have been founded deliberately to recruit students facing decreasing applicants. Thus, the Bologna reform has provided opportunities to attract more students. This also holds true for the doctoral level. The mechanism of reproduction of new generations of scientists becomes a structural mechanism to reproduce nanotechnology, namely when degree programs are created with which the nanolabel is attached. Then, nanoscientists and nanotechnologists are automatically reproduced due to credentials that either contain a specialization in nanotechnology as many U.S. credentials do or that entitle graduates as nanotechnologists, such as when graduating from a German degree program. Once graduates have a 'nanocredential,' they join the field of nanotechnology and promote their studies because otherwise, it would be difficult for them to advance their careers. These graduates naturally will not only have an impact on the academic sector but also on the economic sector, as N1 from the VDI emphasized when pointing to the goal of creating nanodegrees.

In terms of the generally recruiting graduate students, a number of professors pointed out that they either actively asked students if they would like to join their research group or the professors were asked by students interested in their research topics, such as polymer chemistry (A1), semiconductors (P1), photonics (M1, P1) or solar cells (O1). This recruiting procedure points to an informal rule that is systematically pursued in the reproduction of research groups. Formally, doctoral or Ph.D. students are attached to research groups by contracts or scholarships. With students' interest in the research topic of PIs and the decision to join a research group, working with that PI highly influenced the self-conception of graduate students. This revealed the centrality of researchers in recruiting future scientists and workforce and marking the students' self-description.

Institutional change may occur due to governmental reforms and initiatives, i.e., exogenous key events, but it is a "complex research process that follows whereby actors actually determine what institutional changes to make, if any" (Campbell, 2010, p. 92). In Germany and the U.S., universities decided for 'translation,' i.e., the "blending of new elements into already existing institutional arrangements" (Campbell, 2010, pp. 98-99) with the formation of master programs in addition or 'layered' onto the existing organizational structure of universities. Layering and translation thus led to gradual institutional change: "institutions change when new institutional layers are grafted on to existing institutions" (Campbell, 2010, p. 100). Layering and conversion constitute two institutional types of gradual transformation. 'Layering' implies the attachment of new elements to existing institutions, which leads to gradual change of their status and structure (Streeck & Thelen, 2001). 'Conversion,' on the other hand, is defined as the "redeployment of old institutions to new purposes" or the attachment of new purposes to old structures (Streeck & Thelen, 2001, p. 31). The mechanism of layering is differential growth; the mechanism of conversion is redirection and reinterpretation (Streeck & Thelen, 2001, p. 31).

This institutional change through Bologna sustained the influential position of German PIs with regards to the organization of their research groups or the replacement of the hierarchical, disciplinary and departmental structuration of universities. Several PIs asserted that personal interviews in the case of unacquainted external applicants were indispensable because not only qualifications were deemed important, but also the 'personal and social fit' with the PI's research group due to the comparatively small research groups (usually 10 to 20) that interact daily in laboratories and offices:

> "[Doctoral students] normally apply … [We] have two ways to support financially their Ph.D. One is just on the basis of grants. In this case I interview the students personally. So they come to Münster and give a talk in front of the group, and we ask questions. .. I really interview them. And the second way is to recruit Ph.D. students through the graduate school. .. Also the graduate school is based on a system with interviews. So, all the students essentially are evaluated before they enter. And, this is very important for me. I would not hire a person without seeing him or her. .. [M]y group is great. .. I would like to keep this very nice atmosphere. .. I would not hire without knowing what type of personality the new member has." (Interview M1, p. 4)

This goes along with the concept of LPP (Legitimate Peripheral Participation (Lave & Wenger, 2002)) emphasizing that learning has to do with becoming an "'insider'" (Brown & Duguid, 1991, p. 48). Learning, according to LPP, is not about abstract knowledge, but about becoming a functioning member of a group. Therefore, one can assume the professional identity of a PI and his or her identification with a discipline is more consequential for the sense of belonging of students than the existence of nanoinstitutes. Given the principle of homophily (Blau, 1994, pp. 121-122), one can expect that the application procedure described by M1 reinforces homophily and the reproduction of a new generation of scientists based on selecting individuals who have similar interests due to a common background. This process is intensified by a given growth of the organization or university when new positions are filled according to the principle of homophily. The persistence of disciplines structuring academic organizations, but also nanolaboratories attached to universities given that university faculty and departments are involved in recruiting, becomes evident if explained from that theoretical perspective.

In addition, as Thelen (1999, p. 390) explains for political economies, reproduction mechanisms are pivotal in maintaining the "legacy" of a system over time in interaction with change that occurs and affects this "legacy." Consequential are only changes that interfere with reproduction mechanisms (Thelen, 1999, p. 400). In short, this means for the present context that as long as recruitment follows disciplinary lines through discipline-based scientists, positions will be filled with newcomers that anchor themselves in academic disciplines rather than in a high-technology.

Yet, change has occurred, without doubt, as the process of recruitment suggests. The creation of new institutes that are attached to universities and financed by third-party agencies does not necessarily imply a change in existing reproduction mechanisms and personnel selection procedures as it does not change the disciplinary-oriented research procedures either (despite the single incidents of interdisciplinary cooperation projects or institutes that have been established). The central structure of universities, which are examined here, has remained untouched so far by layering of new technology institutes or conversion of college study programs into high-technology programs.

Due to the importance of networks and informal recruitment (Blau, 1994, p. 124), as to be seen in the selected interview cases with the high percentage of students, in particular in Germany, who continue with their Ph.D. at their undergraduate and/or graduate university, personal networks are delineated in the interview conversations. The importance is manifested by the fact that institutional mechanisms operating in the institutional environment are distal, whereas network mechanisms are proximate (Nee, 2005, p. 56) just like social affiliations are (Blau, 1994, pp. 123-124). Personal networks are of great importance for researchers to stay up-to-date as K1 pointed out:

> "Conferences, literature, talking to colleagues [keep me up-to-date]. In particular the Munich network is of great help. There are seminars twice a week where the whole community meets and external guests are invited for talks. This is a very good possibility." (Interview K1, p. 10)

After emergence, an organizational field is structured by "an increase in the extent of interaction among organizations in the field; the emergence of sharply defined interorganizational structures of domination and patterns of coalition; an increase in the information load with which organizations in a field must contend; and the development of a mutual awareness among participants in a set of organizations that they are involved in a common enterprise" (DiMaggio & Powell, 1983, p. 148). The question is if this can also be observed with nanotechnology. Two points can be supported: "an increase in the extent of interaction among organizations in the field" and "the development of a mutual awareness among participants." The aforementioned cooperative relations support the first criterion: "outreach" is becoming increasingly important, in particular between industry and university but also among university centers as shown by the NNIN or by the industry advisory board at PSU. There are also intraorganizational departmental collaborations, such as CINSaT, the Center for Interdisciplinary Nanostructure Science and Technology at University of Kassel, Germany. In addition, conferences with special sessions on nanoresearch and memberships in professional organizations ensure constant interaction and information about state of research in nanoscience and inspirations for own research projects as stated by B3:

> "[At] conferences, [for] societies like this, people present their [most] current work. So it's stuff that hasn't even been published yet. It's state of the art in the science of nanotechnology. You need to go visit these societies or you kind of fall behind just reading text books and reading [the journals], because it takes time to publish [those] article[s]. … To stay up on [the technology], you go to conferences and get the latest and greatest on it." (Interview B3, p. 11)

'Outreach,' conferences and memberships, in turn, increase mutual awareness. A doctoral student talked about the necessity of going to conferences:

> "At the beginning I did not like [giving presentations] at all. … But during the last one to two years I got to know [how conferences work] a lot better. I know that it is really important to present something because one gets quite involved in discussions. This is better than just going around and looking at presentations. One talks about his issues. The feedback [one receives] is useful. But you also have guests who just look at your poster and say, 'boa, that's nice.' … and then there are people who utter their doubts on some issues and one thinks, this could be worth looking at more deeply. There might be some good ideas there." (Interview S2, p. 13)

To sum up, despite the uniqueness of nanotechnology as a cross-technology and its young age as a field, several aforementioned criteria speak for its institutionalization as an organizational field. These are the creation and social negotiation of versatile meanings with respect to nanotechnology, the existence of collective actors in the form of nanotechnology centers, and the structuration of the field of nanotechnology by increasing interaction among the centers and mutual awareness among participants. Local cultures are shaped by intra- and interorganizational collaborations within a center or, more often, with university departments and research groups or industry, such as at Georgia Tech University and PSU or University of Kassel.

7.1.5 'Work Activities' and 'Formal Structures'[5]

"Regulatory pressures" (W. W. Powell et al., 2005, p. 1134) are present for instance in the form of government initiatives or higher education reforms such as the NNI or the German 'Nano-Action Plan.' These influence 'work activities' at universities by providing opportunities for funding and institutional visibility. These pressures are handled by scientists through their participation in nanotechnology on the one hand and through their withdrawal into 'safe' disciplinary realms on the other. Therefore, those who subscribe to "actor identities" saying "what should happen" (here, politicians) are not the ones who must give in to that pressure toward conformity with formal institutional rules (here, scientists), which is diametrically opposed to the reputable pressure exerted by the disciplinary structure of universities (J. W. Meyer, 2010, p. 14).

So, for instance, the German Research Association creates centers for nanotechnology and thus exerts pressure. Here, too, the ones who subscribe to this plan and policy are not necessarily those who use these centers. Those who welcome these centers, professors for example, still remain attached to their colleges and faculties, as do their students. They do not switch to other 'formal structures' but maintain the rationalized myth of the need for nanocenters, the myth of nanotechnology as an advanced technology that is institutionalized due to the belief in economic growth by way of innovations and technologies. They use the centers' laboratories, but their ongoing activities could as well take place in other faculty or college laboratories. There is no feeling of belonging to the 'formal structure' of the nanocenter, to the public agency or policy that says "what should happen" (J. W. Meyer, 2010, p. 14).

The result of the interviews confirms what DiMaggio and Powell, as cited above, spoke about: mimetic compliance for reasons of legitimacy. Actors interviewed in this study are at least partially aware of their compliance and possible non-compliance in their engagement "in common activities" (W. W. Powell et al., 2005, p. 1134). At times, they critically observe institutional change at universities and the institutionalization of nanotechnology. Therefore, from an individual view, there is evidence for both mimetic compliance and decoupling, for instance when researchers join nanocenters and -institutes without fully internalizing nanotechnology as an element of self-categorization (see

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[5] This section is based on Hoser, N. (2010). Nanotechnology and its Institutionalization as an Innovative Technology: Professional Associations and the Market as Two Mechanisms of Intervention in the Field of Nanotechnology. *Nanotechnology Law & Business* 7(2), 180-197.

Turner et al., 1987). Another example for mimetic compliance is when researchers reveal critical views of the ongoing institutionalization of nanotechnology in the form of nanocenters or degree programs but participate at the same time in the field, e.g. by using nanotechnology resources (funding, institutions). In everyday life, researchers therefore must cope with the decoupling of institutional structures and their 'work activities' either mimetically or by being fully aware of it. From an institutional view, 'formal structures' in nanotechnology apparently do not get to the base, i.e., to those who actually are supposed to use them in their daily research activities. And those who fund the centers do not inspect what people working there actually think.

For example, doctorate students attached to the Center for Functional Nanostructures (CFN) at Technical University of Karlsruhe for instance must organize a summer school and report about their research. Yet, basically, it is trusted that members of the center and the public conceive of the center as a legitimate institution. This evidently works since there are no negative voices to be heard in public with regards to the question if the establishment of a nanoinstitute is worthwhile and legitimate. Moreover, in Germany, even researchers belonging formally to a nano-labeled institute were hardly aware of their belonging to a nano-related institution. For instance, L1, who was a doctoral student at the CFN at Technical University of Karlsruhe, joined the Center for her thesis. Yet, she was not aware at first of the formation of the Center by the German Research Association. The collaboration with her first advisor was prevalent for her decision to join his department, not the affiliation with the CFN:

> "No, I did not know [about the CFN when starting my doctoral thesis]. … I liked the topic. My boss asked me if I would like to write my diploma and my doctoral thesis [at his department]. And because I found the topic OK, I said yes. Not before starting my doctoral thesis, they told me, 'by the way, now you are at the CFN.' … It was the topic that was always most important to me." (Interview L1, p. 3)

This decoupling of research policy by DFG, decision-making of L1's advisor (to join the CFN), and action (L1's ignorance of her affiliation to the CFN, although she is doing research under its name) underlines the complexity and difficulty for the demarcation of a field (J. W. Meyer & Jepperson, 2000, p. 112). This is because its definition is constantly discussed and because politics use a definition that cannot be applied by academics as a legitimate label for research. In terms of legitimacy, which is crucial for organizations that are embedded in an environment (Drori & Krücken, 2009), one can note that what is legitimate in DFG's terms is not per se legitimate for academics. In academe, disciplines form the legitimate structure for identity, not institutes which are labeled under the name of a high-technology (Abbott, 2005). In the U.S., this has not always been observed in such a way, since the use of nanotechnology institutes is more open to the public. Therefore, the question of identification does not present itself the same way. Institutes are there for research, whereas faculty remains in its departmental structures from the beginning. They must ask to use the nanotechnology facilities and they are not formally members of them. Nanotechnology is a driver for institutionalization at universities by inciting 'formal structures' in the form of nanocenters and -institutes. These 'formal structures' legitimate nanotechnology and nanotechnology research funding. They do not, however, turn 'work activities,' i.e., research activities, automatically into highly rationalized and efficient tasks or even change the disciplinary organization of universities, even if this form of organization might not be efficient anymore. The study demonstrates how the persistence of disciplinary-oriented research identities enforces the decoupling mechanism for 'formal structures' and 'work activities.'

Another analytical way of addressing the gap between 'formal structures' and 'work activities' is elaborated by Gumport (2005), which shall be shortly mentioned here. She speaks of "logic-in-use" or "logic-invoked" (Gumport, 2005, p. 53) institutional logics that are used in the strategic articulation of reasons of legitimacy. Thus, there are conscious and unconscious manifestations of institutional logics. In the context of this study, this means that institutional logics do not need to be actually applied in order to legitimate action internally. This could explain why the nanolabel is used for reasons

of legitimacy toward the outside and for acquiring third-party funds but not applied when doing research, when cooperating or when working in a nano-labeled institute without using that label in self-descriptions or grant proposals. Most often, such "logic-invoked" strategies are layered to existing "logic-in-use" structures. Nanoscience master programs in Germany, for instance, are attached to the existing discipline-based degree programs.

The Efficiency of 'Work Activities' in Nanotechnology

With 'formal structures' being different between Germany and the U.S., the issue of 'work activities' leads to the question if we can notice such activities that might not be as efficient as promised and that might deviate from 'formal structures.' In politics and industry, nanotechnology is designated as a key technology in future progress and as decisive in international competition. In research, strategic action comes into play when research scientists actively orient toward where funding is available. B3 clearly stated that research directions are re-labeled once third-party funding channels change. Nanotechnology offers the chance that, as a cross-disciplinary technology, diverse funding sources can be tapped into. Yet, the basic science that is conducted at B3's laboratory remained more or less the same:

> "Off the top of my head, I don't have a timeline or a history of GTRI [Georgia Tech Research Institute; author's note] and the lab, but the different labs have changed focus and names over the years for several reasons: one being the trends and direction of technological discoveries and another being because of where the funding comes from. And so the leaders at GTRI .. look forward to see[ing] where things are going, .. to see what the overall drive and focus of GTRI need to be to keep growing and keep doing research. An academic professor who does work only in one specific field could potentially run out of funding because no one's interested in that. Or, for example, NASA with space flight. It's known there's going to be cutbacks in NASA funding. So if you're an aeronautical engineer and designing things for the space shuttle, the funding is going away on that. [The engineers] could be hampered and would have a hard time switching gears to other research areas or they may have to switch to another kind of rocketry ... In our research in nanotechnology, it doesn't matter as we are flexible to change research directions. .. [T]he actual final widget that we make might be different, but basic science is still there. We'll still do basic science in nanotechnology towards a particular application, but that application may change depending on the trends and where the funds are. The funding ... [for] research may come from a different source. Funding is still available, the research will still be performed but the applications may change." (Interview B3, p. 14)

The statement "we'll put anything in there" (Interview B3, p. 14) alludes to the conception that nanotechnology is versatile and, if broadly defined, useful. It is a technology that can be applied to diverse fields. B3's attitude toward re-orienting his basic research toward funding channels was not expressed by every interviewee so matter-of-factly. To him, nanotechnology offered a general platform that is useful in attracting funding with the advantage that it does not lead into the same specialization as some university professors run into. B3, in addition, was the only one who claimed himself being a nanotechnologist. This supports his positive view of nanotechnology. What certainly adds to his strategic way of acquiring funding is that he, as a research scientist, had to acquire not only money for his projects but had to provide for his own salary. Thus, he was under higher pressure than tenured professors in screening for possible funding sources. When talking to tenured researchers in academia the picture was slightly different. In particular, researchers who were not part of a nanotechnology center but affiliated to chemistry or materials sciences departments had a more detached view of nanotechnology. Nanotechnology was seen as a hype and buzzword that was often misused for popularity reasons and used only when applying for grants (B1, C1, C2, F2, Q1, and G1).

From the theoretical perspective of social constructivism, it can be concluded that actors on the micro-level create meanings out of their social world and act upon them, not necessarily congruent with what one might expect of the institutional identities and facts, but it shows that interaction works through negotiation of meanings. Thus, it is required to explore negotiated meanings since one cannot assume that they are self-explaining by just analyzing action and institutional change of contexts. Social constructivism is therefore a perspective enriching the links between socially situated researchers that have been modeled in chapter 6.

To conclude further, nanotechnology represented a central technology interviewees used in their applications of nanomaterial for a specific goal. First, nanotechnology was evaluated as a tool, device, and subject-matter or as hype, fad, and buzzword. Especially for interviewees who primarily applied nanotechnology, such as bioengineers, an exact definition of nanotechnology seemed superfluous. For those involved in the advancement of nanotechnology and spectroscopy issues of size mattered, since the smaller things were able to be seen, the more successful a new nanotechnological development was. If success, as with the former group, depended on content and new material properties, then researchers were more flexible in the naming of their research, entitling it nanotechnology or not. For chemists, to cite a group of researchers involved in another field of application, definition of size was most problematic, as chemistry per se has been using matters of small size since its beginning.

R1 very adequately summarized the issue of nanotechnology definition saying that size mattered in the nanosciences, but the history of academic specialties was different for each field, such as chronoid research or materials sciences. Both fields belong to the nanosciences but have different histories of development. To R1, by contrast, nanotechnology is defined by the STM which provided access to nanoobjects, for his personal history goes back to nanophysics, which started by the invention of the STM (see Interview R1, pp. 11-12). So, with the capability of measuring and manipulating nanoobjects, nanotechnology took hold in science whereby the whole range of nanometers is implicitly seen by R1 as the scale for nanotechnology. However, size becomes secondary, so R1, as soon as objects within the nanorange can be controlled.

When asked about their professional identity, researchers' disciplinary identity, especially of researchers belonging to a department, always came first seeing themselves as polymer chemists or materials scientists. Thus, there was no common identity that could be applied to the informants. This lack of a common identity goes along with the reluctance to adopt the nanolabel, certainly an obstacle toward the stabilization of nanotechnology as an organizational field. Nanotechnology was used as a descriptor (see interview with G1) of one's 'work activity,' not as a core element in identifying one's professional background.

Second, PIs fulfill several roles and functions. This makes their embeddedness into the academic sector and into the field of nanotechnology much more complex when scientists opt in and out of the nanotechnology field depending on which role they perform. The maxims of action, which interviewees revealed, implied a strategic use of the term nanotechnology and a critical evaluation of what is going on with nanotechnology outside the academic sector. Researchers are aware of the prevalence of academic disciplines and, as nanotechnology is not a discipline at the moment, they use their home discipline as a means of legitimacy for their research.

Further, one can state that nanotechnology is an organizational field, however, with research-related 'work activities' being different from 'formal structures.' 'Formal structures' in this context are centers and institutes that carry the label 'nano.' This noticeable distinction reveals a discrepancy between the self-categorization and -conception of researchers and how their organizational work environment functions. This work environment is constituted by formally institutionalized and politically motivated nanoinstitutes and -centers, degree programs, and graduate colleges. Conferences and professional societies where nanotechnology is a visible specialty co-create the field of nanotechnology. In addition, it is nanotechnology promoted politically as a high-technology that fosters the institutionalization of nanotechnology, not nanotechnology promoted as an academic discipline. The 'gap' between 'formal structures' and the internalization of 'nano' as a way of identification has not been closed. Thus, the existence of nano-labeled institutes does not abolish the prevalence of identities rooted in traditional academic disciplines, at least not for the time being. What remains is tension between 'formal structures' comprising politically induced nanoinstitutes and ongoing activities or, in other words, researchers' individual maxims of action decoupled from these 'formal structures.' Hereby, this tension does not impede but enables politics and scientists to pursue their interests.

7.1.6 Preliminary Findings

One can conclude that nanotechnology is an organizational field, with research-related 'work activities' decoupled from 'formal structures' (J. W. Meyer & Rowan, 1977). What these nanoinstitutes as 'formal structures' do is to open the potential for transdisciplinarity, a Mode 2 element, by formally addressing all scientific disciplines that are involved in nanotechnology through their label. The way this potential for transdisciplinarity is empirically handled is shown by scientists' handling nanotechnology institutes. They keep their disciplinary identities but embrace and actually use nanotechnology institutes. So, they manage to balance Mode 1 and Mode 2.

Therefore, Mode 2 and Mode 1 ought not to be seen as two opposed conceptions that must be kept in isolation. Instead, Mode 1 and Mode 2 are combined and linked to each other through interpenetration of disciplinary structures and interdisciplinary technology, theory and application orientation, and different scientific units (nanoinstitutes and study programs connected to rather disciplinary departments and faculties). This empirical finding goes along with the rise of modern science described by Münch (1984, p. 240). Innovations and novelties in academia are created through the combination of a specific form of cognition to other spheres of cognition and action by way of interpenetration, not by way of differentiation. Rather, differentiation leads to the isolation of specialties, not to productive innovations (Münch, 1984, p. 200). The same occurs with the cross-technology of nanotechnology and its Mode 2 criteria that are imposed on universities and linked to existing Mode 1 features, above all discipline-based structures and specialization.

The result is that institutional change is induced by a prolific combination of nanoscience with applicable nanotechnology. This result has different implications for the U.S. and Germany. In the U.S., there is a strong focus on the implementation of nanotechnology in the form of research centers and on the immersion of nanotechnology into existing curricula. This observation goes along with the pivotal position of the U.S., as an LME, in basic research due to the favorability for radical innovations. This is contrary to a CME like Germany where marginal innovations dominate and a spillover of academic research into industry is less probable (Boyer, 2003, p. 167). In Germany, there is a focus on the implementation of nanotechnology in the form of bachelor or master nanoprograms, less on a nationwide infrastructure of institutes, such as the U.S. endeavor. This is demonstrated by the absolute numbers of bachelor and master programs that are higher in Germany than in the U.S. where immersion is pursued (see Feather & Aznar, 2011; Nanowerk, 2010b). Thus, Germany's strategy follows its traditional concentration on the education for concrete job profiles. This focus is opposed to the rather open study profiles in the U.S., with more flexible transitions into the labor market where jobs are not as tightly linked to university degrees as in Germany. (Münch, 2010) This way, German universities have found a way of handling nanotechnology as an applied technology, although historically, German research universities have always been opposed to societally relevant issues. This is in contrast to U.S. universities that have had a focus on the application of ideas from the beginning. (Münch, 1993a, pp. 286-287) For politics, the combination of nanoscience and applied nanotechnology might turn out as favorable for the goal to develop nanoproducts, which would ensure national productivity and economic growth in the long run. In science, the case of nanotechnology furthers scientific progress that is based on rational logic and theory on the one hand and empiricism and technology on the other (Münch, 1984). This tension and its reproduction are elucidated in the following section by looking at scientists' evaluations of the field of nanoresearch using Mode 2 criteria.

7.2 Interpretations of Mode 2–How Transdisciplinarity, Heterogeneity, Applicability, Quality, and Accountability Are Contextualized and Socially Constructed in Research Activities

As written above, Mode 1 knowledge production differs from Mode 2 knowledge production in four dimensions: Transdisciplinarity, heterogeneity, applicability, quality, and accountability. The main difference between Mode 1 and 2 is the societal embedding of Mode 2 knowledge production implying social accountability and the consideration of the implications of academic research within the context of application. This context of application also implies "broader criteria of evaluation … including cost efficiency, value in the private marketplace and social effects [with a] review system [that] incorporates … constituencies outside the academy" (Rhoades & Slaughter, 2006, p. 12).

In the following, these aspects are contextualized in the field of nanoresearch by integrating interview data and extended by looking at (Mode 3 and) the degree of "academic capitalization" (Slaughter & Rhoades, 2004). The contextualization takes place because from the explorative analysis of the interview data, Mode 2 criteria were mentioned, explained, justified or interpreted differently. In science, theoretical concepts are often set up but not exposed to how those involved, namely researchers, view them, i.e., construct them socially as beliefs that guide actions and interpretations. The previous section on neoinstitutionalism has already shown that there is room for discrepancy when it comes to internalized meanings and actual actions. With the exception of the theory of academic capitalism, interviews with researchers are often neglected to see how researchers see their world. Therefore, in this study, the concepts of Mode 2 as interpreted from the view of nanoscientists are presented.

As a result, perspectives differ, as may be the case, from the common definitions from literature and are adapted interactively to scientists' everyday activities and environment, cooperation and project work. The interviews make clear that nanoscientists have mental concepts of Mode 2 terms as they deal with them when interacting with higher education and federal granting policies. However, the application of the neoinstitutionalist approach above demonstrated that nanoscientists still live primarily in a 'Mode 1 structured world.' Disciplines and basic research dominate their communities and their identities, both toward the inside and the outside, i.e., other scientific communities.

This does not mean that within their disciplines, scientists cannot deal with application oriented nanotechnology. It is their self-categorization that nanoscientists base on disciplinary structures for reasons of reputation. Their actual daily realm can still be a mixture of both Mode 1 and Mode 2 elements. Politics uniformly perceives nanotechnology as a primarily interdisciplinary and application oriented technology because politics focus scientific progress in their agendas for promises of economic growth and international competitiveness (J. W. Meyer & Jepperson, 2000, p. 112). In sum, the notions make clear how nanoscientists cope with Mode 1 and Mode 2. The notions are not carved in stone but open for discussion and modification, as they result from scientists' everyday interactions with politics, industry, and other members from the same scientific community. These interactions finally involve both modes of knowledge production and require scientists to successfully balance the two modes. It was shown above what happens when a politically defined Mode 2 field is imposed on a primarily Mode 1 field. Now, individual perceptions of central Mode 2 categories are presented to show how scientists deal with these politically important terms and how these individual perceptions help in balancing both categories of knowledge production.

7.2.1 Transdisciplinarity

Transdisciplinarity in the Mode 2 sense refers to the dissolved boundaries between disciplines and the "shared use of academic and industrial facilities and technology" (Gibbons et al., 1994, p. 75). Others see in transdisciplinarity merely a higher degree of interdisciplinarity (Jansen et al., 2010). To Roland Czada, transdisciplinarity occurs when central issues in science and for humanity cannot be assigned to any traditional discipline any more but between and above them" (Czada, 2002, p. 26). Interdisciplinarity refers to the transfer of methods or theoretical elements from one discipline to another (Czada, 2002, p. 25) whereas multidisciplinarity implies the exchange of members from different disciplines about opinions, research results, and solutions. Hereby, the other discipline is rather a "helping science" that is of service to one's own discipline. Disciplinary borders are not questioned so that the precise adherence to one discipline is an important requirement for the recognition as an expert. (Czada, 2002, p. 25)

For the establishment of a transdisciplinary (Mode 2) field of study like artificial intelligence as discussed by Koch (2005), generating a scientific identity within the particular scientific community is indispensable. This demands a high degree of orientation and susceptibility from single artificial-intelligence protagonists in order to gain an overview of their field: "They must reiteratively reconstruct their scientific identity to a far greater degree than their colleagues in main disciplines" (Koch, 2005, pp. 224-225, transl. by author). Koch finds out that interdisciplinarity is only partially realized. Normally, one discipline is dominating over others so that the remaining disciplines are not integrated completely and the assumptions and paradigms of the mother discipline are taken for granted (Koch, 2005, p. 227). As in artificial intelligence, the question about inter- and multidisciplinarity was central and simultaneously the most interesting and mostly mentioned topic in the interviews. Informants thought of interdisciplinary as an important element in their research. In education as well, interdisciplinarity was regarded as important in particular as nano-related skills facilitate interdisciplinary teaching due to its integration of several disciplines and application orientation. A2 explained it as follows:

> "I think it would be easier to learn and retain if they could see the purpose right in front of them. So I personally think that university coursework should go towards being more interdisciplinary and I think having nanotechnology coursework is a great way to start because you do have to cover many different aspects of chemistry in general in order to understand nanoparticles and how you make them and why you do and why they're interesting." (Interview A2, p. 19)

Similar to Koch's finding (2005), it becomes clear that what interviewees defined as transdisciplinary or interdisciplinary is not what Mode 2 literature views as such. As Abbott points out, interdisciplinarity is a central issue in today's universities. To him, interdisciplinarity is not a new phenomenon. The issue of interdisciplinarity emerged with disciplines simultaneously, not after their development, at least in the social sciences (Abbott, 2005, p. 214). Contrary to what one might expect, interdisciplinarity has a "stable history" (Abbott, 2005, p. 215) meaning that it has always been addressed, but it has never been fully embedded into department structure. As department structure is the central organizational concept at universities, interdisciplinarity could never hold foot as an organizing principle overcoming university departments. This observation implies that disciplinary boundaries are fuzzy and most often cannot be upheld in practical everyday research. Interdisciplinary and disciplinarity go hand in hand.

In the context of Koch's study (2005), the construction of a scientific identity comes into play. In the present case that asks in particular for the professional identity of informants, professional identities are regarded as interrelated with the scientific identity of the scientific community of nanotechnology that has been made up so far of academic professions. The question that is discussed in chapter 7.5 is to what extent nanotechnology exhibits characteristics of a profession and how it might evolve in the future. For nanotechnology, a consistent scientific identity is difficult to deduct as definitions of nanotechnology and membership of the scientific community are ambiguous. First, it must be examined if nanotechnology is transdisciplinary at all. Second, it must be analyzed if a scientific identity is constructed. The latter is ostensibly made more difficult because definitions of nanotechnology vary and as a platform technology, nanotechnology is cross-disciplinary, i.e., applicable in several disciplines. However, the awareness of nanotechnology at universities and its institutionalization that is driven both by politics and by actors from universities speak for the construction of a scientific identity in the form of a social and historical identity (Lepenies, 1981) although nanoscientists remained suspicious of the ‘hype’ around nanotechnology when expressing their professional identities. In terms of the cross-disciplinarity of nanotechnology, the interviews revealed that there was a lack of a uniform use of inter- and multidisciplinarity. These terms were never defined by the informants and could be interchanged. Some apply both terms without specifying why they chose one over the other at the respective moment. Following a general definition of cross-disciplinarity, it becomes clear that the interviewees mean rather ‘cross-disciplinarity’ than inter- or multidisciplinarity when they described their collaborations. Informants solved this problem by speaking of nanotechnology as a tool and method, not as an academic discipline. Lyn Grigg, Ron Johnston, and Nicky Milsom (2003, p. 7) define cross-disciplinary more broadly than interdisciplinarity as follows:

> “Cross-disciplinarity is defined in opposition to disciplinarity. It is concerned with crossing boundaries, opening up new frontiers, dealing with ‘real world’ problems. Its stance is that the world and all its problems were and cannot be defined in terms of the historically evolved, human invented structure of disciplines. It stands for dynamism, flexibility, overthrowing past assumptions and mindsets. To the critics of cross-disciplinarity it is soft, imprecise and commonly non-quantified (and worse perhaps non-quantifiable). To ensure the necessary rigor, disciplinary competence should be the prerequisite and organisational mode of interdisciplinary research.”

As found by Ismael Rafols and Martin Meyer (2007, p. 633), cross-disciplinarity is “an eminently epistemic characteristic” meaning that citations and references are better indicators for generating cross-disciplinary collaboration than co-authors’ disciplinary affiliations and background, i.e., social dimensions. In terms of the “new frontiers” that are explored in nanotechnology, cross-disciplinary also per definitionem grasps more precisely the character of nanotechnology. The required “disciplinary competence” was also given in the case of those interviewed. Informants’ backgrounds were disciplinary based. Some interviewees, in particular in Germany, changed their research focus and their disciplines or ‘felt home’ in two disciplines after they graduated (whereas U.S. informants changed their major rather after their undergraduate studies, which is fairly common in the U.S. higher education system). At the time of the interview, J1 who studied chemistry felt more attached to materials sciences; the same occurred with M1 who studied chemistry and headed the chair of nanoelectronics and nanophotonics. M1 described herself more as a materials scientist in between chemistry and physics. Thus, their disciplinary affiliations as professors and study background disclosed more about their cross-disciplinary collaboration than a look into their publications might suggest. This circumstance illustrates how interviews can conjure richer information than objective data that tend to simplify personalities. M1 oscillated between materials sciences, physics, and chemistry, J1 between chemistry, electrical engineering, and materials sciences. More often than U.S. nanoscientists, German informants seemed to experience disciplinary identity changes. The examples show that materials science seems to replace other ‘big sciences,’ such as physics and chemistry, where nanotechnologists situate themselves. Materials sciences are apparently more ‘neutral’ and encompassing than nanotechnology.

In short, the field of nanotechnology was either considered inter- or multidisciplinary by interview partners, or both at the same time. Transdisciplinarity was not used as a description by anybody. Yet, it was considered a fact that nanotechnology is interdisciplinary because of its integrative character that facilitates collaboration across departments, such as at Carnegie Mellon University (CMU), which is marked by an interdisciplinary atmosphere, so A1. Transdisciplinarity, finally, is not easily to be pinned down. It refers to the mobilization of a range of theoretical perspectives and practical methodologies to solve problems. Transdisciplinarity goes beyond interdisciplinarity in the sense that the interaction of scientific disciplines is much more dynamic. Once theoretical consensus is attained, it cannot easily be reduced to disciplinary parts. In addition, research results diffuse (to problem contexts and practitioners) during the process of knowledge production. In the collaboration projects described by the interviewees, the disciplines are still detectable. Dynamic occurs when participants interact, communicate, and collaborate in research projects which are of a limited time span (Rafols & Meyer,

2007, p. 636). PIs are constantly involved in research projects and thus in contact with other departments. Interaction with other departments is the main indicator for cross-disciplinarity (or multidisciplinarity) from the perspective of the informants. However, cultures of knowledge production still evolve around academic disciplines, not around transdisciplinarity. This distinguishes the Mode 2- from the Mode 3- knowledge production: Mode 3 recognizes the prevalence of academic disciplines as points of reference and sees the diffusion of transdisciplinarity in academia in a more restricted way. Collaboration spans over several departments and disciplines, but researchers remain committed to their “disciplinary cultures” (Rhoades & Slaughter, 2006, p. 13). This is all but contradicted in the interviews in which researchers trace back their occupational identities to academic disciplines, except for B3.

The organization of Ph.D. research in professorial labs helps the collaboration of several disciplines. The interviewees for instance referred here to multi- or interdisciplinarity. Everybody worked on their projects, but they discussed their projects and profited from their colleagues’ knowledge. If group members were from different disciplines, multi- or interdisciplinarity was seen as given. Thus, when it comes to dynamics, transdisciplinarity would be an appropriate term. However, in the single projects, the discipline of the Ph.D. student dominated. Thus, it would be difficult to describe these projects as transdisciplinary. G2 described how research labs function:

> “a lot of people who come into this field actually are not initially multi-disciplinary, but they come from a different background and train themselves in a new field. So then by virtue of choosing the field, they become multi-disciplinary. I mean, in our laboratory, we have 3 chemical engineering-background students, 1 bioengineer, 2 material sciences degrees and a physicist and me. So there’s a lot of diversity, and actually that helps in the lab. Oh, we actually have 1 biologist now. But then each person has a sort of specific thing that they know and we all absorb each other’s knowledge.” (Interview G2, pp. 7-8)

A1 pointed to the necessity of multidisciplinarity for single disciplines because on their own, disciplines, such as chemistry, would not have been of great applicability or relevance. This is what constituted an advantage of nanotechnology which is characterized by multi-disciplinarity:

> “I myself as a chemist couldn’t do much alone. Nanotechnology is a multi-disciplinary area. ... If one would do only chemistry, projects requiring several disciplines would not be developed. .. Chemistry enables but it is not alone. So one really needs to creatively interact with people from different disciplines, and this will benefit nanotechnology.” (Interview A1, pp. 6-7)

At University of Kassel, interdisciplinarity was visibly institutionalized in CINSaT. S1 described the function of this center as follows:

> “We do not have a CINSaT building. This is a little complicated; well, Kassel is a small university … [A]t CINSaT, of which I have become spokesperson just recently, … basically my task is to more or less force people to talk to each other … because nanotechnology is highly interdisciplinary.” (Interview S1, p. 6)

With CINSaT, one can see one example where interdisciplinarity is institutionalized by installing an office for somebody who is personally responsible for the communication between different disciplines. It remains to be seen if this is a successful way of enforcing interdisciplinarity, i.e., if actual regular collaboration projects across disciplines arise from this center. This example shows how nanoresearchers were actively engaged in seeking ways of fostering nanoresearch that enclosed the potential for interdisciplinary collaboration per se due to its wide fields of application.

S1’s statement, however, reveals that S1’s definition of interdisciplinarity was closer to the literature definition of multidisciplinarity. Therefore, one can conclude that multidisciplinarity is the term that captures precisely what informants meant when they talked about interdisciplinarity because it alludes to the combination of several disciplines to produce something applicable and innovative. The term does not emphasize a possible diffusion of knowledge or absorption of disciplinary knowledge bases into a new one. The preservation of traditional disciplines is important here. Thus, nanotechnology from the interviewees' perspective and experience could not be regarded as interdisciplinary per se. Nanotechnology was an enabling cross-technology that was used in different disciplines for different purposes.

Second, a coherent identity has not evolved as yet because of the cross-disciplinary character of nanotechnology and the prevalence of traditional academic disciplines. This was demonstrated when informants were asked about their membership of scientific communities. Materials sciences seemed to be the discipline that better fits nanoscientists when nanotechnology represents a subdiscipline or specialty.

Finally, interdisciplinarity was lived in different constellations: Some research groups combined several disciplines by doctoral students who came from different disciplines and were hired by PIs based on the skills that they needed for their project, such as in J1's case. Others worked in interdisciplinary context by pursuing a research project that was affiliated with several departments, as in A2's case, and which was more common for U.S. doctoral students. In that case, a research problem arises that touches several disciplines so that a doctoral student moves between these disciplines. A third constellation was the network of professors from different disciplines that was established at institutes, such as CINSaT at Kassel, by NIM (Nanosystems Initiative Munich) or the ENNaB in the Munich region. Here, professors were given the chance to talk and start projects. With regards to the latter, as S1 emphasized, there were still things to do to realize 'real' interdisciplinary research.

The findings thus make evident the already mentioned fuzzy disciplinary boundaries. Scientists change disciplinary categorizations over their lifetime and cooperate in projects where scientists place themselves in different disciplines. Disciplines turn out to be constructs that are sometimes not even congruent to people's study background due to the breadth of research fields that they include. During undergraduate and graduate studies, as the interviews enforce, students can already leave disciplinary boundaries through projects with their PIs where applied topics or different disciplines are involved. In Germany, already before the Bologna process, study programs were not only placed within one discipline. Magister studies for instance have always included several disciplines. Disciplinary self-categorization is necessary within scientific communities, since it eases the classification of scientists through other scientists and maintains the reputation of single broad disciplines. It is easier to say, 'I am a chemist' than to say 'I am working with molecules at the nano-scale in order to produce monolayers for wafers.' As such, disciplinary self-categorization becomes an institutionally manifest element of scientific communities.

7.2.2 Heterogeneity

Collaboration has become more interdisciplinary in the sense that departments at a university or between universities cooperate. There are opportunities for interdisciplinary research experience for instance in a post-doc position as C1, a trained chemist, used his post-doc in the U.S. as an opportunity to gain more interdisciplinary experience which brought him closer to research with nanoparticles. But also at graduate school, A2 and A3 gain interdisciplinary experience by working with other professors and departments from CMU or from other universities. This form of collaboration is supported by research groups and PIs, such as A1, which in turn is an attractor for Ph.D. applicants. A2 in particular likes the interdisciplinary experience she gets in A1's group and also would like to continue doing academic research in an interdisciplinary setting:

> "I was 2 years into working with [my advisor]—that's when I joined the project that was a collaboration with engineering departments. That's when I started with this project. … [A1] is my only adviser, but I collaborate very heavily with these other groups. So I meet the professors there, and we have group meetings here with [my advisor], but we also have group meetings on campus with the engineering group and we're there for those group meetings. So I kind of have two groups because of the collaborative project. .. [My advisor] had been collaborating with other professors for several years, and I was the first graduate student to work on the project. He had other post-docs working on the project before I came, but they had left around the time that I was getting here. So we needed another polymer chemist to continue this work. … I started collaborating with these departments— a collaboration between Mellon College of Science and two different engineering departments within Carnegie Institute of Technology. And at first I was just designing and synthesizing different polymers for them to use, but then I just sort of took over the whole project … There's maybe about 8 people that are working on this project in his group. And in [the other] group there's maybe 5 people. Very rough estimates. So it's a very interdisciplinary group … I got to learn more on the engineering side of this project quite a lot, and I enjoyed that very, very much. And so that's one of the appealing aspects of working in the chemical industry, right? You're generally working on very, very interdisciplinary teams. Whereas currently, the way science in academia is structured, it's still more department dependent. So if you're an organic chemistry professor, you do organic chemistry. We're starting to work between different departments more, but it's still not the norm, I would say. … But if I was to stay in academia, I would go on to be a professor and I would want to work in a completely new department that is already based on a hybrid of a few different areas or I would certainly want to work in a department where collaboration between other departments is encouraged. Because it's also been my experience in working with these people that you can answer questions a lot more efficiently. Because for this kind of project, … we have this huge collection of everyone with all their different expertise. … So certainly I would want to continue working in a very interdisciplinary atmosphere no matter where I end up working." (Interview A2, pp. 4, 12-13, 15-16)

A3's biography also reveals interdisciplinary experience, not only in his education but also in his research projects:

> "I come from the college of Staten Island, where I was majoring in chemistry and biochemistry with a minor in biology. Right now I'm working on several projects, so we're working to make non-natural amino acids and growing polymers from them. Another one is with Rutgers [University] and … the University of Pittsburgh for wound healing. And the third one is with a guy … from Duquesne University on purification of polysaccharides." (Interview A3, p. 1)

J1 points to the need for doctorate students with diverse disciplinary backgrounds:

> "[T]he problem [of recruiting young researchers] is a little more complex. I need an interdisciplinary group. I have chemists, physicists, materials scientists. Now, I have one from .. a degree program … [called] 'molecular science.' This is a broad spectrum. Ideally I would [like to have] someone [else] from electrical engineering." (Interview J1, p. 8)

This view of interdisciplinarity exemplified here by statements of J1 and A2 differed from the literature definition of interdisciplinarity. Interviewees rather used the concept of multidisciplinarity than interdisciplinarity. They stressed the problem-solving character of 'interdisciplinary' cooperation, the participation of several disciplines that contributed their share to how a practical (or sometimes also rather basic research) problem could be solved. The need for a diverse setting of disciplines alluded to the equality between disciplines and the lack of hierarchy. Each discipline was equally needed to tackle research problems. Thus, the way informants delineated their research, multidisciplinary was the term that fit best because of the domination of classical disciplines within unconnected mono-disciplinary fields of chemistry, physics, materials science or electrical engineering (Schummer, 2004, p. 461). In terms of interdisciplinarity, Schummer (2004, p. 462) speaks of two forms: One where several disciplines collaborate with each other at equal rank and having strong symmetrical connections, the other where one discipline dominates the others to which it has strong asymmetrical connections. Here, the first form of interdisciplinarity seems appropriate. Namely, it is usually professors that coordinate and collaborate and do not want to give up competencies. In projects with professors and doctorates where a professor has doctorates from different disciplines, the second form might prevail. This would be another need for further research, however, to draw more valid conclusions.

For now, it can be stated that multidisciplinary and interdisciplinary collaboration occurs based on Schummer's definitions, which cannot easily be kept separate. Contrary to Schummer though, also individual scientists, for instance A2, were inclined to be engaged in interdisciplinary research (Schummer, 2004, p. 463). What certainly plays a role in the process of interdisciplinarization at universities is that the present disciplinary institutional structure at universities represents an impediment to interdisciplinary, flexible and innovate research teams as well as students' research involvement (Roco et al., 1999, p. 266). This is discussed in section 7.3.

7.2.3 Applicability

Applicability is always in mind, also when doing basic research. Basic research is seen from the perspective that it will once be used in applied research and in the market eventually. This shows that the market is a factor that must be considered when examining nanotechnology: it represents an intervening mechanism (see the 'Model of Intervening Mechanisms' from section 1.2). The market is considered indispensable for the development of applicable nanoproducts (A1). However, a lack of differentiation between the term applicability and actually doing applied research is to be noticed. Most research done by those scientists who were interviewed is considered basic research, including when scientists were asked directly. Applied research always made up at least a small proportion of research pursued by the interviewees. The awareness of application orientation might be striking as, also stated by informants as an advantage, basic research and its work culture are marked by creativity. Creative potential, however, is highest when costs and time are not 'saved' but rather 'wasted' to open up new areas that are in particular risky and most often do not lead to usable results. Capital, the supposition goes, is freely available in academe, in particular when doing basic research. The case of nanotechnology shows that this maxim of action is not ubiquitous in academic research. Time frames and budgets must be watched when doing research funded by third parties and with greater application orientation. Nevertheless, interviewees are not all in the same position. Some must be more responsible to applicability, budgets, and time, such as B3, A1, while others can pursue their creative potential with the fixed budget they receive from university and the state (K1 for instance).

In a German report on nanotechnology, application orientation was part of the definition: "Nanotechnology is the art to knowledgeably use structures on the scale between one and 100 nanometers that carry useful functions for own good purposes" (VDI Technologiezentrum e.V., 2008b, p. 4). To informants, possible fields of application for their basic research also meant that they were doing applied research. This is why when researchers are asked about the percentage of applied research they do it should be clarified what is meant by applied research. Usually, the time span until a product is realizable is too long to be able to speak of applied research. Still, direct industry contact is in particular noticeable in the U.S.. A1 refers to the importance of companies that Ph.D. students interact with by presenting their research:

> "Interactions with every company are very unique. We interact with a range of companies which are often in competition. Thus, they don't always tell us exactly what they want. They learn from us during semiannual meetings ... There, students present their results. ... It's a very rewarding experience for them because sometimes a first-year graduate student can explain some details of their work to a senior person from industry to do something. Thus for the student it is great feedback. ... With some companies, we additionally have sponsored research. In that case they fund a specific research project. We build general knowledge that is valuable for the companies we interact with. .. These companies themselves patent applications in order to protect their intellectual property." (Interview A1, pp. 9-10)

This statement conveys how professors were not completely free in handling research results. This demonstrates the influence of 'academic capitalism:' Having an 'enabling technology,' as A1 pointed out, nanoscience is interesting to companies. With several companies being research partners, such as in the case of A1, a professor must manage these industry projects and consider the interests of the companies that compete in the market. Thus, the criteria of trust and free flow of information are violated or lose relevance because with industry cooperation, market rules take effect.

Applicability was seen by some U.S. scientists but only one German scientist (P1) as something positive in the sense that it must be fostered. In particular in drug delivery, industry was seen as a valuable guidance for helpful products, but not as a dictate (G1, G2). G1 responded to the influence of the market as follows:

> "I think it influences it in terms of identifying needs, and I don't think that's a bad thing to be addressing problems. I think it's partly what is the need by the public or by the medical community, by … the physiological problem. I think at some part, they influence what is the problem that we're trying to address, but they're not actually influencing the approach that we take in addressing that problem." (Interview G1, p. 6)

This attitude toward the market is similar to A1 who asserted that the commercialization of one's own ideas yield satisfaction and approve one's research endeavors. In Germany, there are contacts to industry, too, often fostered by the federal government or by the European Union within the 7th Framework. It must be noted that industry in some cases would probably not be participating in these projects if it was not demanded by the BMBF or the European Union. O1 traced back the participation of industry to the requirement of the 7th EU Framework Program

> "because the EU Framework Program had one condition for this project. This is that industry partners must be part of the project because they want to fund technology relevant basic research and finally develop some technology. .. And this is why these industry partners participate." (Interview O1, p. 10)

Still, none of the interviewees addresses the cooperation with industry as a 'bad' thing. They regard themselves as autonomous enough to decide if and on which topic they cooperate but see industry cooperation as enrichment as well. As a matter-of-fact, they cannot do without industry funding, in particular if the university's overall strategy is based on industry cooperation. In the end, they find a way of combining basic research university budget financed and industry projects, most often by way of a low percentage of industry projects, although they might be interested rather in basic research projects:

> "Yes, absolutely. [Industry cooperation enriches research]. … [I]f concrete questions come from a company to which I can make a contribution, I say, 'OK, we'll do it.' .. [S]ometimes there are real overlaps … However, it is not the case that industry dictates the direction but, as I said, if there are interesting questions from industry where I see a fit, then [I cooperate]… I [also] do some measurements for companies and acquire ... money for the laboratory." (Interview K1, p. 11)

P1 moreover pointed out that industry has a right, if researchers cooperate with industry, to guide the direction of the cooperation: "This is totally common [that industry would dictate the direction of your research]. Why should someone give you money and not tell you what to do? I do not understand this [reasoning]" (Interview P1, p. 11). This remark is in contrast to the findings by Slaughter and Rhoades (2004, p. 129) where professors defend values of the public good knowledge regime but, at the same time, "play the game," i.e., cooperate with industry and use industry funding. Both in the U.S. and German interviews, no interference of industry cooperation with publishing or the free flow of information was mentioned. What was consistent with Slaughter's and Rhoades' findings is that professors "seemed to accommodate industrial and institutional demands" (Slaughter & Rhoades, 2004, p. 128) in order to pursue research that is more highly valued than teaching, especially to build up reputation. In that respect, J1 viewed third-party funds by the DFG as the “most prestigious third-party fund” (Interview J1, p. 6). Several informants, both professors and doctorate students, deplored the high amount of lecturing hours they had that detracted from their main tasks, i.e., pursuing and managing research. Teaching constituted no criterion for acquiring third-party funds, only publications and research results made one eligible for third-party funds.

The goal of future applicability of research has come to serve as a legitimation for funding and doing respective basic research in energy, drug delivery, or toxicology. The downside of this could be that, as Nico Stehr (2006, p. 48) remarks, the dissemination of knowledge is further impeded and the access to knowledge regulated instead of opened by an increasing market orientation of scientists. Despite high public funding, industry collaboration is a central factor in research funding. With the Bayh-Dole-Act, research has been transferred to the private sector. Together with increasing industry collaborations, there is no indication at the moment why knowledge should become less regulated and remain, at least to the degree it has been in the past, a public good, which was the original idea of university knowledge production.

The difference between Germany and the U.S. in perceptions on patents and cooperation with industry along with the institutionalization of patenting at universities and of industry cooperation in publicly funded projects was noticeable in some interviews. This difference, which implies the slightly more open attitude toward patenting and industry cooperation, might explain the reason for the success of both countries in nanotechnology: the U.S. are strong in the transfer of nanotechnology findings into industry whereas Germany is strong in innovations among others through its focus on basic science. As this difference cannot be confirmed with the study’s empirical data that were gathered to answer a different question, it nevertheless represents an issue that is worth being investigated in future research.

7.2.4 Quality

In the U.S., the Bayh-Dole-Act has moved academic research closer to industry cooperation. In Germany where universities can be patent holder as well, patents still present problems as Q1 pointed out:

> “This is complicated. A patent only makes sense if one wants to develop a product or if one has an industrial partner that wants to license the invention. …But one can hardly get funding to start a company if the university owns the patent. Licensing is difficult because one needs a contact person. And university administration certainly does not help in that. … We have submitted and received quite a few patents and have given up almost all of them without ever earning a penny. Because registering a patent costs money, roundabout 300€ minimum… but if you want to keep a patent, you must pay every year more and then it becomes too expensive for your own private pocket. In 2000, there was a new patent law allowing universities to have patents … Then we tried to register patents via our university … which was partially rather bureaucratic … and then one is no longer keen on submitting patents only to say, ‘I own a patent.’ We did it anyway … because we have doctoral students who want to say ‘I own a patent’ although no money is earned with that and also because they learn how to deal with [patents]. I admit openly that all the patents we ever wrote are of no commercial use…. A lot of ideas that become patents are probably not so bad patents with the only problem that the implementation into a useful product would occur on a timescale from 10 to 20 years. And who is willing to finance a patent for such a long time? … The only patents of our group ever earning money were patents … based on which my junior collaborators founded a spin-off company… if they founded a spin-off, they could … get money from banks only as full owners of their patents. And you need that because if you are not the patent owner, then it is very very difficult to find somebody that gives you a single penny.” (Interview Q1, pp. 2-3)

In addition, J1 delegated patents exclusively to the sector of industry:

> “[When I was working at the high-technology company] we have … done our job … and written a bunch of patents. … This is the job to be done in industry. I think, meanwhile we have 70 .. patents on that topic … at [the company]. I am actually [designated] as the inventor in [that patent]. [The patents] remained at the company, I think around 70. … [I still do patents] but very limited. I only do patents in cooperation. I am not keen on wasting time because my personal experience is that patents are completely useless. We could shut down on any competitor with this ‘patent portfolio’ it is called at [the company I worked]. They, the companies, are just too ignorant to do that. This is a waste of time for me. I do not gain anything personally, just like universities. I am not sure. Here, it has not historically evolved that universities finance themselves partly via patents. They have a patent officer who is not very knowledgeable if you ask me.” (Interview J1, pp. 4, 13)

The issue of patents leads to another Mode 2 criterion, quality. The quality of publications is traditionally measured by the peer-review system. Peer-review is still important in the academic work lives of the interview partners. Publications are highly regarded and indispensable for an academic researcher’s and also a Ph.D. student’s reputation and graduation respectively. However, it becomes clear that third-party funding has become crucial for research projects in nanotechnology. External sponsors, government departments, governmental institutes, venture capitalists (in the U.S.), and companies (also mostly by U.S. scientists), are constantly contacted; proposals are written, and projects adjusted to enhance the applicability of academic research for the market. Here, the influence of the market on the field of nanotechnology becomes evident as depicted in the ‘Model of Intervening Mechanisms’ (see section 1.2).

A1 illustrated the situation of nanoresearch in the context of publications and industry as follows:

> “I think success often depends on timing. ... In fact, I was lucky because there was industrial demand for some well-defined materials along with the emergence of nanotechnology. There are many beautiful examples which are on the covers of many papers. Yet, not many really make it into real commercialization so that companies can start producing these ideas. The materials we have prepared are very robust and they have some industrial relevance. After our first discovery, we have formed a consortium with companies from all over the world. Therefore, we have licensed our intellectual property and know-how to several companies. They implemented our group’s inventions into commercial products.” (Interview A1, p. 4)

A1 additionally described how peers and agencies evaluate proposals differently in a sense of quality versus topic-focused:

> “In the U.S., proposals are evaluated by agencies and by your peers, and they say yes or no. It depends on if you have a good proposal but also on its relevance for the long term strategy of these agencies. Thus, the department of energy promotes energy-related issues. The department for the environment would be looking at green and benign chemistry, etc. We prepare green materials, but also bio-relevant materials, energy-related materials, and other various advanced nanostructured materials. One key issue, however, is controlling materials molecular structure. Every aspect of a molecule goes to the structure, which requires molecules with precisely controlled dimensions, shapes, compositions, and functionalities ... Then there is of course an important question, what do you do with these materials?” (Interview A1, pp. 5-6)

R1 summarized the issue of patents versus publications as a conflict of interest between patents and publications. Either, the production of knowledge ought to be fostered that can be openly accessed, or commercialization of products is pursued. Sometimes, companies also do not acknowledge the worth of a patent, thus patenting efforts remain ineffective. If both are pursued, one cannot excel in neither:

> "After all, patents are important if the implementation, i.e., the market prices of a product, is in focus. If you aim at doing basic research of excellence, then patents are not decisive. In that case, leadership is more decisive in order to remain dominant in science. Patents are rather negative in that case because it costs time .. You must spend time to draft these patents [and] to realize these patents, and during that time you could already do the next experiment being practically ahead of any possible competitor. At the beginning of the 1990s … we still did public patents but not at the moment because if basic research has top priority, [patents] are not the most important goal. And if one has the commercial realization for a goal, then patents dominate. But one must ask oneself again and again which point is of top priority. If the first goal is to do globally acknowledged excellent research and this means being possibly the only one active in a specific research field, then you try to cope with research topics in that you really dominate systematically, where you are the only one. Only then you can become known in the end. With a commercial application, the reverse is required. There, the logic is completely different. One must open up mass markets worldwide and one must have products that can be used by everyone … This is exactly the complementary to [each other]. Insofar, the whole discussion about the possible coupling of both things is complete nonsense, if you ask me." (Interview R1, pp. 16-17)

In sum, one can detect a discrepancy between how patents were viewed in the U.S. and in Germany. A1 saw patents as something favorable but something that always comes with luck when one does basic research. In Germany, a distinction was made between patents and publications: patents are industry-related; publications are the 'currency' in academe. Doing both means that one realm suffers. This is also indicated in the study by Jansen, von Görtz, and Heidler (2010, pp. 65, 67) who find that too many patents and a high number of industry partners affect publications and scientific productivity negatively after a certain threshold level.

7.2.5 Accountability

Researchers doing basic research hardly spoke about accountability. More so in the U.S. where some informants focused on drug delivery, issues of risk were touched on. Researchers in drug delivery for instance referred to pre-clinical and clinical trials and the necessity of testing but their research itself was directed toward one goal that served people's need or the market's need. Toxicology was mentioned by E1 and A3 as important for testing nanoparticles and polymers in the environment to find out about the consequences of the use of nanoparticles when actually applied in the environment. Research thus was goal-driven: Basic research also promised to have a concrete societal use. It was pointed out that experiments would have to be tested in the environment (A2). A2 mentioned the creation of CINT to test research in the environment. Yet, first and foremost, the laboratory experiments in basic research came first emphasizing the need for basic research in nanoscience that is crucial for the development of applicable products as basic functions and syntheses must be investigated first. E1, G2, and A2 all emphasized the advantages and disadvantages that nanoproducts can imply and that must be determined.

E1 mentioned the founding of institutes to counter the danger of doing nanoresearch without thinking about the consequences:

> "There are two centers that I know of focused on nanotoxicology. Both are national centers, including several U.S. institutions, but there are also international universities involved in the research. One center is at UCLA [University of California, Los Angeles; author's note] and one is in North Carolina. … They were formed in response to the nervousness about nanotechnology and … too quickly, scientists did not have enough background to really know what they were doing when they put the products out there and to see the effects on human health and the environment. And now we need to respond to the fact that we have too many products on the market. They don't know what the nanomaterials do and [therefore] have to find out. We will not truly know the impact of the nanomaterials until the products are out there for decades." (Interview E1, p. 3)

Here, E1 alluded to the fact that some implications of nanotechnology are not to be known in short term. The 'shadowy' side of the future orientation of nanotechnology comes into play at that point illuminating the dangers that are inherent in a young high-technology. A3 explained the situation of the risks of nanotechnology as follows:

> "There's an article saying that titanium dioxide nanoparticles were harmless–titanium dioxide is harmless, but the nanoparticles catalyze some DNA degradation and actually gave some mice cancer. But I think it's extremely important and extremely useful, but needs to be studied a lot better before–because they're already releasing a lot of products onto the market that they say will be a lot better, but they really don't do toxicology studies, which are really expensive. So it's always the problem. It's an issue of cost versus benefit. And for industry, it's really expensive for them to develop a product and then have it go through toxic." (Interview A3, p. 8)

A3 clearly valued the benefits of nanotechnology and saw the solution in preventing risks from it by including risk analyses similarly to E1's view. Risk analyses however still do not seem to be integrated in a standard way in academic research. This is certainly due to the basic research character of nanotechnology. But still, the public becomes more and more susceptible for the topic and raises questions of risks. In the interview with K2, the only one where risk issues were mentioned, it became clear that nanoresearchers have been increasingly exposed to questions of risk at public presentations but only lately. These questions were flagged down by spokespersons not to speak of possible risks to the public. In the case of K2, the spokesperson of the master's program 'nanosystems' told researchers not to relate to possible risks in public. K2 was one of two researchers that closely dealt with biophysical issues and thus closer to questions of toxicology.

7.2.6 Excursus: Triple-Helix Model and Mode 3

Reciprocity and interaction between university, industry, and government constitute the Triple-Helix (Etzkowitz & Leydesdorff, 2000, p. 114) Governments can intervene in the institutional dynamics and be transformed just like the actors in university and industry. Mode 2 is extended by the concept of Mode 3 based on the conceptualization of academic capitalism and new economy. The hypothesis is that "not-for-profit colleges and universities … are also players in and part of the private sector marketplace" (Rhoades & Slaughter, 2006, p. 10). With Mode 3, the authors refer to the layering of new structures, such as Technological Transfer Offices, and the installment of new positions, such as managerial professionals, in the context of the 'capitalization' of academia leading to a more interdisciplinary structure (Rhoades & Slaughter, 2006, pp. 14-15). This means that in contrast to the triple helix model by Henry Etzkowitz and Loet Leydesdorff (2000), Mode 3 assumes that higher education, government and industry are no longer distinct realms or intertwined, but universities become "capitalistic enterprises themselves" (Rhoades & Slaughter, 2006, p. 16). Academic capitalism developed by Slaughter and Rhoades (2004, p. 1) "explains the process of college and university integration into the new economy", whereby this process is not irresistible. Yet, universities engage themselves in this process actively by accepting market logic and cooperating with industry with increasingly internalizing the value of money. Moreover, this process does not replace the public good regime where values of public good, such as publications, and free flow of information are still appreciated by professors (Slaughter & Rhoades, 2004, p. 129). However, accepting market values by professors leads to withholding research results and the delay of publications among other things (Slaughter & Rhoades, 2004, p. 129). Thus, the academic capitalist knowledge/learning regime coexists with other regimes (Slaughter & Rhoades, 2004, p. 322).

It certainly cannot be tested here if nanotechnology at universities constitutes a Mode 3 field or complies with the Triple-Helix model. What can be said is that market relations and government relations constitute the dominant sectors that researchers have to cope with in everyday life (see also the 'Model of Intervening Mechanisms' in section 1.2). Researchers must acquire third-party funds that are to be received from the state and from industry. This is a constant interactive and non-linear process as researchers reiteratively write proposals to acquire third-party funds and run several projects parallel. This leads to complains about being a manager instead of a scientist. Autonomy, however, and independence are still regarded as important for research even though the market has a say in some cases that certainly impedes academic autonomy. This is the case with A1 whose statement about his industry cooperation showed clearly that he had to pay attention to which results were presented to whom and he had to coordinate with industry which specific projects were to be pursued. Hereby, the relationship between industry and university was not as open as it is traditionally between researchers who commonly exchange ideas without having to fear that ideas are poached. Interviewees did not view the borders between industry, university and government as dissolved but emphasized their autonomy and occupational identity as academics who produced knowledge that serves society. Helping people, improving people's lives was certainly the focus of the majority of informants. Out of free will or not, U.S. informants, in contrast to German interviewees, saw the market as a possible guide and idea giver, but they did not see their independence as infringed upon. Certainly, if one looks at the research projects that interviewees described, application orientation was always given and relationships to companies were established. In that respect, the borders have become blurred which is increased by the fact that government influences institutional dynamics by intervening into who cooperates with whom and which topics are supported with grants. Given that, one can conclude that the relations between university, industry and government are not of equal status due to the fact that government assumes a central position in funding nanoresearch and actively supporting industry-university cooperation where both are not always equally equipped with coordination competencies.

Researchers thus constantly moved between two worlds: the world of science and the world of industry. Both, as academic capitalism points out, still work according to different logics. However, both logics constantly interact. One cannot say that governments give input, i.e., money, into research and then, via patents industry sells products based on applicable results. In some cases, government makes industry and university cooperate with each other, for instance in Germany with the BMBF. In other cases, university turns to industry or industry to university as in the Munich Network K1 was member of. Researchers took hold in relations to government and to industry, but defended their position as still independent researchers who worked with industry for the public good as in G1's and G2's case who stated that the market gave valuable hints for which research direction would be needed. The defense of one's own independent and autonomous position was stronger in interviews with German researchers. They pointed out that this autonomy was the biggest advantage in academia and that they strove to preserve this independence. This resulted mainly in a small proportion of industry cooperation. However, if industry cooperation took place, industry usually had more say, which received the total approval of P1 who said that, if industry gives money, industry must say what is done.

7.2.7 Conclusion

To sum up, with regards to the definitions of Mode 1 and Mode 2 criteria of knowledge-production, the interviews revealed a lack of a coherent definition of inter-, multi- and transdisciplinarity and a lack of differentiation between applicability and applied research. The reference to Mode 2 terms in interviews without explanation or, if so, without a coherent notion of the terms, attested that informants were aware of working in a 'Mode 2 regime' where interdisciplinarity, heterogeneity, and accountability, in particular, were important when doing research and depending on third-party funds. Thus, scientists created semantic links to central terms of Mode 2 to gain acknowledgement and to manifest membership of scientific communities. These links were formed based on the beliefs the scientists had toward the Mode 2 policy terms. With nanotechnology, interdisciplinarity has gained great importance as interdisciplinarity has been favored by public funding agencies and as a cross-technology, nanotechnology constitutes in that sense a prototype for an interdisciplinary specialty or sub-discipline. Therefore, in everyday interactions, meanings were socially constructed in scientific communities by interacting and communicating with external relevant actors, i.e., public funding agencies or companies. By observing and interacting with their environment, nanoscientists internalized meanings into their roles as PIs to be able to fulfill their (typical) roles as it was expected from them.

Typical roles of researchers, however, underlie change. Thus, nanoresearchers observe that interdisciplinarity, applicability, and accountability are terms to account for when talking about research. As part of their working culture, scientists strategically defined themselves and their research depending on if they interacted with other scientists or with agencies and companies. In the former case, they stressed topics and specialization; in the latter, they emphasized interdisciplinarity, cutting-edge research, and applicability. Thus, scientists' life-worlds were multi-faceted and full of meanings that were internalized and acted upon when presenting at conferences, when talking to peers, when deciding where to apply for funds, and when presenting themselves to the public (including interviewers). If nanoscientists for example stressed cutting-edge research, they knew that they ought not to apply for funds for applied research where industry-cooperation was demanded, but for funds where university was the responsible coordinator as R1 pointed out for instance.

What can be concluded from the informants' notion of Mode 2 criteria? With regards to interdisciplinarity, in literature, it has already been pointed out that the use of the terms transdisciplinarity and interdisciplinarity in publications is often unclear, unspecific or the terms are used to mean the same (Roco et al., 1999). The way interviewees described their research cooperation, multidisciplinarity captures best what informants meant by interdisciplinarity. This is because the descriptions revealed that the participating disciplines remained distinct and gave input toward the problem that was to be solved. Heterogeneity in the form of the collaboration of diverse disciplines appeared in some of the cooperative projects interviewees delineated. To scientists, it did not matter if they actually participated in interdisciplinary research groups that worked according to the literature definition or not. What was important was the acknowledgement that nanotechnology was interdisciplinary and that this term had to be infused into personal meanings and acted upon by hiring diverse disciplines for example. The way the participation of diverse disciplines in projects was actually realized was another matter and not accounted for when informants talked about interdisciplinarity.

With regards to quality, interviewees still viewed publications as the most prestigious criterion for reputation and currency of quality. Patents were applied for in industry cooperation or if appropriate, but they did not replace publications in highly-ranked journals. The pros and cons for patents were weighed and often, patenting was seen as too costly or too time-consuming (see in particular Q1 or J1).

Applicability, no matter which portion of informants' research was actually application orientated, played a role in the kind of topics interviewees did research on and was used in explaining one's research even if the actual research done remained at the basic research level. It became clear that informants did not distinguish between application oriented research and applicability. Informants were constantly aware of how their research might be of commercial use in the long run, but they did not specify the time span of when this might be the case while most of their research was still designated as basic research. What is important is that scientists were aware of applicability and could mentally refer to applicability when talking about their research. It was a requirement that applicability was part of a scientist's 'agenda' even though basic research dominated this agenda.

Dependent on the discipline of origin, accountability issues were raised or not. Unlike in chemistry and engineering, accountability topics were not raised in physics. This might be due to the analytical character of physics, a lower degree of application orientation and, in the case of research for the computer or electronics, a low degree of risk for humans in the first place. However, the interviewees clearly referred to Mode 2 terms and interpreted them in the context of their everyday activities. Mode 2 knowledge production affected their research activities, revealing a tendency toward

Mode 2 knowledge production, as has been found from a network analysis perspective (Jansen et al., 2010).

In terms of the working culture that is to be noticed from the expressions on Mode 2 criteria, one can conclude that a Mode 1 working culture becomes evident, which is balanced with Mode 2 criteria. Researchers must be familiar with Mode 2 categories if they want to succeed in the acquisitions of third-party funding. And they have to succeed if they are involved in high-technology research. Yet, their upbringing in a working culture is infused with Mode 1 criteria, in particular disciplinary structures that channel new knowledge and technological innovations into existing academic disciplines. Thus, everyday working culture is constantly brought into equilibrium by researchers who are responsible for the social construction of the identity of nanotechnology and the strategic handling of Mode 2 terms that frame technology and innovation policy.

Academic research does not take place in a vacuum. It is affected by numerous relations within academia and external institutions. From the perspective of the informants, Mode 3 does not grasp their relations to the state and to industry. Researchers still name the independency of industry as a motivator to go to academia and emphasize that they do not orient their research toward industry, as K1 pointed out above in the section about applicability. What remains is that the Triple-Helix formation corresponds to the structures and sectors that interviewees refer to when asked about research alliances and funding one's research. In the case of some state-sponsored research, BMBF and EU projects even enforce industry-university relations with the state as an intermediator between them, thus bringing the three formal elements even closer. This finding is in line with the study by Jansen, von Görtz and Heidler who acknowledge that public funding fosters orientation toward Mode 2 by directly demanding more interdisciplinarity and applicability. This, on the other hand, makes it more difficult to disentangle the influence of funding agencies and the intrinsic character of nanotechnology as Mode 2. Analogously, with the Triple-Helix, one cannot say precisely if the Triple-Helix is a result of the type of collaboration in nanotechnology or if the state enforces the triad of government, industry, and university. Still, the Triple-Helix relations do not seem of equal status in the case of nanotechnology because the state or funding agencies remain the most important addressee for informants when it comes to third-party funding. Interviewees did not mention industry relations before being asked about them explicitly. Thus, further research is necessary in that respect to see if the Triple-Helix adequately describes the nanoscience field. In the interviews, it became clear that in the U.S., industrial relations were more central and self-evident than in Germany, sometimes because of the given fields of research that were more applicable.

7.3 The German and the U.S. Academic Research System: A Summary and Comparison Contextualizing the Voices and Lives of Nanotechnology Researchers

7.3.1 Institutional Comparison

In this section on institutional comparison, it is hearkened back to chapter 5 on the comparison of the higher education systems in Germany and the U.S.. The assumption goes that national institutional differences lead to differences in the development of nanotechnology in higher education and academia by providing answers of which one is more probable than others given the institutional rules of a society. Points of reference are the departmental structure and the role of professors whereby references are made to chapter 2 that includes the section about national innovation policies on nanotechnology. It is to be noticed that the case of nanotechnology provides interesting insights into how single cases can be different from the overall academic institutional structure and long-assumed beliefs about higher education systems.

Based on the exploration of the evaluations and maxims of action from the interviews in the context of funding and policy, the tension between nanoscience and politics becomes clear once it is delineated how technology policies have evolved in the U.S. and Germany. This tension arises due to the differing interests of the main actors involved, i.e., nanoscientists and politicians. 'Life worlds' or "realities – and therefore actor's interests – are constantly reconstructed and .. ideas and their processing over time shape this process of reconstruction" (Edler, 2003, p. 255). In other words, a constructivist perspective integrates "underlying rationales that define conflicting interests and the forces and processes that change the very perception of actor's interests" (Edler, 2003, p. 257). Political actors are interested in economic growth and national competitiveness (Schaper-Rinkel, 2006, p. 484); scientists are interested in pursuing research for the sake of knowledge production and publication (as to be seen with those scientists that were interviewed in this study).

If one integrates the political view on nanotechnology and innovation in Germany and the U.S., one can see how tension is produced due to the conflicting rationales and interests political and academic actors have with respect to their differing 'life worlds' that demand different maxims of action. Given the national policies of innovation and technology for the U.S. and Germany, it was not predictable that nanotechnology would be absorbed by all industrialized countries. Even though its development was not coincidental, it was contingent (Wullweber, 2010, p. 304). Thus, it was not completely surprising that nanotechnology could become a firm pillar of these policies.

Department and Personnel Structure at University: Flexibilization through Opportunities?

The general statement that there is greater institutional flexibility in the U.S. due to the college and department structure is re-examined here due to the fact that new structural opportunities have arisen in Germany that facilitate the attachment of new institutes and degree programs. In the U.S., more and more nanocourses have been offered over the last decade, however more slowly (Stephan et al., 2007). There are singular associate degree, bachelor, and Ph.D. programs. Yet, the dominant trend is toward immersion of nanocourses and nanocontent into existing programs. This becomes evident at PSU. D1 who was convinced that nanotechnology would not become a separate college program lists several reasons, including reasons of efficiency and viability, which speak in his opinion for the immersion of nanotechnology into existing programs:

> "[In Pennsylvania] we've created pathways so that a student can go to one of the community colleges and then spend one semester here at Penn State learning about nanotechnology. This is a four-semester program where a student spends three semesters at their home school ... We advocate what we like to call a central facility teaching model. In teaching nanotechnology this central facility model is necessary because it is very difficult for small schools to effectively teach nanotechnology. They just don't have the necessary resources. They, in many cases, don't have the nano-literate faculty that will be able to effectively teach the course work and they don't have the equipment. The equipment that we utilize is very expensive, requires maintenance and expertise to keep it running, so it doesn't make economic sense right now to have these equipment sets at each institution. ... We now have all the two-year schools, all the community colleges in Pennsylvania, participating. We also have many four-year institutions which now participate. So this semester, this immersion experience is taught in University Park using lecture facilities as well as Penn State's nanofacilities. Here in Pennsylvania, we have schools that are offering a degree in physics with a concentration in nanotechnology. Or a degree in biology with a concentration in nanotechnology. ... We enable this cross-disciplinary diversity to occur through this center. The federal government liked our centers' approach to nanotechnology education very much and they gave us the funding to become a national center, to do this job for the country. The name of the national center is NACK, Nanotechnology Applications and Career Knowledge. ... Across Pennsylvania is how it started, and now it's across the country. We also have a lot of international interest. The Russians invited us over in the fall. … [A]nd the Russians are very interested in implementing. I've been invited to a European meeting in Barcelona in May [2010] called Genesys, to give a talk on what we're doing here in the U.S.. ... You asked, do I see [nanotechnology] being ... subsumed in other programs and becoming a field of its own. I think it will always be subsumed in other programs because it's so pervasive and I think concentrations are a very good idea. So …, options like getting a degree in physics with a concentration in nanotechnology is a very good way to go. Although I know some universities, … some

> in Germany for example, are creating four-year degrees in nanotechnology. … I personally don't think that's the right way to go … I think you need to build on the courses that you have and then have some kind of immersion like we do. ... I think that the fundamentals don't change; it's just that you bring them all together in nanotechnology. … And the second reason I think the immersion is a better way to teach nanotechnology is that it helps us to keep the old courses and then have an immersion. I think economically it's viable. I don't think we can afford to have a whole series of new courses." (Interview D1, pp. 2-3)

The case of the U.S. suggests that greater institutional flexibility and diversity in higher education institutions do not necessarily imply institutional change in the form of a layering of new study programs onto the existing educational infrastructure and curricula, for instance. Curricular flexibility is given in the U.S., but the institutional structures turn out to be more rigid when it comes to new career tracks. Where layering in the U.S. has become evident is in the creation of new research institutes that are committed to nano-scale research by being funded by the state and/or by external users. Another example for that would be engineering where Germany as a typical CME also provides more career tracks and vocational profiles. To prepare for the labor market, the U.S. regard immersion to be sufficient. In Germany, new programs, centers, and (though very few) chairs are established instead. The thesis derived from the interviews is that Bologna and the 'Excellence Initiative' do not merely imply a trend toward more third-party funding, but have also incited a certain 'flexibility' into the departmental structure by inducing researchers to create degree programs, master programs, and focal point programs. These reforms have no equivalent in the U.S., although there, reforms also took place, such as those based on the COSEPUP report from 1995 (Bartelse et al., 2000, p. 289), yet without the same effect that Bologna and the 'Excellence Initiative' have had. In the interviews, researchers frequently referred to the German reforms when explaining their actions and committee functions and addressing the problem of recruiting skilled graduate students.

As mentioned in the section about institutional change from the perspective of neoinstitutionalism, the mechanisms of innovation, 'layering' and 'translation' describe very precisely the changes in the German higher education system. 'Translation,' i.e., the "blending of new elements into already existing institutional arrangements" (Campbell, 2010, pp. 98-99) with the formation of master programs, research excellence clusters, and graduate colleges that are, in other words, 'layered' (Streeck & Thelen, 2001, p. 31) onto the existing organizational structure of universities. Institutional change thus results from the reinterpretation of the Bologna reform and from the attachment of programs, graduate colleges, and also excellence clusters as "new institutional layers are grafted on to existing institutions" (Campbell, 2010, p. 100).

As is common, professors in Germany are either W2/W3[6] professors or chair holders. In the U.S., professors are members of departments. This is what can be described as organizational coupling: By contracts, German professors who were interviewed were attached to faculties that, in turn, were composed of institutes where the professors worked. German doctoral students were, if they obtained a budget position, also part of faculty. Although graduate students used laboratories, for example paid by the DFG, or had their offices in a DFG-nanocenter, their attachment was closer to their professor's chair or research group. In the U.S., Ph.D. students were attached to the department or college. Departments as opposed to chairs in Germany were set up broader combining up to 40 professorships (all levels) in the case of the informants (and this number might be larger in other departments and universities). Thus, organizational hierarchy was greater in Germany with fewer and more

broadly defined chairs that employed mostly doctoral students, seldom post-docs or permanent research staff.

Ph.D. students in the U.S. were financed by third-party funds having project positions. Professors were responsible for acquiring third-party funds although it can also occur that graduate students as faculty are in charge of acquiring external support (Hackett, 1987, p. 139). Edward J. Hackett (1987) sees this trend critically when he remarks:

> "As internal and external support for grad students is diminished they will be supported by research grants (and contracts) at increasingly early stages of their education. The potential effects of this are a reduced capacity for independent work (because they become important parts of a scientist's research effort early on) and the possibility for premature specialization as they acquire the restricted range of knowledge and techniques required by a research project. The pressure to specialize is intensified by intellectual change in the sciences." (p. 140)

This statement argues that specialization in the U.S. takes place early in graduate studies and is a prerequisite for a professorial position for professors are in charge of certain lines of research. In Germany, chairs and their incumbents rather encompass a broader field of research. This implies that German professors have more competencies in a more hierarchically structured academic system. However, the interviewees were quite specialized in their fields with regards to nano. One reason why this was possible is the need for specialization for the acquisition of grants, but also because the 'doctoral base' in German research groups can be quite large. None of the professors interviewed were actually doing lab work anymore. This is solely doctoral students' work that becomes more and more specialized because instruments are expensive and, as emphasized by R1, understanding and doing his research is not something that can be done "over one afternoon" (Interview R1, p. 15).

In the U.S., professorships are more specialized as the department is larger. One could say that U.S. research groups are more team-oriented than German research groups. Yet, in the meantime, a German professor's graduate students are indeed called members of research groups or teams as well although a majority still holds a position paid by the university as a fixed research staff position. Furthermore, the number of graduate students in Germany can be higher than in the U.S., although in the U.S., the number of post-doc positions is greater than in Germany where a professor can only have, for example, one technician and one tenured doctorate research staff. Therefore, the latter statement must be revised saying that there is a tendency toward more teamwork in Germany–at least with regards to the naming of organizational units.

In terms of coupling and decoupling, which were alluded to when describing the discrepancy between 'formal structures' and 'work activities,' nanocenters and -institutes are attached to universities. However, in Germany, professors are still formally attached to faculty and institutes of a university. In the U.S., professors are attached to departments and colleges. Decoupling takes place because specialization occurs at a lower organizational level, namely within professors' research groups. Professors used nanolaboratories and -institutes, but they did not 'feel' attached to them. They remained mentally situated in faculty institutes or 'Fachbereiche' as they are called in faculty ordinances or departments. Thus, they did not 'make sense' of organizational life at universities by adhering to the practices imposed by external actors, such as the DFG. They were still convinced that traditional disciplines were important and had to be taught, but they arranged themselves with the idea that for 'rational' reasons, institutes with the nano-label have become part of their work lives since they provided instruments, office space, and external visibility. A more adequate term therefore would be "loose coupling" as Karl E. Weick (1976, p. 3) describes educational organizations. Loose coupling implies that entities are coupled with universities, for instance institutes and professorships. However, they all keep their identity. This notion of "loose coupling" in the context of education systems must not be confused with the one that sociological neo-institutionalism established to refer to the relationship between 'formal structures' and 'work activities.'

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[6] After the introduction of a new salary scheme, in addition to C3 or C4 positions for professors with chair, there have been added W3 and W4 professorships that also exist at Universities of Applied Sciences. Thus, formal remuneration differences have been elicited.

Thus, loose coupling describes what has happened institutionally in the nanosciences: Scientists were coupled with nanoinstitutes and -centers that were at the same time coupled with universities. However, professors and doctoral students working there kept their identities that were linked to their fields of research, disciplines, and study background. Furthermore, the Bologna reform demonstrates how opportunities have been created through state policies that exert influence on the institutional setup of universities. In the case of nanotechnology, the requirement to create bachelor and master programs was used strategically to implement new content and research in universities and thus used favorably to realize scientists' interests in not only raising third-party funding, but also in recruiting students via new degree programs and making their universities more attractive to the outside world. In the U.S., institutional change has mainly occurred through the installment of new institutes and research centers in favor of doing large-scale research.

In both countries, doctorate projects were still individual projects. Thus, despite the organization in groups that were subordinated to a professor, graduate students rarely worked in teams on their projects. Yet, they did discuss their topics and exchange ideas as underlined by C2 and O2. Recognizing the fear of researchers that their ideas were poached, C2 described how his group collaborated by discussing their doctoral projects that nevertheless stayed independent from each other:

> "If you have someone who you fear might overlap with your project and might go into your real estate and take over your ideas, people get much more hesitant discussing. And in some groups that's a problem. So what we have in our case is that the projects tend to be quite independent. Of course sometimes you would have another person who also works with carbon nanotubes and you discuss general chemistry ideas, but the project will still stay independent. .. I do not collaborate with a certain person on a very tiny part of the project or have a lot of overlap. But what happens is, .. whenever I think I have an idea that I think is worthwhile pursuing, I bring it up and discuss it with a post-doc or with other Ph.D. students, and they do the same with me. And that's [usually] the collaboration in our group." (Interview C2, p. 7)

O2 emphasized the open atmosphere in her professor's research group and also the informality of seeing her adviser:

> "Everything is very straightforward. One can go by the office and say, 'look, I have some curves, can we discuss them?' … I have my office and the laboratory here on this floor. Most of the others sit downstairs in the other building. He [my adviser; author's note] also simply comes by and sits down and talks to you. We also have a seminar to give a presentation. Then, the colleagues know what one is doing and discuss it. But this is quite uncomplicated." (Interview O2, p. 3)

Another finding supports the traditional orientation of German universities and politics toward the functional view of education, the production of a labor force not by open job profiles as the U.S. do, but by specialized degree programs that are supposed to lead directly into job positions in the labor market. The labor market in Germany is more closed, i.e., less flexible in absorbing graduates with a different study specialization. Programs, in particular undergraduate programs, are less specialized in the U.S. where students often change tracks when they decide for a graduate program. In Germany, despite the Bologna reform, students stay in their degree program and add a graduate program that matches their undergraduate studies. Thus, what was previously mentioned when presenting the static 'Model of Intervening Mechanisms' is supported: the traditional early specialization in Germany which had been done in an exemplary way through the German *Diplom* is now continued by bachelor and master programs that complement each other. N1 from the German VDI saw the production of nanotechnologists as something he was in charge of. He strongly believed that once nanotechnologists enter the labor market, companies will recognize their need to employ them:

> "When I talk to companies, they often say, 'nanotechnologists, we do not really need them.' And it is not surprising because there are only a few nanotechnologists on the job market. But now there are more than 30 degree programs on nanotechnology. Ten years ago no nanotechnologist existed. Meanwhile, there are some graduates. These are degree programs that have been developed recently. For now, those who work in companies, they often have studied physics or chemistry. Yet, one thing is certain: nanotechnologies are very promising, in particular for research organizations and companies." (Interview N1, p. 10)

If these changes at U.S. and German universities indeed will result into more flexibilization and potential for institutional innovation and structural higher education reforms will be seen. What can be said is that previous reforms like Bologna in Europe have created structural opportunities (Blau, 1994, pp. 8-9), but also constraints for institutional change. This does not mean, automatically, that more individuals will fill the vacancies that are created by these opportunities. It also reduces the assumed power that individuals think they have when they incite change within university. Without structural opportunities for new degree programs or new institutes and laboratories, individuals would have but little potential to accomplish what has been accomplished in the realm of nanotechnology in academia.

What the analyzed situation also manifests is that "there is a sharp distinction between what produces the opportunities and constraints in ingroup and intergroup associations … and what determines the likelihood of moving into various positions, including occupations" (Blau, 1994, p. 11). Reforms, political projects and strategies as well as public funding are some examples of what creates opportunities and constraints (e.g.: the focus on one topic of the funding agenda implies the reduction of funding in another area) whereas the individual life courses of the interview sample reveals that the picture is different in terms of who moves into these positions given the different procedures of application and recruitment. The latter is discussed among others with reference to Blau's findings in chapter 7.1 on "The Constitution of the Field" that addresses the involvement of professors in recruitment next to other tasks. There, too, positions that are not vacant cannot be filled no matter how much the influence of an individual. An individual can still be involved in the creation of a new position, but only in combination with other factors, like financing, that support his or her endeavor.

Central Role of PIs

In both countries, graduate research is built around research groups being the smallest organizational units. There are research groups, not departments, headed by a professor who directs the lines of research and topics to be worked on by doctoral and Ph.D. students. In Germany, third-party funding and the state secure doctoral positions, whereas in the U.S., there is a clear domination of Ph.D. positions funded by grants acquired by professors. Several U.S. Ph.D. students explained their joining of the research group by the research topic and reputation that motivated them to send unsolicited applications to the PIs, for instance A2 who was interested in polymer chemistry and heard about A1 and the polymerization method A1 developed:

> "So that was mainly for [my advisor]. I had come from a physical chemistry lab in my undergrad and I had done mostly things like characterization … It was still polymer-based, but I was interested in learning about synthesis of polymers as well. Not just characterization. So this university caught my eye in general because there's many professors doing a lot of interesting polymer work here, and of course if you look at this university, you immediately see [my advisor], and he was so incredibly intriguing, the kind of work that he did." (Interview A2, pp. 11-12)

Thus, the lines of PI research but also personal character as previously quoted from the interview with M1 were crucial in the match of graduate students to research groups and projects. Then, PIs in both countries also actively recruit students whom PIs find are interested in their research. PIs seek students from other disciplines if required. J1 for example does not only want to have chemists and materials scientists in his group but also would like to have an electrical engineer to cope with his research projects. He explained,

> "[T]he problem [of recruiting young researchers] is a little more complex. I need an interdisciplinary group. I have chemists, physicists, materials scientists. Now, I have one from .. a degree program … 'molecular science.' This is a broad spectrum. Ideally I would [like to have] someone [else] from electrical engineering." (Interview J1, p. 8)

What should speak for high levels of communication and organization in nanotechnology, and consequently for a coherent group structure in nanoscience, is the fact that the informants were convinced that "they are in process of formulating a radical conceptual reorganization within science." Furthermore, nanogroups identified a "leader who may be a major source of conceptual and methodological innovation, and who generally serves as a scientific model for at least younger members of the group" (Griffith & Miller, 1970, p. 139), therefore, speaking for coherence in these groups. In addition, the engagement of professors, both in the U.S. and in Germany, in "professional politics to obtain … research support" seems to support the latter (Griffith & Miller, 1970, p. 139). Either professors directed their research toward topics that were funded (see B3) or they actively engaged in obtaining research support, such as R1 in Germany who made his acceptance of the offer of a chair dependent on public funding to be used for the establishment of a nanolab:

> "In Hamburg, the situation was such that there were actually no prerequisites for the nanosciences. I have established this realm back then. .. There had not been any activities in the area of scanning probe microscopy or nanosciences. The initial point actually was my decision to go to Hamburg. [This decision] was supported by the fact that the Free and Hanseatic City of Hamburg decided to build a so-called Microstructure Research Center, as they called it analogously to the Max Planck Institute of Microstructure Physics in Halle. At that time, it was still micro because nano was not known at all and, in particular in political circles, it was not common, whereas micro was linked naturally to microelectronics and microsystems technology. [These terms] were known. Nano was not at all en vogue back then at the beginning of the 1990s. Insofar, it was decided to build a .. Microstructure Research Center headed by three chairs to be established here in Hamburg. And this was accordingly strongly financed with, then it was still in DM, … around 16 to 18 Mio. DM. This was a lot of money. If distributed among three chairs, … it was a multiple of what somebody usually received [as a] recently announced chair. In this respect it was certainly the prerequisite [for me to go to Hamburg] to [have the opportunity to] build here something new." (Interview R1, p. 2)

R1 had a strong view of his personal influence on the development of nanotechnology, even though surely opportunities that were provided by the university made it possible in the first place for R1 to realize his research plans. Changes incited by oneself must not be confused with changes that are enabled through structural opportunities (Blau, 1994). Still, several of the professors that were interviewed can be categorized as 'star scientists' with a high number of publications that were above average. Like R1 and P1, these were professors with a higher-than-average third-party funding budget. Along with the simulation results, this supports the relationship between publication, national level of public funding on nanotechnology, and the influential role of 'star scientists' within research networks (Zucker et al., 2007). In terms of PI's funding strategies, B3 from the GTRI had a more pragmatic approach to procuring funding than R1. He explained his strategy as follows:

> "The reactive nanoparticle project actually came the other way around. The government was interested in who could do something with nanoparticles and they ended up coming to us and we're like, 'yeah, we could probably do that.' Between the project, we kind of honed it in on what we're doing now. But then often we'll take these ideas from one project and then we'll look for other government solicitations and see what we do and if someone else has got something similar out there. But the U.S. government, a lot of the funding in the last few years is in homeland security. There's a lot of funding for sensors and things to detect explosives and things like that. If you're looking at solicitations, it tends to be more in that area than there is in just general defense. … [S]ome worry about, there won't be any money available because they're changing the budget. Well, the government still has a lot of money; they're just changing where it goes. Well, here at GTRI, on the academic side, you kind of change your focus. .. These people have the money, so let's try and alter our research a little bit to go that way. So even though … 5 years ago [we] were doing carbon nanotubes, we try to go that way. There's a lot of work and funding available in energy. Because fuel prices are going up and things like that. Alternative fuels, fuel cells and solar and all those have got a little bit more funding available nowadays. So that's one of the projects we've got in our group[,] .. a solar cell project with carbon nanotubes. So we're able to find a little bit more sponsors available there. Also the nanogenerator, with the piezoelectric, we've got some more folks interested there because we're creating energy from a tiny little device as opposed to burning gasoline. So there's some more interest available that way. So the ideas come various ways and various means and we try to take advantage of who has funding to keep that going." (Interview B3, p. 3)

The initiative for funding and doing research into a certain direction also comes from scientists who do not only react to technology policy and funding opportunities, but also proact, for instance by developing new devices and presenting them to the government:

> "Internally, the Georgia Tech Research Institute has some funding for continuing research for novel ideas ... [So] we can actually get to a certain [level in our research], maybe to a prototype device that we can show the government or to an industry specialist [and say:] 'Hey, this is what we made. What do you think?' And maybe they can provide more funding to develop it more into a product." (Interview B3, pp. 3-4)

Here, the intense contact of U.S. scientists to industry becomes noticeable in contrast to German informants. These statements support the finding that public funding plays a crucial role when looking at the definition of a new academic field. Professors are not 'resistant' to funding channels, but susceptible to them whereas researchers themselves also influence where public money goes. R1 further pointed to the niche of spintronics he was doing research on, emphasizing that he and his group belonged to five groups that did research in that field worldwide. This demonstrates the high degree of specialization in nanosciences. This specialization was possible for R1 as a chair holder due to his comparably large research staff. According to Czada (2002, pp. 37-38), specialization can lead to the emergence of a new discipline at the borders of an existing discipline and to interdisciplinarity. Especially physics, as a heterogeneous main discipline, has been affected by specialization and the separation of new specialties. For nanotechnology, it remains to be seen if it evolves into a discipline. Later, reasons will be stated why nanotechnology probably will *not* become a discipline. The following statement reveals R1's consciousness of doing "research at the very front" (Interview R1, p. 16) in nanotechnology, i.e., at the borders of his discipline, to legitimize his line of research:

> "This is of course also the key for success. I am giving you now a concrete example for what I have been personally known worldwide for 20 years. It is this so-called spin-dependent spin-polarized scanning tunneling microscopy … In this area, between 1990 and 1999 we were the only group worldwide that could publish results in that field. In 1999, it was first possible for a group from the Max Planck Institute in Halle to publish a paper, and we just had the third international conference in that field where unfortunately only five groups were represented worldwide. This is to be traced back to the fact that this is extremely demanding and that co-workers need a lot of know-how but also a lot of commitment. And it is not that somebody can sit down for an afternoon to reproduce it. This is really research for years that we have established over the years at Basel and then … here in Hamburg. After leaving [Basel, this field] was not pursued any longer. We kept working in that field here in Hamburg and extended it so that it is known worldwide that magnetism on atomic scale .. performed in Hamburg is globally leading." (Interview R1, p. 15)

When looking at personal statements, one must always be aware that individuals are placed into a social (institutional) context. In R1's and J1's case, both witnessed large institutional change at German universities and saw themselves as strategists who actively fought for institutional change. In their case, opportunities for structural change were always present: in Hamburg, the city state of Hamburg and Hamburg University were eager to install a center for microstructure research and provided large public grants for this establishment. Thus, R1, with his experience in the nanosciences, had an advantage and took the opportunity to apply for one of the chairs that would come with the creation of the Microstructure Research Center. Similarly, J1 became professor in a time when government initiatives like the 'Excellent Initiative' came into being and opportunities were created to install new programs, graduate colleges, and special research fields. Only P1 explicitly spoke of becoming an academic out of "opportunity" (Interview P1, p. 3) given to him. Other interviewees took a more self-centered perspective in telling why they became professors.

One must bear in mind that individual ego-centered perspectives conveyed in personal statements above blind out the opportunities that were given to the informants due to structural change. So, one can conclude that, along with the governmental initiatives, the organizational formal competencies and institutional influence of German professors, derived from the actual position at university, are still more encompassing than those of a U.S. professor. German professors, as chair holders, are in charge of broader areas of research. These competencies are even larger now with the Bologna process and the 'Excellence Initiative.' German professors are offered opportunities to participate in structural change by heading special research fields, counseling nanotechnology degree programs, and having doctorate students that are formally attached to graduate colleges. However, most of the German interviewees were W2 or W3 professors attached to an institute rather than chair holders. The thereupon following greater number of professors at institutes provides the opportunity for more specialization and possibly for the development of a new discipline, also in Germany (Czada, 2002, p. 38). And indeed, if one looks at all the specialties that physics and chemistry offers, professors' research domains, as to be seen on university web pages and as expressed in interviews, are quite specialized dealing for instance not with nanotechnology, but with nanomagnetism, nanophotonics, nanoelectronics or nanooptics. The strong, but less formal internal positions result from the fact that professors in both countries determine lines of research, doctoral project topics, and the way students are funded. In Germany, the strong internal position is additionally based on the traditional professor−student relationship that is still prominent in individual dissertations where doctoral students are not members of a structured graduate college or doctoral program that have been established over the last 20 years by the DFG. German students are rarely involved with grant proposals and external funding acquisitions.

Coherence between groups might be larger in the U.S. with national initiatives that connect big research universities, but also smaller universities by offering the use of clean rooms and laboratories to external institutions. The interaction with start-ups and external laboratories is more frequently observed in the U.S. than in Germany. Yet, the goal in Germany is not to have a comprehensive NNIN as the U.S. do. In contrast to Germany, the marketing of nanoinstitutes is done by managers and research scientists employed solely for this reason. As tenured professors also use these clean rooms and use them together with their external collaborators, including companies, external institutional coherence is also greater in the U.S..

To conclude, this institutional comparison demonstrates how national differences lead to differing implementation of new specialties, such as nanotechnology is. Organizational hierarchies, the coupling of institutes, departments, and chairs to the university as well as differing conceptions of how tertiary education is supposed to create a knowledgeable college-educated workforce give nationally proper answers to the institutional adoption of a high-technology into academe. The institutional diversity of universities in the U.S. has not lead to the change that is to be observed in Germany where the Bologna reform has served as a 'catalyst' for the aspirations that politics and universities had to prepare

their higher education system for the future knowledge society, to speak in policy terms. In the U.S., nanotechnology degrees are found sparingly and most often in community colleges where they are kept somewhat isolated from research universities and graduate colleges. In Germany, such degrees are installed at the center of research and technical universities as well as universities of applied sciences.

One could ask, then, whether this setting can become detrimental for progress in research in high-technologies if German training is institutionalized so closely to academic basic research and not kept apart from big research universities as is the case in the U.S.. This question can certainly not be answered here. The results of the differing national implementations of nanotechnology might be different, and workforce differently trained. Yet, it will probably be hard to define which nation is better before knowing in which sphere a country wants to succeed in particular. Whereas in the U.S., basic research is undisputedly on the top of the agenda, the training of a skilled workforce has priority in Germany. The latter certainly does not mean that research comes second in Germany. Yet, the German higher education structures are set up in such a way that tertiary education and training are facilitated and realized more straightforwardly and formally, above all in terms of curricula and study programs. One can conclude that national solutions are provided in both countries to the political and academic interests that are channeled into existing institutional structures without impeding institutional change. Interviewing social actors that are part of that institutional change reveals how both interact and provide answers that follow existing institutional settings.

7.3.2 Comparison on the Level of Individuals

The Standing of 'Nano' within the 'Nanocommunity:' Funding and Publication Patterns of Informants

There are several studies on nanoscience as a specialty and the (exponential) rise of the number of publications in nanoscale research. One scientometric study by Schummer (2004), for instance, looks at journal classifications and the number of nanoscale research articles both in nano-entitled journals but also in general journals. Nanoscience is categorized as a discipline in the Web of Science. In the simulation model, nanotechnology is operationalized as a sub-discipline and research program when looking at how nanoscience is established in the scientific community. In the following diagrams, the sources of funding and the scientific journals are presented according to the Web of Science−SCI where the German and U.S. informants from this study published until the beginning of 2011. These objective data are then compared with the statements from the interviews that revealed the reluctance of nanoscientists to define themselves as nanoresearchers and to designate themselves as members of the nanocommunity. The diagrams on funding sources (see Figure 27 and Figure 28) show clearly that U.S. interviewees had a higher proportion of industrial for profit funding with 17% compared to 2% for German interviewees. Public-private partnerships represent 2% for U.S. versus 0.35% (rounded to 0% in the diagram) for German researchers. This demonstrates that, as assumed by Mode 2 knowledge production and by the VoC approach, a higher market orientation in the U.S., being an LME, compared to Germany, being a CME.

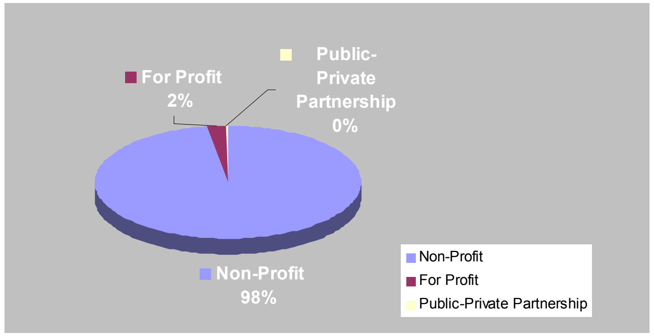

Figure 27: Proportions of Funding Sources for German Interviewees; Own Source

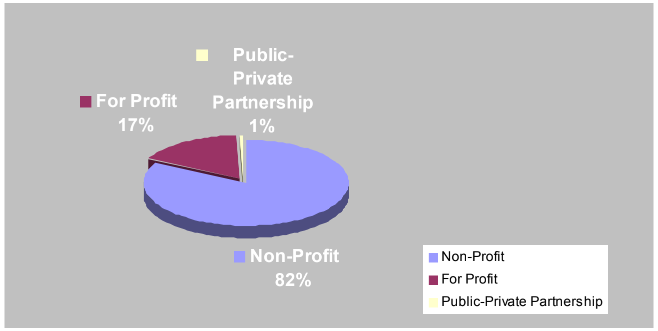

Figure 28: Proportions of Funding Sources for U.S. Interviewees; Own Source

The next diagrams (Figure 29 and Figure 30) delineate the proportion of association-affiliated journals, such as the Journal of the American Chemical Society, the proportion of conference and meeting proceedings organized by academic societies, as well as the proportion of conference proceedings.

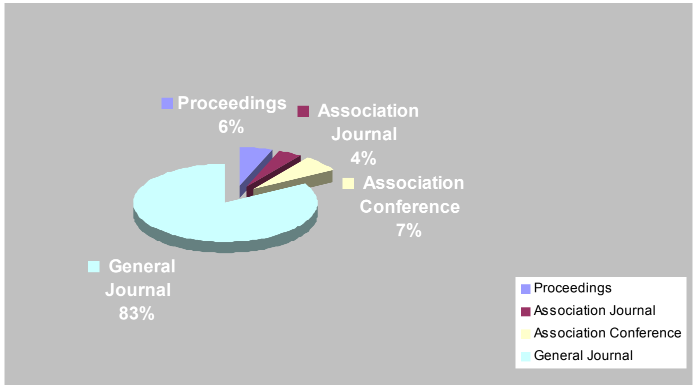

Figure 29: Proportion of Journal Categories for German Interviewees; Own Source

In both country samples, journals unrelated to proceedings and academic societies comprise most of the publications. In terms of proceedings, German interviewees published more meeting proceedings relatively to the total of publications to be found via the Science Citation Index than their U.S. counterparts (6% versus 1%).

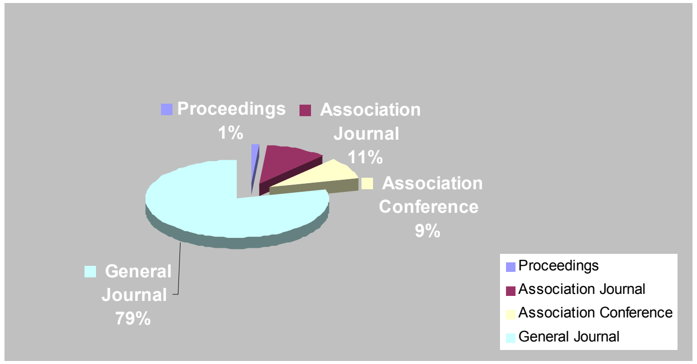

Figure 30: Proportion of Journal Categories for U.S. Interviewees; Own Source

Most interestingly, the picture is different when considering academic professional associations. U.S. interviewees published more association proceedings and more articles in association-related journals than German interviewees. U.S. interviewees published 11% of their articles in society-affiliated journals (versus 4% for German interviewees) and 9% (versus 7%) in proceedings generated at conferences or workshops organized by associations, such as the American Chemical Society, the Electrochemical Society, the Materials Research Society, the American Heart Association or, most prominently and most often cited, the IEEE.

Thus, in relation to the sample interviewed for this study, U.S. associations for academics are more prominent than German associations, such as the Deutsche Physikalische Gesellschaft, on the international level in terms of publications and meeting proceedings. This surprising result is contrary to the assumption based on the VoC approach and the static 'Model of Intervening Mechanisms' presented above. U.S. professional societies thus are not to be neglected when looking at academic knowledge production and communication platforms for scientists, in particular nanoscientists. This result does not mean that associations are not important in Germany, as the interviews with German scientists manifested. Naturally, this finding has to be examined with a representative sample and maybe interviews with representatives of professional societies as has been done in the German sample with a representative from the VDI. Yet, this result hints to the fact that U.S. associations related to nanoscience and -technology are greatly involved, even more greatly than in Germany, in the publication of scientific results on nanotechnology and in providing a network of communication for nanoscientists. They are of central importance for the demarcation of the field of nanotechnology. Associations, as shown by the publications examined here, organize conferences and workshops on nanotechnology and provide a platform for the publication of nanotechnology articles, not the biggest platform as disciplinary-based journals do, but a platform that must not be neglected when looking at publications and proceedings in nanotechnology. Therefore, an important result of this study is that professional academic associations play a central role within and for the organizational field of nanotechnology.

Another question of interest is to what extent the interview partners publish in nano-relevant journals. As a cross-technology and specialty, nano-S &T papers have been difficult to be identified. Several studies developed search strategies for the identification of journals that published most of nanotechnology articles. In Table 10, three strategies are presented that give the percentage of all publications by the German and U.S. interviewees. These strategies follow Loet Leydesdorff and Ping Zhou (2007) whose study is based on the criterion of betweenness-centrality of nanotechnology articles, Can Huang, Ad Notten, and Nico Rasters (2010) who did a comparative analysis of different search strategies, and finally a strategy that looked only for the stem word 'nano' in journal titles. The last strategy was adopted because in the interviews, it was of interest to find out about the relationship to and the evaluation of the word 'nano' the informants conveyed.

Search Strategy	**German Interviewees**	**U.S. Interviewees**	**Journals (alphabetical order)**
Leydesdorff & Zhou	2.21%	3.63%	Advanced Materials; Chemical Physics Letters; Chemistry of Materials; Fullerenes, Nanotubes, and Carbon Nanostructures; Journal of Materials Chemistry; Journal of Nanoparticle Research; Nano Letters; Nanotechnology; The Journal of Physical Chemistry, B, Condensed Matter, Materials, Surfaces, Interfaces & Biophysical
Huang, Notten, & Rasters	29.09%	14.81%	**Advanced Materials**; Applied Physics Letter; Applied Surface Science; **Chemistry of Materials**; **Chemical Physics Letters**; **Fullerenes, Nanotubes, and Carbon Nanostructures**; Japanese Journal of Applied Physics Part 1—Regular Papers, Brief Communications, & Review Papers; Journal of Applied Physics; Journal of Applied Polymer Science; **Journal of Materials Chemistry**; **Journal of Nanoparticle Research**; **Journal of Nanoscience and Nanotechnology**; Journal of the American Chemical Society; Langmuir; **Nano Letters**; **Nanotechnology**; Physical Review B; Physical Review Letters; Surface & Coatings Technology; Thin Solid Films
'Nano'-Label	4.38%	3.94%	Fullerenes, Nanotubes, and Carbon Nanostructures; Journal of Materials Chemistry; Journal of Nanoparticle Research; Nano Letters; Nanotechnology;

Table 10: Share of Nanotechnology Publications in Journals as Classified in Scientometric Studies and in Journals Containing a Nano-Label (Journals Printed in Bold Match Journals Identified by Leydesdorff & Zhou 2007); Own Source

What is shown in Table 10 is that German interviewees are only slightly more inclined to publish in 'nano'-labeled journals and proceedings than U.S. interviewees (4.38% versus 3.94%). Yet, they rather tend to publish in journals that publish most of nanotechnology articles based on the larger sample of journals from the comparative analysis by Huang, Notten, and Rasters (29.09% versus 14.81%). Only in terms of the search strategy of Leydesdorff and Zhou who focused on the top 10 core journals of nanotechnology articles, U.S. interviewees published a higher percentage of their articles, though only slightly (3.63% versus 2.21%). Therefore, no coherent picture can be given with regards to the question if German interviewees are more inclined to publish in core nanotechnology journals or nano-entitled journals than U.S. interviewees. An exception is the extended study by Huang, Notten, and Rasters where German interviewees publish almost 15 percentage points more in nanotechnology journals. This, however, is congruent with the interview results from both country samples: there is a reluctance to confine oneself to the community of nanoscientists and -technologists and a preference for identifying oneself with disciplines by publishing in more general, disciplinary-based journals. The publication results demonstrate that identity is influenced by where scientists publish and vice versa.

To conclude, there are two main findings on the contextualization of the informants in terms of where they published articles and the affiliation of journals to professional academic associations. First, U.S. associations do appear to play a central role, both nationally and internationally, for the demarcation of the field of nanotechnology by providing a platform not only for nanotechnology conferences and meetings, but also for the publication of nanotechnology scientific results. Second, and lastly, both U.S. and German informants were reluctant to publish in nano-labeled or core nanotechnology journals except when taking the larger sample of journals by Huang, Notten, and Rasters where German scientists published a higher percentage of their publications relatively to their total of publications than U.S. scientists. This finding speaks for a tendency of nanoscientists to publish in more general, discipline-based journals than focusing on core nanotechnology journals.

The Emergence of a Nanodiscipline?

Nanoscience is juxtaposed to other disciplines because it is funded as a separate entity without being a formal discipline and because nanoscience lacks institutional features, such as departments or chairs (although a few chairs on nanoscale research exist in Germany). Andrea Bonaccorsi and Grid Thoma (2007, p. 816) explain the integration of nanoscience as a discipline as follows:

> "[A] number of disciplines can be identified, including life sciences after the molecular biology revolution, computer science, materials science, and nanoscience. These broad disciplines share the following properties: they have been growing exponentially or much more than average for a long period, they follow a dynamic process of divergent research, and they are based on institutional and human capital complementarity." (Bonaccorsi & Thoma, 2007, p. 816)

Based on this definition, there is potential for nanotechnology to become a discipline. Still, nanotechnology is not unanimously classified as a discipline due to its multi-, inter- or, as others prefer, cross-disciplinarity (Heinze, 2006a; A. L. Porter & Youtie, 2009). To Alan L. Porter and Jan Youtie (2009, p. 1039), nanoscience is integrated into materials sciences that serves as a macro-discipline for nanoscience. In the present study, nanotechnology is viewed as an interdisciplinary sub-discipline or, more general, specialty based on Jansen et al.'s (2010, pp. 54-55) perception that trans- and interdisciplinarity are interchangeable, at least in the concept of Mode 2, because there is no explicit qualitative difference between the two. The terms sub-discipline and specialty are preferred as a compromise since the discussion about the disciplinary character of nanotechnology is quite undecided. Specialty is defined as "smaller intellectual units (nestled within and between disciplines) [that] comprise the research domain" (Chubin, 1976, p. 448).

To a number of informants, nanotechnology is rather an inter- or multidisciplinary tool than a discipline as G1's statement on the definition of nanotechnology shows:

> "I think we should be sparing in … thinking about how we use that word. Because it really is an approach that one can take and a platform that one can use to create structures that have unique properties. But it doesn't make you a micro-technologist or a macro-technologist. I think it's somebody who's developing technologies that can be used for a whole range of things." (Interview G1, p. 9)

For informants, there is no coherent definition used for inter- and multidisciplinarity. To J1, who asserted that he "need[s] an interdisciplinary group" (Interview J1, p. 8) for his projects, interdisciplinarity refers to the involvement of several disciplines to address a research problem. A1 used multidisciplinarity to emphasize the fact that to solve a problem several disciplines must be involved because one discipline, such as chemistry, has clear limits of what you can achieve with it.

> "I myself as a chemist couldn't do much alone. Nanotechnology is a multi-disciplinary area. ... If one would do only chemistry, projects requiring several disciplines would not be developed. .. Chemistry enables but it is not alone. So one really needs to creatively interact with people from different disciplines, and this will benefit nanotechnology." (Interview A1, pp. 6-7)

Another statement by A1 shows that he used multi- and interdisciplinarity in a similar sense, not differentiating between the two:

> "Nanotechnology as such is very multidisciplinary field. ... It comprises different disciplines, synthesis, processing and detailed characterization of final properties. To build something unique and commercially viable you cannot just talk only to chemists." (Interview A1, p. 17)

This reveals that study backgrounds are important and that researchers remain attached to their academic discipline, such as chemistry. His statement 'several concepts are needed' indicates that disciplines do not dissolve, but are combined and needed when using nanotechnology and could be merged in departments. This observation is in line with another finding from literature: The present disciplinary institutional structure at universities represents an impediment to interdisciplinary, flexible and innovate research teams as well as students' research involvement (Roco et al., 1999, p. 266). Therefore, if observed for the U.S. system, it is a fortiori true for the German system.

Reasons for the preservation of disciplines are summarized by Czada. In line with the reluctance that has been observed for the interviewees, this reluctance of adopting the nanolabel is more understandable if one is aware that interdisciplinarity always encloses the danger of losing one's identity. Individual disciplinary identity, not interdisciplinarity, ensures reputation, the currency of science. The mere take-over of cognitive elements from neighboring disciplines or the voluntary cooperation with them always implies either a withdrawal into one's home discipline or the transition to another discipline. This ambiguity entails then a socio-psychological moment of recognition and social closure or opening of participatory and employment chances. The transcendence of disciplinary borders can imply psychological fears of an identity crisis not only of the discipline, but also of one's own personality since one's home discipline offers reciprocal understanding as well as material resources as long as it cares for the maintenance and the creation of new chairs and research resources. As interdisciplinarity is easier the more recognition and belonging one's discipline provides, disciplinary identity seems to be an important condition for interdisciplinarity. This was noted by the informants who placed disciplinary training above interdisciplinary training in nanotechnology. (Czada, 2002, pp. 29, 33, 38)

In sum, there is little incentive to change disciplines and adopt a new disciplinary identity that has evolved out of a new specialty. There is high status involved in traditional disciplines which constitute the organizational form of universities. Universities are structured according to departments or colleges and faculties or chairs respectively, not according to specialties. When one looks at scientific change and the slow evolution of traditional disciplines (Czada, 2002), it is through specialties and "boundary research" (van der Most, 2009) that change in the form of new ideas and methods can be induced into universities. Thus, nanotechnology, as a new technology, offers the opportunity for the development of a new discipline although the status quo shows that there are obstacles to this end coming along in particular with the cross-disciplinary character of nanotechnology.

What opens up the potential for interdisciplinary collaboration in nanotechnology is the fact that new findings contribute to the development of science and disciplines. Thus, despite the strong forces of discipline preservation that are noticeable in the interviews, disciplines have changed in an evolutionary way, new disciplines and specialties have emerged, and interdisciplinarity has occurred. Methods and theoretical elements are borrowed and continue to be developed in other disciplines. Skeptics about the core of their discipline do research at its border and collaborate with other disciplines. Sticking to one's discipline, by contrast, impedes interdisciplinarity. With that, S1's statement that he saw himself in charge of promoting the talk between natural science disciplines already enclosed the danger of losing identity. (Czada, 2002, pp. 29, 33, 38)

Thus, there were elements of both multidisciplinarity and interdisciplinarity to be noticed with German research, yet less interdisciplinarity than in the U.S. with its heterogeneous research groups paid by the NSF, NIH (National Institutes of Health), or the DOD as well as the more broadly set up departments and colleges that collaborated in practically relevant fields, such as environmental engineering (see A2 and A1). In Germany, the mixture of disciplines occurred, if at all, within research groups, which was dependent on the openness of professors. In the U.S., the collaboration of different departments with the participation of a doctoral student appeared more probable due to a greater concentration on problem-solving rather than, as was the case in Germany, on incremental innovations within specialties in main natural disciplines. Of importance is, naturally, that if a center is called interdisciplinary, that this standard is lived up to. However, this has not been visible to a 100% since disciplinary self-categorization, problems of communication and the orientation toward disciplinary autonomy still dominate in the main disciplines of physics, chemistry, and engineering. Overall, multidisciplinarity grasps more precisely how interviewees evaluated nanotechnology, as they all kept their disciplinary identities and looked at problems by asking: What is my discipline able to solve and where are other disciplines needed? How can other disciplines help me in my research endeavor? (Czada, 2002, p. 25)

Despite the observable establishment of nanosciences as a sub-discipline, there was a 'halt' to be noticed when it comes to researchers and their self-conception. The reluctance to integrate nanotechnology as a feature of professional identity was noticeable in both Germany and the U.S.. A majority of informants evaluated nanotechnology as hype and buzzword and pointed to the inflationary use of the term compared to other technologies and topics that are of equal importance, but do not attract that much attention, for instance microtechnology or toxicology. Along with Abbott, the persistence of traditional academic disciplines is to be noticed. In the case of nanotechnology, this is physics, chemistry, biology, and engineering. Materials science is a new and fairly uncontested discipline. It might be because of the missing hype around materials science as a less 'politically infused' term that makes materials science less problematic in adopting it as an element of identification. Moreover, the lack of a consistent definition of nanotechnology in academia as demonstrated above, combined with the lack of a common epistemic content for nanoresearchers and the cross-disciplinary composition of nanotechnology as a platform technology, impedes the emergence of a single nanodiscipline. Therefore, for the time being, nanotechnology constitutes a sub-discipline and specialty. If it turns into a discipline, this will be decided by the development of academic disciplinary structures and their actors.

In the end, these observations support a decoupling from 'formal structures,' namely nanoinstitutes and nanocenters, as stated above in the analysis of nanotechnology as an organizational field (see 7.1). With nanotechnology being interdisciplinary, it can be noticed that nanosciences are more anchored in research in the U.S. than in Germany due to the more comprehensive government initiatives NNI and NNIN. In Germany, there are single nanocenters, but they are not as interconnected as the NNIN for instance. What adds to the greater engagement of the U.S. in nanoscience is the higher interaction with companies and start-ups. In Germany, on the other hand, the traditional focus on (higher) education and the early specialization of students is pursued. The idea of educating nanotechnologists is pervasive in Germany, in particular in politics, whereas in the U.S., the degree programs are held more general. Specialization in nanofields is possible, too. However, U.S. universities do not create new comprehensive degree programs. As the example of PSU shows, the immersion of nanoeducation into existing programs dominates the U.S. education strategy.

To conclude further, interdisciplinarity is institutionally favored in Germany in particular due to new degree programs in nanoscience and-technology that are established. This leads to interdisciplinary, mixed research groups in Germany as J1's or M1's research groups exemplified. In the U.S., interdisciplinarity occurs mainly through the creation of interdisciplinary centers, such as B3's institute at Georgia Tech University, and through students who collaborate with other departments, as A2 does. Institutionally, cooperation between and within specialized departments opens loopholes for interdisciplinarity at U.S. higher education systems.

Applicability: Knowledge Regime Feature or Mental Concept?

To informants, applicability and use of research were central concerns or drivers for the creation of lines of research. There was always applicability in mind even though scientists did mostly basic research. Applied research and basic research approached each other. M1 explained it in the following way:

> "[W]e rarely do .. research .. just for pure curiosity without a final goal. I must say. … We are always driven [by] a final aim that could be applied or … just to unwrap a phenomenon or understand a process. But there is always an aim at the end of the project. So I would say 30% of my research is more applied. That means it has a final aim to produce something that could be used as a product. And .. 70% of my research is really basic research in the sense that we are trying to understand phenomena or we are trying to understand how to combine the chemical structures in order to obtain the properties we wish to have: so in other words what are the combinations of atoms or molecules … to have a certain function." (Interview M1, p. 3)

The informant H1 very precisely described the dynamics in the U.S. market in science and technologies. No German researcher gave such a view about nanotechnology. H1 further hinted to the fact that government funding programs are receptive for nano but that these programs do not call explicitly for nanoscience projects. Thus, nanotechnology seems to involve a community that has triggered a certain momentum in where public funding goes. Government programs focus topics, such as energy. This topic is, for example, the direction that H1's nanoresearch specialized in and for what H1 received funding. To government, it does not matter if nanotechnology is used to progress science in general and for its own sake. Government is interested in the progress of certain fields of application and it embraces nanotechnology if this technology fulfills the purpose. As H1 noted, nanotechnology is the state of the art for a lot of topics that have government priority, which incited dynamics in the economy by financing technology start-up companies, however, not nationwide.

> "I think [I am part of the nanotechnology community] although I do not prefer to be called a nanotechnologist. [The influence of the market] is a good thing. ... The upside is we all have … [these] small companies we created for .. the technologies. The companies that contain the word nano .. So that is the upside. You see the dynamics of the economy. … [Yet,] the money [is] limited ... This country is just too big to unify [i.e., to consolidate financial resources]. … [Government agencies] have all kinds of nano-programs, [the] National Science Foundation. They don't simply call it nano so identifying those programs that fit your research requires the view from multi disciplinaries. But if you look at all the titles. The proposals. They are topics that focus nanotechnology more [strongly]. Under the Obama administration we have quite an amount of money. And energy. It has more emphasis right now, but there are just too many players out there jumping into 'energy' research." (Interview H1, p. 6)

For Germany, one must note that the German Federal Ministry of Education and Research explicitly funds high-technologies, such as biotechnology, and is thus less focused on topics that H1 mentioned here for the U.S.. Several doctorate students mentioned applicability as a motivator, such as S2 and J2. Although students dealt with basic questions about the quantum mechanical effects on an atom level, they always referred to a possible use in semiconductor physics or storage devices in computer industry. To S2, the applicability at the end of the research process was of central importance. He said:

> "[Orientation towards applicability was important from the beginning] at any rate. Many of my acquaintances asked me when CERN, the particle accelerator in Switzerland was opened, if I did not want to work there. And I replied 'no, absolutely not.' I was not at all interested. I am interested in developing something for the aircraft industry or cars or something like that. Those things that keep the world together .. are not of my research interest. …Of course, one must create the basics first to integrate [these basics] into a concept and to have a sensor in the end or so. … It is given here that we have a further goal. There are groups where this is not the case at all. We consist of two groups. One is [active] in micro- and nanoscale magnetism phenomena and the other does atomic and molecular physics. [The latter] is probably also very interesting, but they measure specters etc. … I do not see a greater reason behind it. This is simply basic research so that they know how it works. There is a goal, but no application. Basic research must be done but to see this goal at the end, that there is potential for applicability, this is the important part." (Interview S2, p. 3)

This statement obviously shows that application was an important factor for S2. He distinguished nanoscale research from atomic and molecular physics and addressed the orientation toward application in nanoscale research. S2 had a rather deprecatory stance toward atomic and molecular physics saying "I do not see a greater reason behind it. This is simply basic research" (Interview S2, p. 3). To laypeople, nanoscale research and atomic and molecular physics might be very close to each other as they both deal with small size on the atomic and molecular level. Yet, S2's statement shows that there are differences in nanotechnology beyond size, and one of the greatest differences is the orientation toward applicability. Similarly, J2 considered applicability as something highly relevant. J2 explained how applicability related to basic research on monolayers:

> "[We do] application-oriented basic research. This means the application is clearly given. We know what we want to do. We want to do organic electronics and to produce functional devices, transistors, memory devices or simply capacitors. When doing research, questions arise affecting basic research, such as how a molecular monolayer is arranged or how the package of such molecules is set up." (Interview J2, p. 3)

This citation demonstrates how applicability and basic research are interwoven. If one does application-oriented research, this does not mean that questions that actually belong to basic research emerge. J2's statement also shows that applicability was highly favored: "We know what we want to do" (Interview J2, p. 3). J2 implicitly asserted that research done is not open-ended or, more negatively stated, erratic and random. The open stance toward applicability, however, by no means implies that German researchers had intense contact to industry. It became clear in the interviews that U.S. researchers were more involved with industry than German scientists. From that point of view, the strategy of the EU or the German BMBF becomes understandable when requiring industry cooperation from university scientists.

In times when third-party funding becomes more and more important and more and more oriented toward applicability, basic research is not at the other end of the scale of research, but is getting closer to applied research, thus, supporting Mode 2 knowledge production. Social accountability even comes along with applicability in this context, because nanoinstitutes 'layered' onto universities are opened to offer their services to community colleges, other universities, start-up companies, and industry. This leads to the difference between German and U.S. university collaborations. The type of interaction and cooperation is a more direct one in the U.S. than in Germany. Whereas in Germany direct industry cooperation is extant, but minimal, industry cooperation takes place under the frame of projects funded by the EU or BMBF that require universities to collaborate with industry and to integrate several disciplines into one project. Thus, an orientation toward applicability is institutionalized formally by making it a demand for grant proposals. P1 summarized this cooperation: "There are many funds that can only be used if industry companies participate. Yes, so we have for instance .. BMBF" (Interview P1, p. 8). M1 pointed to the greater degree of applied-oriented research fostered by industry collaboration enforced by public agencies: “So, we have of course basic research paid by DFG and we have of course some projects there. We have projects that are more industrial oriented also within DFG. These are all BMBF” (Interview M1, p. 3). O1 also participated in the 7th EU Framework Program:

> “There is for example one EU project. This is the 7th EU Framework Program, and I am the coordinator for this program. And this means the EU pays for the whole research [project]. And Mekoprint [, the cooperating industrial company,] receives funds, too, because the EU Framework Program had one condition for this project. This is that industry partners must be part of the project because they want to fund technology relevant basic research and finally develop some technology. .. And this is why these industry partners participate.” (Interview O1, p. 10)

This statement is elucidating because O1 basically said that industry partners are only part of the research project because the conditions for applying for funds require industry participation. And O1 later in the interview made clear that what he does is not to be produced in mass industry as many more questions must be solved that range into basic, open-ended research. R1 gave an historical outline of the development of public funding for industry-university relations and simultaneously deplored the concentration of the BMBF on funding large-scale research. Unlike with M1, P1, and O1, R1 had not increased, but decreased his involvement in industry collaboration:

> “In the 1990s, I still collaborated more often with industry. These collaborative projects were also funded much more strongly in the 1990s by the … BMBF, .. in particular alliances that were indeed coordinated by university partners. This funding, above all of alliances that were strongly driven by universities, practically died out completely at the beginning of the new millennium. The BMBF now funds mainly large-scale research. … and, very strongly, industry-led alliances. … Although one might say, public funding has been increased in absolute numbers, it has not been increased in the proper fields unfortunately. .. In particular in the field of new technologies, be it nanotechnology or in general new technologies, the alliances between universities and industry partners have been funded much less over the last 10 years than … in the 1990s.” (Interview R1, pp. 6-7)

In the U.S., industry can be part of the advisory board, thus an institutional member as mentioned above when citing A1. Furthermore, problem-solving leads to the collaboration of different departments and disciplines (see A2 and A1). PSU is another example for an intense cooperation between university and industry. D1 delineated this cooperation as a relationship that tried “to keep the companies happy” but that “serve[s] the students:”

> “One main way that industry influences our education program is through our advisory board. This board is a critical component of what we do. We are training these students to contribute to industry, so we must have their input in order to provide an effective educational experience. When a student comes out of that immersion experience, they have a skill set. We go over that skill set with industry every year. ‘Do you like this? Are we doing what you want?’ Now, we don’t always please them because this company might want this and this company might want that, so we try to keep them all as happy as possible. We must in the end do what we believe is right for the students that we serve. We take the industry input and then strike the best balance to serve the many industry sectors that our student’s will find themselves working in upon their graduation. Our philosophy is, we you want to give the students a skill set that makes them able to get a job in the future. Because as you know, the economy is going to speed up faster and faster. Change will be faster and faster and faster. I truly believe that you have to train students for a lifetime of change. So we develop skills that we think are very important for students and they can build onto those the rest of their lives. At the same time, we want those skills to be skills that companies like, but we don’t serve the companies, we serve the students. So we try to keep the companies happy, but we also try to make sure the students have a good future. So it’s a balance that we try. So to answer your question, the industry plays a big part in helping shape the education that we provide.” (Interview D1, pp. 8-9)

This statement shows that, along with N1 from the VDI, universities were seen as suppliers providing (‘serving’ as D1 stated in the last quote) students, being in the role of consumers, with skills that make them valuable employees. These skills must constantly be matched with the speed of change in the economy and the need for economic growth. The consumer view of students goes along with the academic capitalism-approach elaborated by Rhoades and Slaughter (2004) who observe an increasing trend toward economic logics at universities. Students are regarded here as consumers who have the right to get adequate education for what they pay for their studies and that have to be prepared for a more and more flexible labor market. The question, of course, is to what extent a balance can be kept between serving the industry and the students if the functional role of a university is taken seriously. Industry certainly has, to stay in the world of economics, much more to ‘give’ than students do when it comes to material resources and, not least, funding.

To summarize, applicability of research has become not only an issue in the knowledge regime that nanoscientists face, but also an issue that frames every researcher’s work, regardless of whether he or she does basic or applied research. Researchers must be able to relate to application orientation by cooperating with industry and to situate their work within that frame which is linked to other Mode 2 features, such as interdisciplinarity. The form of governance in technology policy has changed: Instead of hierarchical governance, new and innovative collaboration beyond disciplinary boundaries should be formed (Wullweber, 2010, p. 303). ‘Open-ended’ research is no longer an equivalent of the term ‘basic research’ as J2 suggested saying “[w]hen doing research, questions arise affecting basic research” (Interview J2, p. 3). In the U.S., public funding agencies still fund a high percentage of basic research. With regards to nanotechnology, grant programs are defined more broadly and interdisciplinarily by integrating several disciplines, as H1 mentioned in the interview. However, there are basic research directions and application-oriented final aims given by the size of the budget each department has for research. Dependent on the government, there are times when either the Department of Defense has a greater budget or the Department of Energy as described above by B3. With that, in the U.S., application-orientation is greater than in Germany, as the largest funding agencies next to the National Science Foundation always have specific interests be it the DOD or the DOE. In Germany, where universities receive fixed budgets from the state and where ministries fund research next to the DFG, which is the biggest German third-party funding agency, basic research is still less application-oriented and, as M1 remarked, represents still a larger part one’s research.

Comparison of Life Courses of Professors and Students: Professional Careers in ‘Nano’

This section deals with life courses of those researchers interviewed. When looking at professors, dominant themes were industry experience, tenure, and post-doc times. Some of the professors and the coordinators had industry experience, such as K1, O1, S1, B1, and D2. They wanted to do something different after spending years at universities. One exception is P1 who stayed in academia due to “opportunity” (Interview P1, p. 3). Those who came back to academia usually longed for a job with less working hours (B1) and more security (S1) or for greater autonomy with regards to lines of research and a more flexible way of spending grants without having to think always about the commerciability of research results (K1). S1 explained his return to academia as follows:

> ““I spent a while in Japan and had the opportunity there to work [in industry], i.e., to stay longer in Japan. For family reasons, I decided to go back to Germany. I went to a company … which was about to establish a microtechnology department … I got really interested in that and I thought, this is exactly what I am looking for, a real challenge, I would like to do that … Then this company got into … real financial trouble so that it was not clear if this company was going to survive. And when it was known that they had financial problems, they [the company; author’s note] said, they would not establish a new

> department. So, this [plan] was given up within half a year after I had started to work there. It just was not possible anymore and we were anxious if the company survived at all. Then, I really came into management and headed projects. I also became head of the [R&D department systems technologies]. So, I had several coordinator positions but this was not physics any more. This just had to do with business … And then, something came up with lasers and I remember, I said, 'I'll do that! … I know about that.' And this was an impetus for me to ponder if this is for life or not and I realized, this whole thing really interests me. And then, there were the problems in the company that were still there. It was not sure if the company was going to make it. Finally, I said, 'well, I am going to university,' and my family thought, I had become crazy because I merely earned a third of what I earned at the company where I really earned quite well. On the other hand, it was fun until the [higher education] reforms came, i.e., [a change in the legislative foundations of universities and also the later change to] this bachelor-master-system." (Interview S1, pp. 27-28)

This statement shows the complexity of reasons of joining academia. There are external reasons, i.e., problems in industrial companies, but also inner factors, such as enjoyment in doing research and development projects. Yet, as S1 indicated at the end of his statement, reasons to join academe do not override drawbacks, such as the increase of administrative tasks and regulations for professors. K1 mentioned academic freedom and independency for going back to university after gaining industry experience first, before returning permanently to academia. Economic constraints are given less often than in industry andwith good ideas, one can realize creative projects also in academia. B1 who had a Ph.D. from Georgia Institute of Technology and went to a large computer company had several reasons that made him go back to university, not as a researcher or professor, but as a coordinator of the Nanotechnology Research Center. He delineated his reasoning as follows:

> "My history is: I graduated from here with my Ph.D. in 1996. I went to work with [a large computer company] and I stayed there 8 years. And I came back here in 2004. And my duties since then have been to recruit external users, whether they [were] from companies or other universities. Now, the reason they hired me to do that is that our NSF project, this NNIN project, is to recruit external users. … My motivation was—it was personal. [The computer company] is a hard company to work for. The division that I was in was hard to work for. … It was a lot of hours, a lot of stress and when I saw this opportunity come open, I wanted to get back into the academic setting. There's its own level of stress and hard work here, but for me, it's a little bit more manageable. I wanted to get back into the academic setting. The industrial setting was great as far as the money goes. There's much better money. But my free time, I didn't have any free time at all to raise my kids. I would go weeks at a time without seeing them awake. … I had to be in the lab at about 7 every morning. I wouldn't get home until 7 or 8 at night. And it was in Portland, Oregon, so there, from fall to spring, it's dark. I never [saw] the sunlight. So it kind of got depressing, and I got tired of it. [I] got an ulcer. And decided I didn't want to do it anymore. The money was good. I gave up a lot of money to come back to academia, but the lifestyle was better." (Interview B1, pp. 3-4)

B1 supported S1's experience: More money is to be earned in industry, but work conditions are different, usually including more stress and, in S1's case, job insecurity. This demonstrates the reasoning and trade-offs researchers make when going back to academe.

The majority of researchers were on tenure-track, in Germany 100%, in the U.S. 15 out of 17. Two researchers from Georgia Institute of Technology had to provide 100% of their salary. One, B3, was a senior research scientist involved in research for the Department of Defense with no teaching load. The other is B2 who was responsible for marketing and sales of the nanoresearch institute at Georgia Institute of Technology. Most of the professors on tenure-track, in particular those from the U.S., had done a post-doc. Besides those from the U.S., M1, C1, J1, and A1 who were not from the U.S. originally also spent their post-doc period in the States. C1 and A1 stayed in the U.S.. J1, for several reasons including family reasons, rejected an offer from Harvard University and decided to go to University of Erlangen. O2 was offered a tenured research position without having to do a post-doc.

L1 thought about going abroad for her post-doc as well. She actually did not want to do a post-doc, but she conjectured that it might be easier to join industry afterwards since she lacked experience in synthesis of chemicals.

All in all, the life histories show basic similarities. It was usually decided at the doctoral/Ph.D. level if one stayed in academia or not. Some spent a few years in industry, but did come back to academia, usually having been quite involved in research and development and also published papers and applied for patents. One very good example is J1 who, while he was working at a well-known international high-technology company, he applied for industry patents and published in highly ranked journals during his time there.

> "These are no polymers that are … comparatively thick but that are really singular .. only due to their layer size a molecular layer. This was at the time … a revolution. [At the company] we also had … two, I think, ground breaking publications … in Nature … [published by] a colleague who was with me at [the company] at the time, who is now at the Max Planck Institute in Stuttgart, and myself and some more people who worked in the background. This really was a revolution. … [The company] had financial problems, let's put it that way, and … [me and] my group …, we have done our job … and written a bunch of patents. This is the job to be done in industry. I think, meanwhile we have 70 .. patents on that topic … at [my former company]. I am actually [designated] as an inventor in [that patent]. [The patents] remained at the company, I think around 70. We always also published .. publications in highly-ranked journals, not too many, but in Advanced Materials, Nature, Applied Physics Letters etc. And we were … invited to conferences … We were only allowed to go to one or two a year. And we were there. This means the relation or the contact to an academic career was .. always given. At that time, … they had this position posted, and [my job experience] was relatively close to what these people expected. It was a chair for polymer materials, but it was basically about electrically active polymers. .. Meanwhile I have nothing to do with polymers any more but with nano with small molecules. But it matched the job placement. And I just sent my application to them and was relatively cool about it. I actually sat across the street [from the university] at the [company's] research center. It took forever and was basically plan B, just in case [the company] really kept having problems." (Interview J1, pp. 3-4)

This shows that publications and constant contact to academia are crucial in staying and returning to academia, much more important than patents. To show his independency, J1 emphasized that he just applied out of opportunity. He did not depend on the offer of a chair for his company was not about to fire J1. In addition, one must not stay too long in industry if one wants to keep the option of academic research open to him- or herself. This is emphasized by Q1 who asserted that one who has spent ten years in industry has been too long away from academia. Q1 would rather hire graduates or graduates with just a few years of industry experience. One must keep in touch with university, in particular with PIs, to have a chance to go back. On the other hand, professors found it more and more difficult to have time to write articles. S1 described the problem of writing a paper when other tasks, such as administrative ones or teaching, are demanded since creativity is hard to control and plan:

> "Well, with publications it is as follows: Just recently I could write this or that publication because I see it as one of my tasks. But I really had to look for the time to write. Usually, [I write] in the mornings, … from six to eight, i.e., before I come to my office. This is because once I am here [in the office], it's over … and in addition, which is in particular problematic, creativity is lost a little. One cannot say 'I have … done six hours of administrative tasks, now I have half an hour … for creativity and then, there is time for something else … .' This does not work." (Interview S1, p. 23)

Identity change, individual interests, and PI–student relationships

In each country, four of a total of 17 researchers interviewed indicated that they changed their disciplinary identity due to the lines of research they pursued at the time of the interview. They were oriented toward grant topics, collaborations, personal interests, and more applied topics that demanded a change of course. J1 said, "I am actually quite exotic as an engineer [in the graduate school on molecular systems], but I am a chemist when it comes to my study background. I still have a strong connection to my colleagues in chemistry" (Interview J1, p. 6). Professors, such as M1, claimed that even open-ended research does not come without an application in mind. A doctoral student, S2, referred to the practical orientation that comes with basic research because research must be of use.

Students mentioned they had a close relation to PIs in the sense that PIs and students usually knew each other from their undergraduate and graduate studies. Students asked, or were asked, to join the professors' research groups. In other cases, the subject-matter and reputation of a professor incited a graduate student to apply for a position in that professor's research. This can be quite competitive, as professors can only take a limited number of students. If a professor is very renowned for his or her research, this competition gets even stronger, such as the case of C2 showed who reported about the strong competition when it came to applicants for his supervisor's research group. Several students, on the other hand, valued tenure. O2 who was offered a tenure-staff position by her PI said:

> "I wanted to go to industry first, I really did. My boss, however, moves to Bielefeld and offered me a tenured full-position. … Yes, and a tenured position for lifetime, this is almost unrefusable in these times." (Interview O2, p. 5)

P2 also valued tenure; however, as he was not offered a tenure-track position, he decided that going to industry was a less risky 'road' to take after graduation. A2 wanted to do something else to have more variety after graduation, but she still wanted to do research. S2 evaluated tenure in a negative way. S2 mentioned his supervisor who did not perform any laboratory research any more due to administrative and organizational work. As S2 wanted to stay involved in research and development, he wanted to join industry after graduation:

> "No, actually, I want to keep doing what I am working on now. But I do not see how I can do this if I continue my academic career. … I realize this with our boss who has to do mainly administrative work. Writing proposals, fight with the administration, giving lectures etc. And this is work I would not like to do. I would like to go into development or so … where there is nothing repetitive to do." (Interview S2, p. 14)

G2 could imagine staying both in science and industry by doing a post-doc and running a start-up simultaneously. Thereafter, she wanted to decide where to stay once it is clear if she enjoys the 'entrepreneurial environment' or not:

> "So hopefully I will graduate over the summer. … This actually played into the program that I chose as well .. [because] the Berkeley/UCSF [University of California, San Francisco; author's note] program has a very entrepreneurial component to it. So just by virtue of being in the Bay Area, I think a lot of people start businesses, and our program is no different. So, two of my colleagues, who are in the lab with me, and me started a business. … The company is probably going to be located just across the hall from the current lab because the building that we work in …–it's original purpose was to spit out technologies from academic labs to industry. And so because of that, it .. has what we call an incubator for start-up labs, and what that means is you can actually rent lab space from the lab bench and it's suitable for professional[s]. … I'm also very interested in the fundamental questions that these materials bring up. But I mean, personally, I'm interested right now in investigating .. and working on getting something actually from the lab to people. Because I'm very interested–like I said earlier, I'm very interested in improving people's lives. And that's my fundamental, sort of driving cause although the science is very interesting also. So myself, I went through quite a bit of difficulty deciding whether I would start this company and go to work for the company or if I would try to go into academia, either in a lab as a post-doc or become a professor, and so I decided to come to work for this business, but with the thought that if I don't end up liking working at a start-up company or don't end up enjoying the entrepreneurial environment, I would be very excited to come back and actually be a professor at some point." (Interview G2, pp. 5, 10, 12)

G2 also mentioned enjoyment as a factor in deciding where to work. What becomes clear is that she enjoyed the research environment. G2 also alluded to the fact that, unlike in Germany, professorial positions can be obtained much earlier without doing a habilitation, but only a post-doc, if at all. This reveals the different situations Ph.Ds. and doctorates are in when deciding where to work. G2 never mentioned job insecurity in industry or worse career chances in academia at all, but made it only dependent on her likings. P2, by contrast, mentioned the insecurity of completing an academic career in Germany since professorial positions are less structured and also less in number. In the U.S., with a career track of assistant, associate, and full professor, at least the academic career path is more transparent and institutionalized, for professorship is formally attached to organizational university positions.

With most students, it became clear when they were talking about high-school that their interest for natural sciences developed during high-school. They had core subjects in natural sciences or participated in government programs (G2, G1) that encouraged students' engagement in natural sciences. Then, often as undergraduates, students already did some research work for their professors and developed their interest in research, which was crucial for their decision to do a Ph.D. In G2's case, a motivation to "improv[e] people's lives" (Interview G2, p. 12) was incited and motivated her to do biomedical engineering. In chemistry, when it comes to the reasons to do a Ph.D., another important aspect was the fact that industry usually only hires PhDs. The importance of a Ph.D. is underlined by the role the reputation of a PI plays when joining a research group. The recruiting of new graduates and thus the reproduction of research groups is based on two pillars: on the PI's reputation and on the personal acquaintance with the PI through previous undergraduate assistantship or thesis supervision. The centrality of PIs is derived from the fact that PIs serve as a link between undergraduate/graduate studies and their own research groups or as an attractor for external aspirants for a Ph.D. program and university research groups.

7.3.3 Excursus: Comparison of Nanotechnology to Biotechnology

There has been a lively discussion going on about the adequacy of the VoC approach to explain the development of biotechnology in Germany compared to LMEs, such as the U.S. and the UK. The divide of arguments basically arises from the evaluation of how successful biotechnology is in Germany based on different sample approaches and how the pattern that is to be observed there complies with the VoC approach. Lange (2009) and Herrmann (2008) negate the appropriateness of VoC to explain the biotechnology sector in Germany due to its success, which is uncommon for a CME. Herrmann (2008) observes a hybridization of entrepreneur policies as creative policies that circumvent the constraints of the German national economy through internationalization of human capital as well as through atypical contracts. With regards to institutional heterogeneity, Lange notes that German biotech firms also tap into foreign financial capital (Lange, 2009, p. 198). Casper and colleagues (Casper, 2000; Casper & Kettler, 2001; Casper, Lehrer, & Soskice, 1999), however, regard the biotechnology sector in Germany as unsuccessful compared to the UK or also the U.S. and assert that VoC is still valid, but must be extended by a focus on change because hybridization of business policies is a sign for economic change. Yet, despite this hybridization, biotechnology companies cannot override the national institutional framework of a CME that results from the type of national economic model.

Without doubt, patterns emerge both in the U.S. and in Germany. In biotechnology, hybridization of business strategies have been noted, the specialization of German biotechnology sector on platform technologies, i.e., cumulative technologies that provide tools for higher risk and more instable biotechnology research (Casper et al., 1999, p. 15). To Casper, these observations confirm the VoC approach in the sense that specialization occurs within national economies in different industry sectors by hybridization of business policies that take advantage of institutional complementarities without being able to circumvent whole national economic frameworks (Casper, 2000, pp. 909-910). The latter is demonstrated by the fact that biotechnology prospered in the 1990s when the UK had an economic downturn. Overall, however, biotechnology in Germany–not least because of the failure of the *Neuer Markt* for technology listings–was not successful due to the German CME that does not favor radical innovations in advanced technologies, such as biotechnology (Casper & Kettler, 2001).

In the case of nanotechnology, it is of interest to check if observations for the biotechnology sector from above are expected to hold true for nanotechnology. What unites both technologies is that the publication of scientific breakthrough articles by academic researchers and the engagement of U.S. firms are closely related in terms of time and place (Huang et al., 2010). One study by Huang, Notten, and Rasters (2010) found one important difference in the (early stage of) development of nanotechnology compared to biotechnology when it comes to R&D investments. In nanotechnology, technological change has occurred through physical capital investment in contrast to biotechnology. The nanotechnological sector is more dependent on traditional R&D investments at laboratories and firms than biotechnology. This is what additionally explains the advantage Germany has in nanotechnology with its strong focus on physics, successful public research institutes, and incremental innovations as well as machinery investments.

How might nanotechnology differ, if at all, from biotechnology? There is nanobiotechnology as a field of application, but nanotechnology comprises more than nanobiotechnology. This is underlined by a study finding that nanodistricts in the U.S. do not specialize necessarily in nanobiotechnology (Shapira & Youtie, 2008, pp. 196-197). That is, regional clusters emerge in different fields of application of nanotechnology. Therefore, the cross-technological character of nanotechnology as a "general-purpose technology" (Shapira & Youtie, 2008, p. 187) becomes evident as one major difference to biotechnology hybridization. Further differences become manifest in its cross-disciplinarity (see chapter 7.2.1), its combination of both Mode 1 and Mode 2 features in university knowledge production (see chapter 7.1) and the beginning professionalization of nanotechnology in the market, but not in academe (see chapter 7.5). Cross-disciplinarity is facilitated by the "general-purpose character" (Shapira & Youtie, 2008, p. 187) of nanotechnology allowing the participation of several disciplines in its application.

What is further and substantially different from biotechnology studies of the kind of Herrmann (2008), Lange (2009), and Casper and Kettler (2001, p. 6) is that these authors used a firm-centered approach. In the present study, in which nanoresearchers from universities were interviewed, the approach is quite different. One must bear in mind that this study focuses on the academic context using other methods and thus yields findings of a different kind. It can however be analyzed on a micro- and institutional level how national contexts enable the establishment of nanotechnology in Germany and the U.S., although some institutional facts and individual beliefs, as previously discussed, seem to represent rather impediments than enabling conditions at first sight.

In both countries, nanotechnology represents a fundamental element of governmental science and technology policy. In terms of economic growth and international competitiveness, innovative technologies, including nanotechnology, is seen as one component of national frameworks of policy (Edler, 2003; VDI Technologiezentrum e.V., 2009). Nanotechnology companies have been established in both countries, with U.S. companies naturally outnumbering those in Germany. Dependent on the definitions of a nanotechnology company, there are differing numbers of companies. The German Ministry of Economy counts even 650 to 700 companies working in nanotechnology of which 200 are "core companies" (Bundesministerium für Wirtschaft und Technologie (BMWi)). Furthermore, another overview by the VDI Technologiezentrum counts 735 SMEs and 237 large companies working in nanotechnology (VDI Technologiezentrum e.V.: Kompetenzatlas). The BMBF speaks of 740 nanotechnology companies in 2009 that deal with the development, application and delivery of nanotechnology products whereas in biotechnology, it speaks of fewer companies amounting to almost 600 (Bundesministerium für Bildung und Forschung (BMBF), 2009). On one website, there were 192 German companies and institutions, including universities, in the "German Nanotechnology Companies and Institutions Directory" from 2007 to 2009 (nanoproducts.de, 2007-2009). On another website, there were 30 companies. The website that counted merely 30 German companies in 2009 counted 354 nanotechnology companies located in the U.S. (Nanotechnology Now, 2009). It is noticeable that large companies, such as HP and Bayer, are also included into the firm database disclosing their nano-R&D activity. Another homepage counted 1146 companies located in the U.S. and 200 in Germany (Nanowerk, 2010a). Mostly, they were technology companies not only working in nanotechnology, but also other technologies and several topics. One can see that with regards to the number of companies, the cross-disciplinary character and the resulting versatility of nanotechnology as a useful tool for multiple sectors become obvious, since a unanimous classification for nanotechnology companies is not easy to establish. Where do these differing numbers come from? As already mentioned, a nanotechnology company can be defined in various ways. The VDI Technologiezentrum for instance considers companies that mention nanotechnology on their website as nanotechnology companies. The Bundesministerium für Wirtschaft und Technologie differs between companies doing only nanotechnology and companies using it among other technologies. Others emphasize the high involvement of the public sector in nanoscience and -technology and include universities and research institutes.

Overall, the U.S. as an LME and Germany as a CME have been successful in nanotechnology. In particular, in U.S. research and German higher education, nanotechnology has been institutionalized successfully. In Germany, there are more bachelor programs in nanotechnology than in the U.S. (eleven versus six) and only one more master program in the U.S. (17 versus 16). What is to be noticed is that two programs out of the six U.S. bachelor programs and four programs out of the 17 master programs have a "concentration" or "specialization" on nanotechnology. Thus, nanotechnology does not represent the main track and credential title, but students are trained in main disciplines first. The fact that Germany has more bachelor programs confirms the focus of Germany on undergraduate training and on an early specialization. The fact that there is a higher number of Ph.D. programs in the U.S. confirms that specialization in the U.S. takes place at this level of education. (Nanowerk, 2010b) Another overview by the VDI Technologiezentrum confirms an even higher involvement of Germany in the provision of undergraduate and graduate studies in nanotechnology. There, Germany offers 18 bachelor and 25 master programs (VDI Technologiezentrum e.V., 2008a). Only in industry, the need for nanotechnologists does not appear to be as urgent as politics sees it, as pointed out by N1. This occurrence on the nationally different institutionalization of nanoscience in higher education confirms what H1 has observed for the U.S., namely the difficulty to consolidate financial resources to make nanoresearch more efficient: "This country is just too big to unify" (Interview H1, p. 6).

From the perspectives of informants and based on the interview analysis, nanotechnology has been successful in the German academic sector. As mentioned earlier, the STM, a radical innovation, was built by a Swiss-German cooperation. The advanced position in physics, as expressed by German physicists and a wide network of public research institutes (Heinze & Kuhlmann, 2008), were also favorable to nanotechnology. With government, state (*Länder*), and regional initiatives that put nanotechnology on their agenda, nanotechnology became a priority in technology policy in the 1990s and early 2000s. Of all the observations that have been made in previous studies, internationalization and hybridization in knowledge production can be observed in Germany. The dominant research institutes in Germany employ foreign scientists. International cooperation takes place via the 7th European Framework.

In terms of specialization on platform technologies, this finding from biotechnology studies cannot be confirmed. The university research centers have quite diverse research foci. This does not mean, however, that analytical nanoresearch is not strong in German nanotechnology, as shown by University of Hamburg. Naturally, it must be tested to what extent industry has absorbed innovative academic research. As technology policies in Germany and Europe explicitly demand industry cooperation, there is great impetus for a university–industry spillover. However, due to the early stage in nanotechnology in terms of applicability of academic research, the time horizons are too long for industry. Still, German professors and doctorate students talk about research that has been done for industry and that is actually implemented in mass production or further developed in the R&D departments of companies.

What is fundamentally different with nanotechnology–and this is why a comparison to biotechnology must be done cautiously–is that nanotechnology is a cross-disciplinary technology that can be used as a platform technology in different academic sectors and disciplines. Furthermore, it is strongly financed by public money in a direct way via national government initiatives, something that runs counter the U.S. ideology that goes against public intervention in industry (Etzkowitz, 2003, p. 46). Yet, as the NNI focuses on academic research, institutional change has been incited at U.S. research universities. Compared to nanotechnology, the U.S. have been spending less on biotechnology. The U.S. NSF, used here as the pendant to the BMBF, invested $357.050,014 ($357.1 mio) (National Science Foundation (NSF), 2008), i.e., around 268.458,657 (268.5 mio €), from 2005 to 2010. Table 11 on BMBF government biotechnology funding (biotechnologie.de, 2010) shows that from 2005 on, expenditures have been increasing, with the exception of 2007 (numbers in mio €):

2005	2006	2007	2008	2009	2010
178.1	223.6	218.2	243.5	259.3	267.9 [projected]

Table 11: BMBF Government Biotechnology Funding; Source: biotechnologie.de

Therefore, from 2005 to 2010, Germany spent 1,390.6 million € for biotechnology. These figures do not capture the total amount of federal funding, but only what the German Federal Ministry of Education and Research spent. This is done to be consistent with the nanotechnology data and to trace the involvement of universities as these projects require the participation of industry and universities. Finally, this study is about academic research. Thus, the focus lies on universities and the link to industry. One can see that compared to nanotechnology where government funding in Germany amounted to 165 million € in 2009 (VDI Technologiezentrum e.V., 2009, p. 78), funding for biotechnology with 259.3 million € was almost 100 million € more than for nanotechnology in 2009. This might speak for a higher priority of biotechnology in the BMBF that appears to be in need of funding more than nanotechnology where Germany has been among the leading countries from the beginning, unlike in biotechnology.

The U.S. National Science Foundation spent even less on biotechnology over the period of 2005-2010 compared to the BMBF as to be seen by the figures above. Furthermore, the NSF spent less on biotechnology than for nanotechnology which the NSF for instance alone in 2009 spent $509.8 million for, i.e., around 383.308,271 € (National Nanotechnology Coordination Office, 2010). Overall, the U.S. government spent $2212,8 million (around 1663,76 million €) (National Nanotechnology Coordination Office, 2010) in the frame of the NNI. This is four times as much as the NSF did in 2009 and almost four times as much as the German public authorities (VDI Technologiezentrum e.V., 2009, p. 78). For the period of 2006 to 2010, Germany spent about one third less than the U.S. government; the German BMBF spent about two-thirds of what the NSF spent in that time frame (Bundesministerium für Umwelt, 2010; National Nanotechnology Coordination Office, 2010). Therefore, compared to Germany, the U.S. have a stronger focus on nanotechnology than on biotechnology.

In short, the U.S. spent more on nanotechnology compared to German expenditures. In biotechnology, the central academic research funding agencies, NSF and BMBF, show different patterns. The BMBF spent more on biotechnology than the NSF and, interestingly, more on biotechnology than on nanotechnology. Thus, one cannot say that nanotechnology in Germany is considered more important than biotechnology. Within Germany's high-tech-strategy, more high-technologies than just nanotechnology are funded. The fact that more money is invested in biotechnology by the BMBF might have occurred because nanotechnology has been more successful in Germany and thus has been seen in less need for funding. With a turnover of almost 2 billion € back in 2007 (biotechnologie.de,

2008a), the biotechnology industry sector, with at the time 496 companies (biotechnologie.de, 2008b, p. 6), was much less economically important than the 750 (according to a VDI estimate) nanotechnology companies that produced a turnover of 33 billion € (Institut der deutschen Wirtschaft (IW) Köln, 2009). In 2009, there were 740 nanotechnology companies compared to almost 600 companies in biotechnology (Bundesministerium für Bildung und Forschung (BMBF), 2009). Thus, for the time being, nanotechnology, for diverse reasons, can be considered more firmly established in the German economic sector and in German higher education research.

Given that policy can influence research by frequent and non-linear interactions on different levels (Edler, 2003) and that each high-technology confronts policy-makers and researchers with different characteristics, different policies and funding foci concerning individual advanced technologies can arise. Nanotechnology is different from biotechnology due to its cross-disciplinary character that opens even wider fields of research and application and due to its rank on national policy agendas. That said, nanotechnology might be an even more striking example for the deficiency of the VoC approach demonstrating that a high-technology can persevere in a CME. Of course, as an innovative technology, it remains to be seen if nanotechnology will be established on the long-term horizon in German academe and industry. What can also happen is that as a cross-disciplinary technology, nanotechnology will lose its particularity for science policies and become routine as predicted by Lux Research (2010). Furthermore, the dependence on public funding is precarious. The past showed that for academics, it is dangerous to rely on the permanency of public funding as national agendas change. In the U.S., after 9-11 for instance, the funding for energy was cut in favor of homeland security and national defense. Similarly, as P1 pointed out, few topics have been funded over decades by the German government.

To sum up, the interviews corroborate that nanotechnology has become a fixed position in the academic landscape and in national technology and innovation policies both in Germany and the U.S.. Whereas the U.S. focus on large-scale research (see also Boyer, 2003), Germany also focuses on the visible institutionalization of nanotechnology in the form of undergraduate and graduate programs. Nanoscience has been institutionalized over the last 20 years in Germany and the U.S. in a remarkable pace. It has not replaced or dominated the 'big sciences,' but as a cross-disciplinary technology it has been absorbed as a specialty and technology across the main disciplines. While the success of biotechnology and nanotechnology is not surprising in the LME of the U.S., the CME of Germany is a more interesting case as biotechnology and nanotechnology are high-risk technologies. Compared to biotechnology, nanotechnology seems more successful in public research than in terms of the number of companies and in terms of turnover. Biotechnology has a high status in Germany's high-tech strategy just as nanotechnology has. Yet, nanotechnology appears more adaptable to Germany's national economy with regards to its prominence in higher education and its economic significance. To conclude further, both advanced technologies have been incorporated, unexpectedly along VoC lines, in Germany and thus represent promising cases for further research that compares these two technologies in a more general way.

7.4 Cultural Production of Coherent Identities in a 'Scientific Nanocommunity'?

In this study, it is not only asked which meanings are produced and operative in the academic field of nanotechnology, but also how these meanings are situated within historical, social, and cognitive contexts. As such, these contexts relate to respective historical, social, and cognitive identities (Lepenies, 1981) that are effective in the broader context of the scientific community of informants, a community that does not only comprise nanotechnologists and nanoscientists. Thus, not only social relations are virulent for the creation of meanings, but also cultural processes that have to do with historical and cognitive identity formation. The mechanism of decoupling makes the tension arising from the gap between 'formal structures' and 'work activities' more tolerable and even positive because decoupling justifies these structures in the environment and makes it possible for culturally derived ‘work activities’ to forsake the obedience of rules of efficiency.

This gap alludes to the kinds of identities that operate in scientific communities as a whole (as analyzed for sociology by Lepenies (1981)), not only in the academic field of nanotechnology. In this section, therefore, the organizational analysis of the academic field of nanotechnology is extended by looking not only at the social identities that are made evident in the interviews, but also at the historical and cognitive identities that are active in the field. The three different kinds of identities have already been touched on in previous chapters. Now, they are tied down in a framework to combine interview data (chapter 6.1) with the institutional comparison (chapter 3 and 6.3) and the historical development of nanotechnology in Germany and the U.S. (chapter 3). Originally, this framework of cognitive, historical, and social identities was used to analyze sociology as a scientific community (Lepenies, 1981). In the following, this three-fold scheme is applied to nanotechnology as a special case of high-technology and cross-disciplinary specialty. What can be said about the cognitive, historical, and social identities in the nanotechnology community overall?

To address the cognitive identity of nanotechnology first, it becomes clear at once that nanotechnology presents a quite unique case. There is no single, common field of application for nanotechnology. Nanotechnology presents an analytical tool that is applied in several fields and disciplines, like materials sciences, chemistry, physics, and engineering. The breakthrough of nanotechnology started with the invention of the STM that enabled researchers to see atoms and molecules on the nano-scale. In terms of ‘coherence and uniqueness’ that are regarded as central features of cognitive identities (Lepenies, 1981, p. I), surely there is uniqueness in the form of radical breakthroughs in nanotechnology with the STM and the C^{60} fullerenes that promise innovations (see chapter 2). Coherence, however, appears to be lacking due to the cross-disciplinarity of nanotechnology. Nanotechnology differs in that regard from microtechnology and biotechnology that are more restricted in their areas of application. If coherence is deemed indispensable for the emergence of a scientific community, nanotechnology might never become a scientific community per se, but be immersed in existing or newly developing scientific communities, such as materials sciences. On the other hand, ‘eclecticism’ allows flexible strategies in ‘theory-political disputes’ (Lepenies, 1981, p. X).

Thus, the lack of coherence, or a coherent theory in nanotechnology (on nanotechnology and chemistry see Loeve, 2010), does not have to be disadvantageous to the stabilization of nanotechnology at academe. The strategic use of nanotechnology in terms of proposals and self-categorization has already been discussed in chapter 7. The past shows that politics had an early interest in funding nanotechnology as a high-technology and with that, also in basic research involved with it. Scientists became aware of that, but they know that nanotechnology has not the reputation of a discipline, such as physics. There is a scientific community that deals with nanotechnology, but it is not mutually exclusive with regards to other communities anchored in existing disciplines. This could be observed both for Germany and the U.S.. The circumstance that nanotechnology was promoted by politics since the early 1990s (at least in the U.S.) (Schaper-Rinkel, 2010b) leads to the historical identity of nanotechnology.

A historical delineation of nanotechnology with its differences in Germany and the U.S. has already been delivered in chapter 2. At this point, it suffices to say that there is no unified, but unique history of nanotechnology in Germany and the U.S.. However, the fact that ground-breaking discoveries have occurred in Germany and Switzerland with the STM in the early 1980s and then spilled over to the U.S. demonstrates that the two industrialized Western countries are indeed interconnected. What adds to the uniqueness of nanotechnology is that several main disciplines participate in the scientific community of nanotechnology, illustrating the cross-disciplinary character of this high-technology. What is constitutive of the historical identity is the constellation to neighbor, rival, or auxiliary disciplines that are important for the emergence and stabilization for a scientific community (Lepenies, 1981, p. XX). Nanotechnology as an analytical tool has been auxiliary to the sciences in academia, but

it was not seen by every informant of this study as a rival discipline. If it was a rival discipline, then one informant, A1, suspected that it would become a true interdisciplinary discipline comprising all natural sciences. Others saw in nanotechnology a supportive technology that was applied to basic research, not more.

What certainly aids the stabilization of the nanocommunity are the existing infrastructures in the form of (competence) centers and institutes in Germany or the NNUN, now NNIN, in the U.S. as well as the grant policies in Germany and the U.S. that have had nanotechnology on their agenda since the 1980s/90s. It became clear in the interviews that the focus in the U.S. was on a nationwide infrastructure for nanotechnology basic research, whereas in Germany, the training of nanotechnologists was emphasized and demanded, in particular from politics. To German scientists the progress of their research was in the foreground so that they promoted the institutionalization of nanotechnology both in the form of centers and study programs. This development has occurred due to the Bologna reform that has prescribed the establishment of bachelor and master degrees and that was used pragmatically by universities to increase their reputation by offering new and specialized degrees.

The noticeable institutionalization of nanotechnology in the academic landscape, despite an evident reluctance toward it as expressed by German scientists, elucidates the characteristic social identity of nanotechnology as a scientific community. This identity has been discussed in chapters 2 and 7 already, though without linking the institutionalization to the identities of scientific communities. Institutionalization is crucial for the stabilization of a community and its survival, also in the fight for academic reputation (Lepenies, 1981, pp. I, IX). For now, nanotechnology raises mixed feelings in terms of its future status in academia. However, given its institutionalization, a crucial condition is provided for the survival of nanotechnology. Again, the fact that the theoretical, here analytical, program of nanotechnology is not clearly to be separated from other programs or disciplines (see the paragraph on the cognitive identity of nanotechnology above) does not undermine the chances of its institutional securement (Lepenies, 1981, p. IX).

The institutionalization of nanotechnology has occurred in a similar way to the institutionalization of sociology where a new form of institute emerged that was attached to university, but not absorbed by university (Lepenies, 1981, p. XV). The existing nanoinstitutes are legitimated among scientists despite the informants’ detachment from the self-definition as a nanotechnologist and thus have a high chance of survival (Lepenies, 1981, p. II). This is due to the pragmatic stance of scientists and their need for funding and reputation that nanoinstitutes give, at least outside academia. What additionally speaks for the institutionalization and institutional change as stabilizing factors for the nanocommunity is the (political) influence of people and their constellation (Lepenies, 1981, p. II) with regards to the development of nanotechnology. As outlined in chapter 2, renowned scientists, who applied nanotechnology and were even involved in scientific breakthroughs in its early period, spoke for the case of nanotechnology in front of politicians to advocate the inclusion of nanotechnology into their agendas. The influence of politics, or the ‘politization’ of nanotechnology (Lepenies, 1981, p. V), has certainly changed the self-concept of politicians, industry, and the public. So, nanotechnology did not have to ‘fight’ for its existence due to political support in the form of favorable grant policies and plans for institutionalization (see Lepenies, 1981, p. XIII).

As social and cognitive identities reinforce each other (Lepenies, 1981, p. IX), one will see how the ‘factuality’ or ‘factual reality’ of institutions in nanotechnology created by its social identity will affect the incoherent, but unique cognitive identity of nanotechnology (Lepenies, 1981, p. I). The social identity of nanotechnology developed both because of scientists who were committed to its institutionalization and by scientists who are ambiguous toward this development, but who realize that academic reputation and political-financial support are indispensable in high-technology research. The awareness of the ‘sacrosanct’ reputation of the ‘big sciences’ and of their anchoring in institutional structures in university, combined with a fear of a nanotechnology hype and the experienced constant change of political agendas, renders scientists fairly unconcerned and pragmatic about the institutional factuality of nanotechnology. As the interview and institutional analysis demonstrates, nation-specific traditions of institutionalization in higher education are noticeable when comparing Germany to the U.S. as they were observed for sociology (Lepenies, 1981, p. XXII).

Except for a cognitive identity, a historical and social identity is clearly to be detected in nanotechnology, which speaks for the existence or at least for the development of a nanocommunity. It will be seen in the future if nanotechnology exhibits a coherent cognitive identity despite, or maybe even because of, its cross-disciplinarity and applicability in the main disciplines of physics, chemistry, engineering, and materials sciences. Or, nanotechnology will represent a case demonstrating that for a scientific community, a cognitive identity does not have to be coherent, but can be quite multi-faceted and implemented in different fields of application. What seems manifest, however, is that nanotechnology will probably be a cross-sectional community of scientists coming from different home disciplines. Finally, with regards to the cultural production of a common identity, one can conclude that despite or because of tensions as to what nanotechnology means and which status it should have within academe, individual actors that are the source and 'managers' of these tensions unconsciously contribute to the formation of a common identity.

7.5 Nanotechnology as a Profession[7]

The VoC, the neoinstitutionalism and the Mode 1 and Mode 2 knowledge production approach deal with macro- and meso-systems. Focusing on these systems alone, however, would make this discussion incomplete because considering the labor market from a micro perspective will shed more light on the complex development of nanotechnology. The 'Model of Intervening Mechanisms' in section 1.2 illustrates this perspective on the labor market and the transition from education systems. Specifically, professionalization and the requirements for this process of institutionalization must be considered as a paramount element in the 'Model of Intervening Mechanisms' that addresses professional careers and the influence of professional organizations (Heidenreich, 1999).[8]

It is important to remark here that professionalization, as a term existent both in the U.S. and in Germany, has slightly different connotations. The English word professionalization emphasizes a process that aims toward the attainment of a social status for a professional group (the definition used here). By contrast, the German word 'Professionalisierung' first refers to the individual's potential of achievement, an achievement which is then in turn linked to the social status associated with a profession in the English interpretation. As noted in chapter 3, professionalization concepts have been viewed critically by Abbott (1988, pp. 16-19) who pointed to their flaw of focusing on structure rather than work. Here, for reasons of simplicity, professionalization is used to refer to the institutional process of development of nanotechnology into a profession, not in the sense of how it is conceptualized within the frame of professionalization theories.

The social status as an academic is guaranteed also for academics who do nanoresearch. The group of nanoresearchers is even smaller and thus maybe more exclusive than the group of chemists, engineers, materials scientists, and physicists. Networking takes place at conferences, among others at conferences organized by professional associations which are often categorized by disciplines (see ACS and APS for the U.S. or DPG, VDI, & DECHEMA for Germany), but also content-related. The preceding analysis of publication journals of the interview sample supports greatly the importance of professional associations for academic professions not only for conferences and networking, but also for publications. This corroborates the integration of professional associations in the 'Model of Intervening Mechanisms' (see section 1.2). In the following, the extent to which nanotechnology as technology and research field exhibits the features of professions is analyzed in the context of professional organizations, institutional organization, and the work of scientists.

B3 stated the associations he is a member of and described the reasons why associations are important to him, pointing to the time lags in publication that impede the exchange of knowledge:

> "I'm a member of a technical society called TMS, the Minerals, Metals & Materials Society. It used to be the [minerals, metals and materials society,] but they shortened it just to TMS. And also MRS, the Materials Research Society. Really, [I joined] to stay up on the state-of-the-art and the technology. .. When you work on different things, you want to see who's doing what. You don't want to reinvent the wheel. … Those societies .. [are] basically the cutting edge of technology. There's [sic; author's note] textbooks, which is basically what's been done … [in the more distant past]. [On the other hand,] current publications in different journals .. are out there for people to see [current topics, but those are actually a year or more prior due to publishing delays.] … But [at] conferences, [for] societies like this, people present their [most] current work. So it's stuff that hasn't even been published yet. It's state of the art in the science of nanotechnology. You need to go visit these societies or you kind of fall behind just reading text books and reading [the journals], because it takes time to publish [those] article[s]. If something was just published this month, it was submitted [at least] six months ago [, probably a year or more]. So the [actual] work was done six months prior [to that]. [So research presented] in a brand new publication, .. was actually done about a year .. [or more prior]. To stay up on [the technology], you go to conferences and get the latest and greatest on it." (Interview B3, p. 11)

Some conferences, however, offer separate discussions on nanotechnology, as A2 asserted:

> "We just don't have so much opportunity to interact with other universities. That's become easier now since I'm associated with [an institute that looks at the environmental implications of nanotechnology], because that puts us within direct connection of several other universities who are working on similar problems. So it's been a lot easier to interact with people at these universities. So for that, I'd say, mainly the only time we really interacted with other types of universities was at meeting, for example, the ACS national meetings or local meetings. ACS has a bunch of local sections, and for the Pittsburgh section, we'll get people from all over the city. People from here, and from Pitt [University], and from Duquesne, and so if you go to these types of meetings, it also gives you a chance to interact with more types of people. At least a few [are focused on polymerization and nanoparticles]. The topics change quite a bit. They're focused on all of chemistry. So they'll be at least a few presentations and a few discussions about polymer chemistry and nanotechnology." (Interview A2, pp. 17-18)

A2's statement underlines that organizational belonging influences if one has a chance to talk to other departments and universities or not. As B3, A1 supported the importance of conference to stay up to date and to be rewarded and earn reputation. At the same time, A1, being a member of the ACS among others, emphasized the indispensability of membership in professional societies. Thus, membership is like an institutional rule that academic professionals must adhere to if they want to formally belong to their scientific community of physicists, chemists, materials scientists, engineers, etc. In addition, membership gives satisfaction as it ensures that research becomes visible and acknowledged, for instance by awards. The following statement summarizes what motivates a researcher in his or her tasks:

> "Yes, sometimes you are recognized with awards ..., which is very pleasant. Sometimes your colleagues are awarded, that gives you also a similar pleasure. However, perhaps the best satisfaction is when your inventions are commercialized and help our world in one or the other way. Also, working with students

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[7] This chapter is based on Hoser, N. (2010). Nanotechnology and its Institutionalization as an Innovative Technology: Professional Associations and the Market as Two Mechanisms of Intervention in the Field of Nanotechnology. *Nanotechnology Law & Business 7*(2), 180-197.

[8] On tendencies of occupationalization and professionalization see Martin Heidenreich, Berufskonstruktion und Professionalisierung: Erträge der soziologischen Forschung (1999). The neoinstitutionalism approach focuses the reciprocal relationships of the emergence, structure, and development of cognitive schemata (knowledge) and the institutionalization of patterns of perception, behavior, and relationships.

> is very rewarding, watching how they progressively develop and start creating new things themselves." (Interview A1, p. 17)

H1 saw it as his task to bring the engineering society closer to nanotechnology, labeling the society as conservative:

> "There are reputable large scientific organizations, such as SPIE. They are now in the transition from an old-fashioned organization to a new organization accommodating rapidly changing and expanding relevant technical fields with the emergence of 'nano.' SPIE actually has a [long] history. … Their core is still electrical circuits … We try to add nano to this .. traditional society, SPIE. … To get more [funding and] attention to this still very small community. We cannot be seen as a bunch of geeks who are not really contributing to the real world. We try to establish a little solid foundation." (Email communication H1, May 19, 2011)

Thus, H1, who also did not want to be called a nanotechnologist, tried to enhance the visibility of nanoscience and institutionalize nanoscience as something that must be taken serious. H1 alluded to the application orientation by saying that they are "contributing to the real world" (Email communication H1, May 19, 2011). This statement, on the other hand, shows that it is not easy to change a strong professional society from the bottom-up. The example of SPIE presented shows that traditional disciplines and topics dominate in professional associations. This might be exemplary for all other societies that have existed for over a centenary. Another aspect that was raised in the context of the importance of professional organizations is the character of an altruistic community that focuses on the public good. This view has been supported by both American and German researchers.

O1 also stressed the importance of supporting the community by being a member of associations. The salience of (academic) professional associations expressed by most interviewees is contrary to the findings presented in Robert D. Putnam's study (2000). Putnam analyzes the decline of civil, religious and political engagement and other organizational affiliations, such as professional associations, in short, the decline of social capital, putting at risk social cohesion and solidarity. Membership rates, i.e., relative, not absolute numbers, of professional associations have been decreasing after 1970, at least in the eight national professional associations cited by Putnam (2000, pp. 84, 439, 444). This finding cannot be confirmed here for all the associations in which the informants were involved, except for the American Society of Mechanical Engineers and the IEEE, two associations experiencing such a decrease as mentioned in Putnam (2000, pp. 439, 444). Still, most informants in this explorative, not representative study are aware of the need to connect with others on networking and publication platforms that professional associations and conferences have been providing in a unique manner. How can this be? One explanation Putnam offers is that membership in associations must still be handled cautiously as compared to active participation. All informants were members of an association somehow, but degrees of involvement varied from merely paying the dues and receiving journals to going to conferences and to functioning as a board member. O1 said with regards to his involvement:

> "I am member for instance of the American Chemical Society, the ACS, and .. the GDCH [German Chemical Society; author's note], and then the Higher Education Association. This [association] is not only for professors, but also for students. ... Membership for example allows reading the literature of these organizations and then there are conferences where we are getting … informed constantly and professional issues are reported on, or scientific issues … This is for instance partially in one's own interest and also for the whole community. … [The ACS and GDCH] have their own journals where we publish our results. And we support them as well through our membership." (Interview O1, p. 21)

S1 for instance stressed his membership of a regional association that supports high school students, but, unlike O1, mitigated the relevance of associations for professional topics and research:

> "[W]ith the DPG one cannot … resist; one is practically becoming member as a student … And then one remains a member somehow … I have also somehow become member of the board of a regional section [of the DPG]. This is quite OK. I see this rather as an altruistic support of certain useful activities that are done by this regional [DPG] section. The section supports [activities to promote physics]. They make some fancy things so that people get more acquainted with physics. … Insofar, this is certainly important. Only the real professional issues, they do not go via associations but actually only via conferences, workshops, networking etc. There, one gets to know people, sure, but [associations] are not the central instrument for that." (Interview S1, p. 30)

G1 did not only stress the importance for community, but also the higher level of influence associations can exert:

> "Yeah, so we're definitely involved [in professional societies]. I think one of the things is that, because we're multi-disciplinary, we're involved in a lot of different organizations, ranging from material MRS and also ACS chemistry. Also, obviously, BMES, Biomedical Engineering Societies, and the nanotechnology/biomedical community. [They are important because] I think being a part of the broader community is important for a scientist, as a person who is educating the next generation. Via professional societies or doing service for the community in some way—editorial boards, grant reviews, NIH, all that is important because it really shapes the future of the various fields and also forms a community that's broader than just one institution. … I think you get to know other people and form a critical mass in a field that in some ways, if you do it right, can allow you to make a bigger impact than any one person in policy-making. It also is a great venue to students to be able to learn about a field, gain exposure and connect to other individuals. … I think [professional societies] are [setting up guidelines for curricula]. It depends on what societies. It's probably less the society that's involved. I think they do have some advisory roles, but I think ultimately it either comes down to ABET [Accreditation Board for Engineering and Technology; author's note], which is an accreditation committee, which also has impact from societies, and then the institution itself." (Interview G1, p. 7)

G1's statement also shows that she speaks of a nanotechnology community in the context of professional associations. Thus, these associations seem to provide a platform for nanoscientists and locus of exchange. This suggests that, if nanotechnology wants to have a standing in science, it must connect to professional organizations and at the same time free itself from the grip of traditional academic disciplines. As a society, namely, an association can exert greater influence than a single researcher. What can be conjectured about the future of nanotechnology with regards to professions? Following Abbott (1988), it can be expected that disciplines either compete in their role as academic professions for the jurisdiction over nanotechnology, or nanotechnology will be subsumed as a stock of knowledge under every scientific discipline, as it is basically now, and included as a general profession into an existing professional association. Or, nanotechnology will even found its own professional organization.

All in all, associations are still an institutional factor of influence, also in the U.S.. What G1's statement indicates is that as opposed to the professional societies in Germany, in the U.S., accreditation committees are setting up curricula. However, these affect societies and universities in turn. In the U.S., the chemical society is most involved in curriculum planning by setting up guidelines for certified chemistry degrees as E1 asserted:

> "The curriculum does have an influence over the certification of chemistry degrees ... They don't quite dictate what goes into the degree but there are certain [guidelines] … That definitely influenced my graduate degree, which I didn't know at the time. And it influences how the programs are set up here at Santa Clara. I don't reference [the guidelines] for what I need to teach in my classroom every day. … So, I could teach maybe a nanotoxicology class but that wouldn't fulfill many of the basic guidelines that it [ACS; author's note] has for a certified degree. So, I have to teach a biochemistry class instead. ... Thus, there are certain classes that are required for a certified degree. And so we have a ... diversity in

> our curriculum in the chemistry department. I don't know, it would be interesting to have more flexibility." (Interview E1, pp. 14-15)

This statement shows on a very practical level how ACS guidelines affect college teaching. U.S. professors, depending on their discipline, are more or, in the case of chemistry, less flexible in what they teach.

To give an example of how intervening German associations can be and how they become indispensable for researchers, S2's example is given of how he automatically got in touch with and even became member of the DPG because of being one of the best physics graduates at high school. This reveals how the DPG as a central actor intervenes in 'recruiting' the best high school graduates for physics. It also shows that nano-specific seminars exist, also at DPG conferences where they are most often not designated as nanotechnology, but where they are nevertheless present. This supports the thesis that dominant societies subsume specialties, such as nanotechnology, and thus make it harder for specialties to gain their own independent standing as an academic profession:

> "Yes, I am [member of the DPG]. For several years now. Actually, exactly since I have left school. … I don't know, I think, … the three best physics graduates from high school received one year [of membership] for free. As I continued studying physics, I stayed. … Most important for me are two things: First, one knows what is going on through the journal. Professors always write what is state-of-the-art … with half a year of delay. Secondly, DPG organizes so many conferences and one gets deductions for visiting them. … And there, one gets in contact with other doctorate students and can gather ideas. … Usually, a doctorate student goes three to four times [to a conference]. One is a must, the big DPG conference, spring conference. Everybody from Germany basically goes there that do something related to the topic. Otherwise, there are single topics, such as magnetism. … There are seminars that are oriented towards nano … [for example] the Nano Network Hessen. … A lot has been already done in that direction, even though a lot of the times with another name. Often, it is not entitled Nanotechnology. … But the fact that everything moves towards nano is seen at each conference." (Interview S2, pp. 12-13)

In sum, these statements all underline that professional academic associations are of importance. The influence on curriculum and on students, however, is far greater in Germany than in the U.S.. In the U.S., associations become mainly important for conferences, networking, and publishing research. In addition, in Germany, associations look for early contact with students and an early institutionalization of young academics. Doctoral students in Germany participated more regularly in conferences, also abroad. Still, networking at conferences and reading literature are central aspects mentioned by German researchers as well. In particular, reading professional journals, as mentioned by O1 and S2, distinguishes Germany from the U.S.: In the U.S., the time lag between submission and publication date was deplored (see interview with B3), which gives associations and their conferences an advantage as researchers can keep themselves up to date. In Germany, professional associations influenced curriculum-making due to the participation of professors in these organizations (McClelland, 1991).

In the U.S., by contrast, curricula are set up by accreditation committees and industry directly and thus are in charge of credentialing and ensuring standardized curricula due to the lack of nationwide uniform governmental criteria for awarding degrees in the natural sciences (and other disciplines). To use college degrees as objective measures for skills and abilities, some standardization must occur. This, as was shown in some interviews, takes place via accreditation committees and in the case of chemistry via a professional association. In Germany, accreditation agencies have not reached the status of an influential body, such as U.S. accreditation committees have. As several studies pointed out (Kehm, 2007; Serrano-Velarde, 2008), the functioning of accreditation agencies in Germany is still in its childhood.

In terms of nanotechnology and its relation to professional associations, the stances were different as to how nanotechnology should be present. Whereas H1 saw the need for the integration of nanotechnology into SPIE, others did not. J1 even saw no importance in professional organizations, and S1 did not notice any importance for professional issues, but more in networking advantages. H1's example manifested how problematic the integration of nanotechnology into professional associations is. H1 was in favor of integration into SPIE. However, this is an association based on engineering. There are further associations to which nanotechnology is central as well, which would speak for a completely autonomous association for nanotechnology to get rid of its subordination. As long as traditional disciplines dominate not only universities, but also professional associations that are dedicated to the provision of future generations of physicists, engineers, chemists, and materials scientists, the small community of nanotechnology will have difficulties in separating from these large associations. In both countries, membership in the largest disciplinary professional organizations is a must: in the U.S. more so for senior researchers, in Germany more so for younger researchers, since they often cannot avoid it as, with the decision to study physics, membership comes along automatically. For senior researchers it is an instrument to stay up-to-date, for younger researchers in Germany it is a way to be able to go to conferences and to read professional journals, and to do that by paying less. In a nutshell, professional associations in Germany are more manifold with regards to their charges: they do recruiting, organizing conferences, publishing articles, and they are constantly in contact with universities and their professors, who are members, to declare the need for degree programs, such as in the nanosciences. N1 fulfilled this role in the VDI. He advises universities in the establishment of nano-related programs emphasizing that nanotechnologists will be needed in the labor market in the future.

Next to participation in networking conferences and presentations, co-authoring is also important for a specialty to become visible. Therefore, nanotechnologists remain a small, but visible group: there is visibility on conferences, although on the whole, these conferences are otherwise not different from non-nanogroups. The identification by academic discipline, not by technology, still comes first. Additionally, visibility occurs through nanotechnology centers that maintain public relations, relations with politics and industry, and thus foster public awareness.

The structural elements of professions are institutions, personnel, organizations, recruitment policies, standards and codes, political activities, relations with the public as demonstrated in the last paragraph, as well as informal mechanisms of sociability and control (Bucher & Strauss, 1961, pp. 325-326). If nanotechnology is a profession, then it will have these structural elements. The nanotechnology field already has institutions, organizations, personnel, and recruitment policies that are discussed subsequently. It remains to be seen how the field evolves in terms of other structural characteristics of professions.

(1) Institutions and Organizations in the Nanotechnology Profession

There are organizations and institutions exclusively installed for nanotechnology as mentioned in chapter 5. There are, however, differing approaches in the U.S. and in Germany. In the U.S., to be seen at PSU, nanotechnology skills are merged into existing natural science programs, to be described from an institutionalist perspective as "translation," i.e., "the blending of new elements into already existing institutional arrangements" (Campbell, 2010, pp. 98-99). In Germany, however, "layering" (Streeck & Thelen, 2001, p. 31) delineates the approach of universities to install new programs, in particular master programs, and thus extend the array of offers of degree programs in order to recruit new students in natural sciences. This type of institutional change also leads to "conversion" (Streeck & Thelen, 2001, p. 31) by reinterpreting the opportunity to implement the Bologna reform and its purposes. From the perspective of the state and its consultancies, the production of nanotechnologists is the motivation to create new degree programs. This is emphasized by N1 from the VDI:

> "When I talk to companies, they often say, 'nanotechnologists, we do not really need them.' And it is not surprising because there are only a few nanotechnologists on the job market. But now there are more than 30 degree programs on nanotechnology. Ten years ago no nanotechnologist existed. Mean-

> while, there are some graduates. These are degree programs that have been developed recently. For now, those who work in companies, they often have studied physics or chemistry. Yet, one thing is certain: nanotechnologies are very promising, in particular for research organizations and companies." (Interview N1, p. 10)

(2) Personnel in the Nanotechnology Profession

Next to distinct organizations, there are distinct personnel in the nanotechnology profession. The personnel include not only academic or industrial researchers, but also staff and technical assistants who completed apprenticeships in Germany or U.S. community colleges, but were not trained in a traditional discipline, such as biology, chemistry, materials sciences or physics, which are the dominating disciplines in nanotechnology. These personnel are needed in the administration of nanocenters and in nanolaboratories at universities, industry research facilities or otherwise public research institutes.

(3) Recruitment Policies in the Nanotechnology Profession

The nanotechnology field has two central mechanisms of recruiting nanotechnology personnel. First, personnel are directly recruited from the market: from industry (e.g., in the case of staff or technical assistants), or from universities, (e.g., Ph.D. students). Second, and probably most importantly, in a core technology, such as nanotechnology, academic professors function as recruiters for research institutes or industry laboratories. They do this by collaborating with industry and public research societies and by functioning as the primary investigators in university labs that cooperate with industry. Thus, they are the link between industry looking for competent researchers and Ph.D. students who are looking for job positions.

7.5.1 From Profession to Professionalization

After presenting the structural elements of professions, the question about processes strikes important. The same way nanoresearchers are examined in this study on a meso- and micro-level, professions must also be analyzed from the perspective of processes. As Abbott (1988, p. 19) emphasizes, structures dominated professionalization theories rather than work: Professionalization "ignored who was doing what to whom and how, concentrating instead on association, licensure, ethics code" (Abbott, 1988, p. 1). This is what is central in this section about professionalization: In the interviews, it was asked 'who is doing what to whom and how.' Everyday 'work activities,' interaction, communication processes were of interest. Modes of communication proved to be of great relevance, both for professors and Ph.D. students. The everyday lives of the interviewees were largely marked by interaction, presentations, meetings, contacting sponsors, writing proposals, advising students, and conferences. Conferences are a reason why memberships in professional associations are considered indispensable: It is at conferences that networking and "socialization" (Interview H1, p. 7) occur, which can be conceived of as informal rules and (reproductive) mechanisms within scientific communities, and this way, communication and personal contacts are nurtured. Researchers keep themselves up to date when participating at conferences. This stimulates their research. Professors function as PIs and links between students and the labor market (both industry and academia). Personal contacts are important and relied upon when looking for jobs. When Ph.D. students were asked how they would apply for jobs, nearly all of them referred to their PI, professors and/or supervisors or executives they knew that they would ask for establishing contact to another job position. F2 even would avoid submitting resumes to some company he would not know anybody:

> "Well, generally when people look for jobs, they .. find a job for whom they know. Personal contacts are a big deal when looking for a job. And so places that I would be looking would be places where I know supervisors, where I know managers personally, where I worked. I've done small projects before, such as Texas Instruments, SANDIA national laboratories, .. the Department of Energy .., National Instruments. [These and] few other places like that would be where I would go first just because I know people who work there. The second thing is that … I would very likely not look for a job that wasn't actively looking for me. If they just said, … 'submit a resume and we see what we do for you,' I would not likely submit a resume." (Interview F2, p. 9)

Successful professionalization takes place when a profession effectively manages a knowledge base, among others by developing an internal hierarchy (e.g., doctors and nurses). Thus, a profession fulfills a societal function. Doctors, to continue the example, are in charge of curing patients. Professions have codes and norms directing the behavior of its members. The American Medical Association, for example, has a Code of Medical Ethics for its members (see homepage of the American Medical Association). Having these rules of behavior allows the profession to distinguish itself from others. There can be many identities, values and interests that identify a profession.

Professions, thus, have a relatively high standing compared to general occupations and imply "theoretically based discretionary specialization" rather than mechanical specialization: "work that cannot be performed mechanically because the contingencies of its tasks vary so greatly from one another that the worker must exercise considerable discretion to adapt his knowledge and skill to each circumstance in order to work successfully" (Freidson, 1999, p. 119).

The nanotechnology field does not fall squarely within this definition of professions, thus making it a unique case and difficult to assert if professionalization will be successful or not. Nanoresearchers often work in several disciplines which work together either in academia or in industry. Nanotechnology is a cross-discipline and platform technology that is subsumed formally as a specialty simultaneously under the natural sciences and under professional associations (see Abbott, 1988, p. 106). Thus, for example, in university research labs funded by industry or the National Science Foundation, engineers or chemists work with biologists when it comes to drug delivery. The applied research orientation and integrative nature of nanotechnology that combines several disciplines (A. L. Porter & Youtie, 2009) supports this notion of despecialization. Specialists in traditional disciplines are nonetheless needed in nanotechnology, but are required to expand their research and collaborate with other disciplines. An internal hierarchy, another professional characteristic, can be noticed. With PIs and their research groups that are predominantly made up of Ph.D./doctoral students, there is a hierarchy based on age and experience. Students might be more specialized and knowledgeable after completion of their doctoral thesis in their respective topic, but nevertheless, institutionally, professors are ranked higher in the university hierarchy as it used to be in the Humboldt tradition when doctoral candidates were dependent from the (full) professor (Johnson, Rapoport, & Regets, 2000, p. 126; Ringer, 1990, pp. 36, 81).

Professions are marked by long-term career paths and "distinct personal and public occupational identity" (Freidson, 1999, p. 120). They are socially closed and constitute distinct and recognizable social groups within the labor market (Freidson, 1999). Given that nanotechnology is a relatively new organizational field, long-term career paths are not clear. As with other technological fields, however, academic and industry career paths emerge that, compared to Germany, are less continuous in the U.S. with its more flexible labor market. For this section, one can conclude that nanotechnology exhibits features of a profession, but still, it would be overhasty to infer that nanotechnology will be a future profession.

7.5.2 Occupational Identities

With occupational identities being a characteristic of professions, this point will be elucidated next. Biographies are individual (narrative) reproductions of a chronologically ordered sequence of social positions. As social positions change during life courses, biographies are subject to change, too. Thus, in each period of life, a new identity must be learned and adapted. Occupations serve as a basis for finding identities in adult age. In work organizations, identities are imposed on individuals, not negotiated. (Windolf, 1981, pp. 52, 55) In the interviews, identities of two periods of life were identified:

occupational identities of professors and Ph.D. students whose main tasks revolved around research in nanotechnology.

Socialization, “wholeness” and task-identity, continuity (challenged by increasing fragmentation of life and career paths), qualification, allocation of individual qualifications to a job position represent some characteristics or rather functions of professions (Arnold & Gonon, 2006, p. 75). Qualification and task-identity were confirmed in the individual biographies. Receiving credentials, schooling, and interest-driven motivation were central in all biographies, most importantly in the students’ biographies when they were giving reasons for the research group they applied for. It always had to do with fascination for a researcher, for what he did that they found interesting and appealing. Nobody mentioned, for instance, the reputation of the university. Certainly, joining a research group had to do with socialization: Interest in a researcher’s topic is not enough. One must adapt to the local (lab) culture that prevails in a lab at university. This is why students rotate between labs (G2) or change labs when they are not satisfied with either their project or their PI.

Occupational identities in the context of nanotechnology were built on traditional academic disciplines. All informants except for B3 hesitated or refused calling themselves nanotechnologists. B3 replied,

> “When someone asks me what I do, I say I work in nanotechnology, science with nanomaterials. … I use microscopes (both optical and electron microscopes) and other techniques to actually *‘see’* what I’m doing. … I’m not specifically a metallurgist; I’m not specifically a ceramist. Even though I do work with metals and I do work with ceramics; I’m a nanotechnologist first.” (Interview B3, p. 6)

All the others were reluctant to see themselves as nanotechnologists first. The reluctance to call oneself a nanotechnologist despite the visible institutionalization of nanotechnology in the form of nanocourses and nanocenters or, more often in Germany, nanoscience and nanotechnology degree programs, can be linked to a ‘strategic self-classification’ or ‘strategic self-understanding’ of researchers as in the case of artificial intelligence (Koch, 2005). This means that, depending on the context, academic researchers are nanotechnologist or not. In the interviews, they referred to their disciplinary identity, i.e., to established academic disciplines, whereas they did not make a secret about using nanotechnology in proposals.

Therefore, it might be expected that nanotechnology probably will not become an autonomous profession, but be subsumed under academic professions or, if nanotechnology is successful in industry and the economic labor market, under professional associations. Abbott (2005, p. 210) asserts that disciplines remain a “core element of the identity of most intellectuals in modern America” up to today. He argues that disciplines “offer more or less stable career identities” (Abbott, 2005, p. 216) in contrast to other institutional structures, such as in our case nanotechnology or nanoinstitutes. Disciplines do not merge because knowledge demanded from scholars must be manageable (Abbott, 2005, p. 216). As knowledge becomes more and more specialized, it would be hard for scholars to cope with a great body of knowledge. On the other hand, disciplines are not split, because the departmental structure of American universities is based on disciplines and vice versa. Natural sciences represent a special case because these disciplines “make a natural hierarchy of generality” (Abbott, 2005, p. 217), e.g. biochemistry and physical chemistry. Although boundaries between natural sciences are crossed at times, in particular in nanoscience, naturally, there is an understanding of what is the realm of chemistry and of physics. According to Louis Menand (2010), with the “increased professionalization of academic work”, the professoriate is converted into “a group of people who were more likely to identify with their disciplines than with their campuses” (p. 144). To Menand, and here is his connection to knowledge production, “the key to professional transformation is not at the level of knowledge production. It is at the level of professional reproduction. Until professors are produced in a different way, the structure of academic knowledge production and dissemination is unlikely to change significantly” (Menand, 2010, p. 121). The interviews show that professional reproduction take place in a similar way in the U.S. and Germany and, historically, not in a very different manner from decades and even a century ago. The core hierarchical position of the professor is the same as it had been in the 19th century when the “German mandarins” (Ringer, 1990) established the chair system with one professor at the top and graduate and doctoral students at the bottom.

The self-description of nanoscientists points to a strategic approach to self-categorization: As a new field, using the nanolabel is not appropriate in any situation. For reasons of reputation and identity-coherence, personal disciplinary background is more important and indispensable when presenting oneself to others. There is an uncertainty around the nanolabel as it is unclear how nanotechnology will be absorbed, if at all, in academia, if it will become a discipline, or if it will be immersed into existing disciplines. This uncertainty and the popularity of nanotechnology in politics and industry certainly add to the detachment with which academic nanoresearchers approach the use of nanotechnology.

7.5.3 Role of Professors in Scientific Communities

Biographies as mentioned in the last paragraph were part of the interview questions. Here, it became clear that the role of professors is multi-faceted: They were researchers but their everyday lives consisted of meetings, advising, and applying for grants. They fulfilled the role of mentors, principal investigators, ‘scientific managers,’ and administrators. G1 described her workday as follows:

> “It’s usually a combination of writing grants, meeting with students, reviewing papers with them, giving presentations, usually doing a few administrative functions of running the graduate program, and meeting with committees in that capacity. And then thinking about new ideas, hopefully, which is probably the least amount of time.” (Interview G1, p. 7)

Apart from common characteristics of the role of German and U.S. professors, differences in their tasks arise from the differing organizational structure at universities. With the chair structure, German professors gain competencies within university that are more encompassing than those of U.S. professors. With the Bologna process, competencies, however, were diminished and new tasks introduced. The Bologna reform also provided opportunities to change and/or add curricula and degree programs in the form of bachelor and master credentials. U.S. professors, by contrast, are embedded into department structures, not chair structures, where they head more or less large research groups. Unlike German professors, their tasks can include frequent communication to industry and start-ups or spin-offs, which is important for raising third-party funds or ordering materials, nanoparticles or crystals for example, for their research.

With professors being ‘scientific managers’ and administrators, this phenomenon seems to be a trend in higher education: As Nadine Hoser (2008) found out about medical e-learning courses in continuing education at one of the most renowned universities in Chile, Universidad de Chile, professors assume more and more the role of ‘facilitators’ enabling communication and transfer of content, answering emails and watching group discussions. Doing research and teaching becomes less central. Slaughter and Rhoades (2004, pp. 311-312) pointed out, “the traditional tripartite faculty role of teaching, research, and service altered during the period from 1980 to 2004”: as professors received more and more merit for research instead of teaching, their individual preferences shifted toward research as well. The professors and doctoral students interviewed admitted that they liked teaching.

> “I came back from industry because I wanted to be a teacher again … I like teaching and I see it as an important task to teach somebody. … Otherwise, everything is static, … and there is no regeneration.” (Interview O1, pp. 18-19)

However, teaching subtracted time from doing research and publishing, which is necessary for third-party funds. In particular at universities of applied sciences, the teaching load is proportionately higher than at German research universities:

> "The biggest chunk here [at universities of applied sciences] are lectures. Unlike research universities, each professor here has 19 contact hours teaching load. This means, just with standing in the classroom and teaching, half a week is over. Lectures must be prepared and wrapped up. Course material must be uploaded in the internet, exams must be held, etc. That is the biggest chunk." (Interview K1, p. 13)

This is analogous to U.S. universities when comparing state universities to research/private universities where teaching loads vary as well.

To give an example of the rise of another discipline, Joseph Ben-David and Randall Collins (1966) traced back the emergence of the discipline of psychology and described this with 'role-hybridization' (in contrast to mere 'idea-hybridization'). 'Role-hybridization' refers to

> "the individual moving from one role to another such as from one profession or academic field to another, [who] may be placed at least momentarily in a position of role conflict. This conflict can be resolved by giving up attitudes and behaviors appropriate to the old role and adopting those of the new role; in this case, identification with the old reference group must be withdrawn" (Ben-David & Collins, 1966, p. 459).

To solve this conflict, innovations might occur by the individual who merges the old methods and techniques with the new role's ones and thus creates an entirely new role. As can be noticed from the interviews, this is not the case with nanoscientists. The reason is that, unlike Ben-David and Collins (1966, p. 460) described, "the chances of success" in natural sciences are not "poor." Rather, the number of positions is not stable so that scholars are unlikely to move into the new field of nanotechnology. Chemistry, physics, materials science, and biology are disciplines that enjoy high status and are seen as indispensable for technological and social progress. Numerous government initiatives, both in Germany and the U.S., give proof of this. Women are encouraged to study natural sciences, and high school initiatives try to bring students closer to the world of physics and chemistry. Chairs are established, for instance the chair in nanoelectronics at University of Münster that is part of a tripartite department of biology, chemistry, and physics.

Founders that are open to new roles by taking over new methods as well as followers (i.e., disciples) are required for a discipline to emerge. In the context of the analysis of interviews with nanoscientists, it became clear that new methods were used, but scientists would not identify themselves with new roles as nanotechnologists. What is more appropriate for the situation of nanoscientists, as narrated in the interviews, is the term 'idea-hybridization' (Ben-David & Collins, 1966, p. 460). This term refers to "the combination of ideas taken from different fields into a new intellectual synthesis. The latter does not attempt to bring about a new academic or professional role, nor does it generally give rise to a coherent and sustained movement with a permanent tradition." 'Idea-hybridization' is to be compared to 'cross-pollination' between ideas from different disciplines (Grodal & Thoma, 2009) that facilitates the mobility of concepts and thus fosters (radical) innovations. There is a clear limit to the internalization of ideas meaning that new professional roles do not emerge. Therefore, despite certain evidence for the professionalization of nanotechnologists fostered by degree programs and government initiatives, professionalization comes to a halt in the world of science.

Yet, also for a scientific community to emerge, scientists would have to identify themselves with nanotechnologists and see themselves as a member of the respective community (Gläser, 2006, p. 155) by recognizing a stock of knowledge and orienting research tasks toward this stock of knowledge. However, this is only conditionally the case with nanoscientists. Scientists interviewed can be classified as members because they actually do nanoresearch. Yet, instead of moving from one role to another, they take up ideas and methods from nanotechnology and do research on respective tasks, but always withinn the frame of their discipline. Thus, one can speak of an integration of nanotechnology into academic disciplines, be it for better chances of funding or because of necessity as research tasks are only to be addressed by nanotechnology. Nanotechnology, after all, is described as a cross- or interdisciplinary technology which also implies that it is not a discipline on its own.

This leads to the conclusion that when talking about nanoscientists, one should be careful referring to them as a scientific community. Nanotechnology is part of academic research as a subdiscipline or specialty, with specialties being defined as "smaller intellectual units (nestled within and between disciplines)" (Chubin, 1976, p. 448). It is suggested speaking of the disciplines involved (materials science, chemistry, physics, etc.) or, if nanoscientists or nanotechnologists are used, then one should rather emphasize the still developing professional field of which its future as a scientific community or discipline is yet uncertain. Materials science, as the youngest of the main disciplines involved, is most probably the discipline that will capture most of nanoresearch. As the boundaries of scientific communities, in particular national communities (Gläser, 2006, p. 186), are fluid anyway, one can situate nanoscientists in their disciplinary community (communities) and the nanoscientific/nanotechnological community although scientists would hesitate to position themselves in the nanocommunity (let alone solely in that community). Yet, and this is the most interesting aspect, by actually doing nanotechnology, these scientists contribute to the nanotechnological stock of knowledge, be it consciously or unconsciously. Positioning in traditional disciplines and departments represents the prevailing organizational order.

Furthermore, there was evidence for the disappearance of the individual as an 'epistemic subject' (Gläser, 2006, p. 372) in a scientific community. Research is done in research groups with a PI and his or her doctoral students and/or post-docs or permanent research staff. Thus, the hypothesis according to Jochen Gläser (2006, p. 181) that tasks that were to be done by a single researchers are now performed by a research group is supported by the interviews. PIs are those who direct the program of their group, who come up with ideas by screening literature, and who manage their group. They are in addition those who build their reputation and communicate with others most often, although actual research and creation of knowledge is performed by Ph.D. students. As noted by de Solla Price (1970, p. 12), hard sciences have a higher percentage of references cited in the last five years. He speaks of an 'Immediacy Effect,' "a special hyperactivity of the rather recent literature which was still, so to speak, at the research front" (de Solla Price, 1970, p. 9). S1 supported the abundance of literature available and the fact that doctoral students cannot catch up with the literature:

> "It is such that, and this is my experience, [there are many ideas emerging from lab discussions between me and my students. Students are very enthusiastic, unfortunately, however, most of their ideas have] been published somewhere already [, which I have to check due to my extended experience.] This does not mean they [the doctoral students; author's note] are stupid but they have .. very good idea[s], which, unfortunately, ha[ve] been coped with already. And this is the stupid thing in science. They [the doctoral students; author's note] cannot know everything [and me neither] … There is so much [research and development] out there ... But this discussion goes on quite often. In my group it is as follows: I give a direction [, preliminary suggestions for experiments,] for the doctoral thesis and then, they must start [and the project should develop by itself]. .. Doctoral theses are independent scientific contributions, i.e., they must discover something on their own." (Interview S1, p. 24)

Experience, networks, and reputation are assets that only PIs obtain and constantly build on by publishing with Ph.D. students and guiding research to assure that relevant knowledge is created and the "knowledge gaps" (Gläser, 2006) are filled. It can be noted that also Gläser (2006, p. 261 e.g.) speaks of autonomous decisions of professors and their central role, thus, underpinning that it is still researchers who obtain a central position in scientific communities.

The social order that emerges in the production of scientific knowledge is an emerging phenomenon resulting from the autonomous decisions of professors (Gläser, 2006, p. 261). So, simulating the cooperation networks and research direction of research centers that are funded by state agencies deems appropriate to analyze which social phenomena emerge in higher education. As mentioned above, disciplinary anchoring dominates among academic researchers. However, to integrate change in research programs that are directed by professors or PIs, in the model, research areas, not only disciplines change. These areas are topics like solar cell research, circuits, nanooptics or monolayers. Even if discipline-based self-categorization is rather stable, research topics can move in different directions depending among others on the funding available. Q1 demonstrated this:

> "And here, in general, the level of science is comparable with that in the U.S.. … What is missing is the idea that it is nothing to be ashamed of to transfer good scientific ideas into production. When, at the beginning of the 1990s, we applied for a chair in applied physics one of my colleagues argued 'applied physics is no physics at all.' Then, I replied, 'it makes no difference, we need the word 'applied' to get funding from the ministry. The person hired can still do basic research.' And that was what we did. Yes, but at that time 'Applied physics,' was considered somewhat indecent among many colleagues. And this attitude is different in the U.S.. Out of necessity. You do not get funding otherwise. Research programs in the U.S. are more application-oriented." (Interview Q1, p. 7)

Asking about their careers, the motivations for staying in academia (or not) were also discussed. Autonomy (F2, A3, K1), flat hierarchies, freedom (K1), transfer of knowledge (G2, G1), teaching future researchers and professionals (B1, E1, O1), interdisciplinarity (A2), applicability of basic research to help people (A3, G1, G2), less practical research because of funding from public institutions that allows more long-gestation projects (G2), interest-driven environment (A3), tenure positions (O2), and less stress including more flexibility in working hours (B1) were reasons for staying in or joining academia. Thus, not only Ph.D. students reveal a "taste for science" at the beginning of their academic career, but the "desire for independence, publishing, peer recognition, and interest in basic research" (Roach & Sauermann, 2010, p. 422) is still effective later in academic careers when comparing preferences for research careers in industry or academia. In the interviews, the desire for independence, i.e., autonomy and freedom, were most prevalent. Long, often uncertain career tracks with no guarantee of full professorship (C2), constant funding challenges (F1, A3), a higher number of positions in industry (C2), and less 'useful' research unless funding came from industry (G2) were mentioned as possible disadvantages of academia. Academic freedom, interestingly, has one of the most enduring characteristics of the academic profession and its identity that has been formed in the U.S. in the 1910s, as Jonathan R. Cole (2009, p. 53) points out. This freedom is guaranteed in exchange for the delivery of discoveries and practical benefits for society. In the German case, the development of a professional identity had been effected earlier with Wilhelm von Humboldt's ideals of freedom and solitude, which are surely equally important in the German academic profession.

Professionalization further implies the elaboration of a specific competence for professional action involving a client (Hesse, 1968; Kurtz, 1997). This competence is endorsed by university degrees and certificates. Notably, attending universities and receiving graduate degrees and certificates are not a guarantee for professionalism (Dewe et al., 1992; Kurtz, 1997, p. 148). Other features of professions are their focus on single cases and the non-standardization of professional actions with several logics involved: the logic of the market, of bureaucracy, a specific ethos, and expert knowledge. Expert knowledge is central in nanotechnology because nanotechnology is often described as a tool. This means that skills are involved that must be transmitted in education. This explains the founding of degree programs for associate, baccalaureate and graduate students. It conveys a functional view of education: a knowledge base forming expert knowledge must be transmitted through schooling and represents a set of skills that requires hands-on education and certification. Concerning

professionalization, Abbott (1988, p. 102) remarks, "[a]s is traditional, abstract knowledge is central. But the justification for it is new; knowledge is the currency of competition."

For this study, Abbott provides a very manageable definition precisely because he realizes the abundance of definitions which makes the analysis of professions more and more difficult and tedious. Abbott (1988, p. 318) explains, "a firm definition of profession is both unnecessary and dangerous; one needs only a definition strong enough to support one's theoretical machinery. My loose definition–professions are somewhat exclusive groups of individuals applying somewhat abstract knowledge to particular cases–works well enough. In fact, profession is not 'objectively' definable precisely because of its power and importance in our culture." With this definition, nanotechnology fulfills the criteria of a profession under the condition that abstract knowledge can be found in nanotechnology. The knowledge base of a profession must be abstract, but also concrete enough (Abbott, 1988, p. 104) in order to be an effective and relevant profession. The problem in nanotechnology, as the name suggests, is that it does not include a delineated corpus of knowledge in the form of an epistemic system (although some prospects on a common epistemology exist, e.g. quantum theory, which are, however, still disciplinary based (see Loeve, 2010 for chemistry e.g.)). Nanotechnology is very abstract as it can be implemented into very diverse fields of application and thus it might be diffused into existing professions. This might pose an obstacle to it becoming a profession. As "two professions cannot usually occupy the same jurisdiction at once" (Abbott, 1988, p. 88), the vacancy that develops in the case of a new technology or task must be taken over by existing professions or by new professions that strive to take hold. It is exactly this circumstance that cannot be answered for now (Abbott, 1988, p. 90).

If problems arise with the knowledge base of nanotechnology, one might ask if, nevertheless, a common social practice for nanopractitioners can be observed. A professional habitus is developed resulting from the practice of a profession (Schützeichel, 2009). This 'habitus' is revealed in the interviews when typical workdays and study days were described. It became clear that professors fulfilled multiple roles, Ph.D. students were interest-driven when joining research groups, and nanotechnology was seen as a tool that was necessary for advancing in personal projects. Looking for sponsors, writing reports and proposals, collaborating with other professor and departments, presenting research, and visiting conferences represented constant tasks that the interview partners identified with because as A3 remarked, "I wanted to do chemistry" (Interview A3, p. 8). Identification took place via academic disciplines, not through methods and technologies that were used. Therefore, the habitus is more similar to the already existing one and thus, making it difficult to view nanoscientists as a separate academic profession. Even the institutional heterogeneity for nanoscientists who are often formally part of the university, but work in nanoinstitutes and use their laboratories does not make them 'exclusive' cases, for this would apply to 'any scientist' who does research outside university in public-research institutes or governmental centers.

Occupational images in the natural sciences were characterized primarily as broad because being a natural scientist opens a wide range of jobs in academia, industry, and the service sector. To P1, "the occupation of a physicist is comparable to lawyers. It is an occupation that opens multiple occupational possibilities" (Interview P1, p. 4). This is why some of his former colleagues had gone into consulting or other companies. "Only a fraction of my former colleagues ended up in research," so P1 stated (Interview P1, p. 4). L1 related the occupational image of chemists to nanotechnology. To her, the naming of nanoinstitutes could even offer an opportunity to improve the image of chemists in society

> "because it raises more interest … I mean, when you say, I am doing chemistry, one is principally the one who pollutes the environment and creates nothing of good quality. .. With the term nanotechnology, people have no idea at first what it actually is. And then it is called technology, which means, it cannot be bad per se. Because of that, I think, it has a more positive effect if one presents [chemistry] under this aspect, when one says, yes, Karlsruhe has quite a lot of chemistry." (Interview L1, p. 5)

In the field of nanotechnology, ‘clients’ and a focus on single cases must be seen in a more differentiated way. Researchers who are actively cooperating with government and/or industry and thus oriented toward a more applied approach in their research, such as inventor-authors who do not only publish, but also patent, fulfill this requirement of professionalization. Ultimately, society serves as a client when researchers are concerned with drug delivery or the enhancement of energy efficiency. However, academics doing basic research (e.g., those working for German Max Planck Societies) might not see themselves in a direct client-interaction. Their budgets are state-funded, and their focus is on exploring molecular synthesis or molecular reactions without a direct application in mind. Nonetheless, non-standardization of professional actions (each new application represents another challenge), the logic of the market, and expert knowledge speak in favor of nanotechnology’s professionalization. Professors in their role as researchers, teachers, and managers can be seen in a network of client-relations to the state (not only through budgeting, but also by giving expert advice for instance), to industry (if industry cooperation exists), and, not to forget, students. Additionally, the fact that individuals can earn nanocertificates as well as traditional degrees in the natural sciences and engineering speaks for the legitimization, yet not necessarily professionalization, of nanotechnology (Abicht et al., 2006; Baron, Busch, & Gleiche, 2009; Stephan et al., 2007; Vogel & Campbell, 2002). Even undergraduate and graduate programs have been developed that are dedicated exclusively to nanoscience and -technology. In the future, industry will require not only college-educated workers, but also technical workers with a degree from a community college (in the U.S.) or an apprenticeship (in Germany) (Abicht et al., 2006).

Generally, emerging professions determine their new tasks themselves (Heidenreich, 1999). A “cognitive base” (Heidenreich, 1999, p. 11) is established which is the result, not the condition of, a successful professionalization strategy. Cognitive base refers to the distinct knowledge base over which professions have control (Heidenreich, 1999, p. 12). In the case of nanotechnology, various academic disciplines are involved in creating the knowledge base, called ‘expert knowledge’ above. For a profession to develop, researchers would have to actively set the boundaries of the nanotechnology knowledge base. In nanotechnology, however, it is unclear what the knowledge base is due to its interdisciplinary character. The boundaries of the nanotechnology knowledge base seem constantly in flux because of the participation of several disciplines and scientific discoveries that are based on new knowledge. This makes the control of a nanotechnology knowledge base, if there was a concrete on, difficult.

7.5.4 Professional Associations in the Context of New Tasks and Professions

The German sociologist Martin Heidenreich observes that in Germany, processes in the labor market are structured via occupations and professions (i.e., academic occupations) (Heidenreich, 1999, p. 3). This underlines the presented model’s focus on professional associations as intervening factors in Germany (cf. the ‘Model of Intervening Mechanisms’ in section 1.2). In the U.S. however, structuration takes place on a company-level, which reflects the market-dominance orientation in the U.S.. Currently, change is occurring with respect to professional associations due to the Bologna process. The assumption on the closedness (i.e., tight regulation and predetermination) of professional careers in Germany and their openness in the U.S. must be reassessed because Germany’s educational and professional culture is changing. The Bologna process supports the principles of open education and labor markets. Open degree programs, such as law, did exist in Germany before the Bologna process. But, the influence of professional associations and the German State, most importantly by running the examinations in professions like law, medicine, and teaching (‘Staatsexamina’), secured tight control, which reflects the political economy of a CME. By implementing the Bologna process, this control is dissolving. Not everyone is content with parties losing control. Specifically, the national representatives of professional associations that had power are being pushed back by the global economic and knowledge elites who are becoming representatives for professional organizations (Münch, 2010). The

old institutions are concerned because these new elites that stress market principles and market rationale are threatening long held German practices, such as the traditional emphasis on long-term relationships, collaboration, and the influence of professional associations on the curricula of applied studies like engineering (Münch, 2010).

Adjacent, but still unanswered research questions for the field of nanotechnology are: What characterizes a nanoscientist and a nanotechnologist? Is a new concrete job profile of a nanotechnologist emerging (most notably in Germany)? Are careers in nanotechnology filled with institutionalized patterns of capacities and skills? In the model discussed above, labor markets serve as an indicator of the degree to which of institutions have accepted technologies. Specifically, jobs being available for those doing nanotechnology research, indicates that institutions have accepted nanotechnology.

In examining the professionalization stage of nanotechnology, historical and cultural factors must be analyzed. Researchers De Vries, Dingwall, and Orfali did such an analysis in bioethics, which they deemed to be a new profession in the medical sector (DeVries et al., 2009). They noted that bioethicists strove to develop a bioethics profession. The development of the bioethics profession shows that there can be such a thing as “a profession in process” (DeVries et al., 2009, p. 557). That is, developing a profession takes time, and there are points where a profession does not exist, despite there being people in the field practicing this emerging profession. Or, more specifically, the term ‘nanotechnologist’ exists, but was hardly adopted by most researchers in the field or even avoided (A3, C1, F1, G1, G2, F2, A2).

Similar to the bioethics profession developing, the nanotechnology profession seems also to develop. At the beginning, U.S. bioethicists, just like nanotechnologists, did not have “institutionalized support of centers for bioethics, professional journals, government commissions or graduate programs and professorships” (DeVries et al., 2009, p. 559). But this has changed. Today, there are centers (e.g., the Center for Functional Nanomaterials (National Nanotechnology Initiative; NNI Research Centers)), journals, magazines, and degree programs in both bioethics and nanotechnology in the U.S. and in Germany. Degree programs exist at the bachelor, master, and Ph.D. levels. People can also specialize in certain areas and earn nanocertificates. (Abicht et al., 2006; Stephan et al., 2007; Vogel & Campbell, 2002) One doctoral student, P2, mentioned the applicability and systematic appropriation of nano-related techniques during his doctoral program that can also be used in other applicable fields. The applicability of what one is studying is very important including to L1 who alluded to the salience of practical experience during college:

> “If you want to head a laboratory in crop science or in pharmaceutical research, you just have to knowledgeable in synthetic work. And you learn it best if you work synthetically. This is hardly to be learnt from books. You just need this practical experience.” (Interview L1, p. 7)

This need for practical experience is what drives doctoral graduates to do internships, training, and, most importantly, become a post-doc before applying in chemical/pharmaceutical companies even though one does not intend to stay in academic research. Above all, the fact that new institutes are created in nanotechnology both in Germany and the U.S. nurtures the expectation that a nanotechnology profession will develop as Abbott (1988, p. 93) suggests: “New organizations often create new professions.” Therefore, a first big step has been accomplished in the creation of new centers. However, if these centers will become fully academic centers equal to disciplinary units, merely attached to universities or completely autonomous centers remains uncertain.

Even if a profession has not yet developed fully or exclusively in the nanotechnology field, multiple professional associations influence the nanotechnology research area because nanotechnology research is, as yet, integrative and cross-disciplinary (although the latter is disputed) (A. L. Porter & Youtie, 2009). Research in nanotechnology based projects generally involves researchers from various disciplines, such as chemistry, physics, materials science, and engineering, which might end up in competing for the jurisdiction in nanotechnology tasks (see Abbott, 1988). Momentarily, there is no distinguished academic discipline for nanoscience and -technology unlike in the case of artificial intelligence which has become a discipline, but not a technology (Ahrweiler, 1995). In addition, there is no single professional group combining all nanotechnologists, after from an educational point of view, at least in Germany, nanotechnologists have only recently started to exist (unlike in the U.S. where no such intention of producing nanotechnologists prevails).

The VoC approach, neoinstitutionalism, and professionalization theories shed light on nanotechnology in the context of education, the labor market, professional associations, and the market. The VoC approach with its distinction between coordinated and liberal market economies does not account for the fact that Germany is among the top leaders in nanotechnology. As another strategy of analysis, the neoinstitutionalist approach with its distinction between 'formal structures' and 'work activities' provides for clarification in finding out how the field of nanotechnology actually works institutionally (i.e., which processes take place in institutions, such as academia and industry).

In the context of 'rationalized professions' (J. W. Meyer & Rowan, 1983) that demonstrate the process of decoupling of 'formal structures' from 'work activities' and their functioning as myths, legitimacy is given by institutionalized social rules that help participants to socially construct professions. In nanotechnology, this process of social construction is still negotiated. Social rules, such as "licensing, certifying, and schooling" (J. W. Meyer & Rowan, 1983, p. 25), exist in the field of nanotechnology. There are certificates and accredited degree programs both in Germany and in the U.S.. Nanoscience is not an established academic discipline, and D1 and D2 actively support an immersion of nanotechnology into existing disciplines and degree programs for instance. However, and this supports nanotechnology as being a part of 'rationalized professions,' the nano-related knowledge base is already firmly institutionalized by social rules that regulate the adoption, certification, and translatability of nano-related knowledge from the higher education system into the labor market. The case of the Center for Nanotechnology Education and Utilization demonstrates this matter: the center is dedicated to the promotion of nano-related skills and fosters associate and baccalaureate degrees in addition to Ph.D. degrees to provide a workforce for industry. Thus, even though nanotechnology per se is not a 'rationalized profession,' it is strongly intertwined with academic professions and regulated respectively. To sum up, there is not yet a clear and definite professionalization in the field of nanotechnology, although there are indicators in favor of it, while its development remains to be seen.

7.5.5 Summary

As to be seen from the analysis above, one can summarize that the professionalization of nanotechnologists has started; but it cannot be said if it will be successful due to the singularity of nanotechnology. It cannot be precisely delineated, for instance, if professionalization is limited to industry (where it has already started) or will successfully take hold in both industry and academia. There are drivers for the professionalization of nanotechnology, single researchers or state representatives arguing about the importance of nanotechnology for economic growth, yet, together with other technologies, such as microtechnology or materials engineering. Thus, one might conclude in line with a study on nanotechnology in Ireland (Lux Research, 2010, p. 29) that in due time, nanotechnology will become routine, at least in industry, and its 'special' character will fade away together with funding. This would in turn suggest an integration of the knowledge of nanotechnology into existing professions. If nanotechnology, however, does remain a distinct profession, it more probably does so in the market outside academia where its professionalization has already begun. This transferal of professionalization into the market has the potential to resolve the tension that arises due to the differing interests of politics and scientists. The former want to establish a profession or at least fund nanotechnology to promote economic growth, while the latter are interested in groundbreaking science with or without application-orientation.

There are, however, signs that nanotechnology is still different from other fields of professionalization, as there are individuals convinced of its specialty and future importance and who actively promote the 'case' of nanotechnology. As one can see from the interview results, funding gives impulse for lines of research and is capable of co-creating and permeating a whole field once public funding agencies are convinced of the cause. In Germany, politics sees nanotechnology as a professional field that must be fostered. Thus, the creation of nano-related degree programs is encouraged in Germany to produce nanotechnologists being graduates from these programs. Also, the institutions created in Germany and the U.S. on nanotechnology support the notion that "new organizations often create new professions" (Abbott, 1988, p. 93).

Yet, in academe, professions of physics, engineering, and chemistry are still dominant, to be seen in how they are still prevalent in professional organizations. Nanotechnology may be integrated into conferences and sessions and work groups, but this does not erase the dominance of traditional disciplines. In addition, as graduates are trained by physicists, chemists, etc. and not by avowed nanoscientists, this would speak against the fact that nanotechnology will soon rise from the status of a specialty to the status of a discipline.

The question that was addressed was if nanotechnology and the involved science will develop into a new profession or will be subsumed, and if so, under which professional association. Momentarily several associations integrate nanotechnology as a section. If nanotechnologists will become more numerous and nanotechnology can show an effective treatment of relevant social problems or tasks, competition will arise with professional associations fighting for the jurisdiction in nanotechnology. Nanotechnology, thus, shows that professions are interrelated due to the grip of associations over nanotechnology knowledge. Viewed as a technology, nano-S&T will less likely become a profession. In terms of new organizations that create vacant positions for nanotechnologists and in the case of reaching an "equilibrium between extreme abstraction and extreme concreteness" (Abbott, 1988, p. 104), nanotechnology will develop as a profession in the labor market. In universities, it will be seen if academic disciplines compete for the integration of nanotechnology with one 'winner' of the race or if they each manage to subsume it under their own discipline. For now, everything speaks for an immersion into scientific disciplines. Similar to the structural impediments to the disciplinarity of nanotechnology, the observation about the uncertain future of professionalization in nanotechnology can be viewed from another angle: the dominance of professions can be strong because of uncertainty, not despite uncertainty, thus, hampering professionalization. As stated by DiMaggio and Powell, "delegation, professionalization, … and maintenance of face are all mechanisms for absorbing uncertainty while preserving the formal structure of the organization."

8. Discussion of Results

This explorative dissertation gives manifold insights into how complex the delineation and historical development of a new technological field is especially if its analysis is based on the academic sector with its own structural and cultural elements where distinct formal and informal rules as well as beliefs are valid. This dissertation comes up with hypotheses derived from simulation and narrative interview data. The hypotheses make clear that the process of implementation of an advanced technology cannot be seen as a one-way street or as an input-output relationship when trying to foster technological innovations and economic growth. Rather, working cultures based on norms, beliefs, and related meanings are located within institutions, i.e., universities and their research groups, which are exposed to external pressures, such as grant policies. These interactions seem to run counter to external political forces, but, in the end, the tension which emerges in the field produces the identity of nanotechnology within the scientific community. This identity is marked precisely by the ambiguity and reluctance that nanotechnology evokes in nanoresearchers who develop prolific strategies to deal with public funding on the one hand and to nurture the importance of firmly established academic disciplines on the other. These two strands represent the two sides of the coin of the academic community and the identity of nanotechnology.

The results of this explorative study are three-fold: first, the emergence of a research network due to nanotechnology funding and the impact of public funding were simulated; second, since the model does not give insights into the organizational life of academic nanotechnology, meanings of nanoscientists and their view on nanotechnology were explored drawing on data from 33 interviews; third, based on these meanings and evaluations of nanotechnology, central organizational characteristics of the academic field of nanotechnology were established. These hypotheses additionally hint to the limits of the VoC approach that relates solely to the macro-level and cannot adequately explain the success of nanotechnology in a CME. An analysis of the meso-level (in chapter 5) reveals the differing national implementations of nanotechnology at universities that show how, in different national contexts, an advanced technology can be successfully incorporated into higher education and research systems.

In this chapter, the findings from chapters 6 and 7 are first combined and discussed with respect to what they disclose about the academic field of nanotechnology. Then, the results from chapter 7 are discussed in detail since they are essential for the question about institutional and related cultural change as well as the production of identities within the scientific community of nanotechnology, an institutional process that is inherent to the ongoing change with respect to nanotechnology. The discussion that focuses on interview data takes place along three lines: the institutionalization of nanotechnology in the two countries, examined in an institutional comparison, and a summary of the status quo of the process of professionalization in the two countries with respect to the previously described institutional changes; cultural change in institutional contexts and the production of a professional identity with regards to nanotechnology; and, finally, the field of nanotechnology as characterized by both Mode 2 and Mode 1 features that constitute essential characteristics of the field.

8.1 Combination of Agent-based Modeling and Interview Results: a Résumé

The simulation results were obtained from modeling the emergence of a research network due to nanotechnology funding in an abstract way, the number of nanoresearchers, and the relationships between the probability of interdisciplinary and identity change. Modeling was applied to explore the effect of public funding. The findings demonstrated the importance of research networks and the central role of 'star scientists' as well as the limited influence of how public funding is distributed. These simulation results confirm what the informants expressed in the interviews on the importance of networking, conferences, professional associations and the attraction 'star scientists,' in their role as PIs, exerted upon

doctoral students who wanted to become members of the research groups. In addition, the limited influence of public funding can be noted in the interviews when investigating the self-categorizations of academic scientists.

Most interestingly, institutional change that is favorable to nanotechnology was not mooted at all among scientists as well as funding sources for nanotechnology that PIs tapped into in the need of third-party funding. It was the more subtle and less visible level that revealed a reluctant stance toward nanotechnology as a promising 'innovative technology.' That was expressed freely in the presence of another academic researcher who did the interviews. This manifests a divide between a politically pushed and an academic nanotechnology. That divide is also expressed in the interviews. Nanoresearchers differ between their self-categorization in terms of academic disciplines, which provide the source of their professional identities, and the strategic handling of the political side of nanotechnology, with which researchers cope with in their everyday work lives and which forms a central part of their research.

The tension between political and scientific interests is resolved positively when nanotechnology funding enables academic science and academia embraces the structural institutionalization of nanotechnology at universities in the form of new institutes and programs. This way, both sides can realize their respective goals without one party taking up the other. The latter is modeled realistically by the simulation of the spread of nanotechnology where the limited influence of funding on nanotechnology diffusion and research networks can be detected. The tension is also resolved by transferring professionalization, one kind of institutional process, into the (industrial) labor market where companies decide if they hire nanotechnologists or not. Professionalization has started in the economy both in Germany and the U.S., and job placements are available that specifically look for nanotechnologists. Since the demarcation of a scientific community which is dedicated only to nanotechnology remains doubtful in the near future, the construction of distinct identities that are necessary for a scientific community to develop has also not become a force that is strong enough to help resolving the tension. The interviews are discussed in more detail in the following sections as interview data provide the main data for the analysis of the inner life of the organizational field of nanotechnology at universities rather than the simulation data that illustrate the structure of the field.

8.2 Case Study: Institutionalization of Nanotechnology in Germany and the U.S.

As mentioned above, the success of nanotechnology cannot be explained properly by the VoC approach. Germany as a CME shows that for a successful implementation of nanotechnology, there are ways for a CME to foster and institutionalize an advanced technology. Hereby, it was noted that institutional differences lead to differing incorporations of nanotechnology in given higher education systems. The national higher education systems represent crucial institutional areas in an analysis on the institutionalization of nanotechnology because main differences can be detected in education systems which serve as anchor points for the institutional integration of new technologies. Next to differences, similarities that also arise from the exploration of interview data must not be neglected. Based on the institutional structures of Germany and the U.S., differing national implementations of nanotechnology into higher education are to be noticed. Whereas the German political economy with its focus on education and training fosters, besides research, the institutionalization of nanotechnology in higher education systems in the form of career tracks, the U.S. focus on 'big science' to be realized in new research institutes which are committed to nanotechnology. Naturally, despite varying foci, research in nanotechnology as the source of innovations and economic growth is on the political agenda in both countries. It is merely that education forms an area of nanotechnology support that is not as emphasized in the U.S. as it is in Germany. Therefore, new structural opportunities emerge in a new organizational field through the creation of positions in nanotechnology. These positions then represent opportunities for the institutional anchoring of nanotechnology.

In the following discussion, similarities and differences are listed. Similarities are to be noted in terms of institutional change and the mechanisms of decoupling and layering, of regulative pressures in the form of political reforms and policy agendas, the role of PIs and professional associations (see the 'Model of Intervening Mechanisms' in section 1.2) as well as publication behavior. Differences arise, besides the differing national incorporation of nanotechnology as mentioned in the previous paragraph, with regards to the realization of interdisciplinarity, professionalization, and the mechanism of translation. The similarities demonstrate how similar developments can occur despite different national higher education structures and research systems. The differences show how institutional structures provide paths for institutional change in addition to the influence of social actors, such as nanoresearchers, who mediate between the institutional and the individual level in universities.

In terms of similarities, one can say that institutional change occurred in both countries of comparison by way of layering and translation (Campbell, 2010). It is remarkable how the implementation in both countries took place rather through new (and costly) institutes and centers than in the form of individual internalization and new professional identities, i.e., pervasive personal commitment of researchers in the advancement of nanotechnology. Decoupling, therefore, adequately describes the change with regards to nanotechnology: 'formal structures,' i.e., new institutional layers, are separated from 'work activities' at universities so that nanotechnology becomes incorporated by way of new institutes and programs, but not as an additional discipline at universities. This divide can also be defined as a divide between political endeavors to foster nanotechnology and higher education contexts that cherish the natural sciences which belong to long established academic disciplines. Politics exert pressure on universities with regards to applicability, advanced technologies, and the need for innovations. This study has shown how researchers who are affected by these pressures deal with them in their everyday lives. The academic world cannot withdraw itself from these regulative pressures, also for reasons of legitimacy. However, due to "reputational pressures" (W. W. Powell et al., 2005, p. 1134), nanoresearchers must situate themselves simultaneously within disciplinary scientific communities, such as physics, chemistry or materials sciences, to legitimate their research and job position in the academic field. This observation becomes further evident if one looks at the importance of professional associations that are still based on academic disciplines and at the publication behavior of the interviewees who publish in general and discipline-based journals rather than in journals that are exclusively dedicated to nanotechnology as demonstrated in section 7.3.2.

With regards to differences, another interesting hypothesis about interdisciplinarity points to how interdisciplinarity is institutionally favored in Germany, in the area of education, through new degree programs in nanoscience and-technology. This circumstance opens opportunities for interdisciplinary, mixed research groups in Germany since PIs recruit students for their groups from interdisciplinary study programs. In the U.S., interdisciplinarity is facilitated in interdisciplinary centers where users come from a wide array of disciplines and get to know each other when working in these centers and laboratories to do research. Departmental collaborations also represent interdisciplinary settings that arise from approaches aiming at problem-solving and applicability. Therefore, there is potential in both countries with regards to interdisciplinarity even though the dissolution of disciplinary boundaries cannot be observed as yet. The establishment of career paths in nanotechnology in the German higher education system additionally represents an opportunity for professionalization of nanotechnology. It is also in Germany where institutional change takes place via 'translation' (Campbell, 2010), that is the attachment of new programs to existing career paths in both undergraduate and graduate studies. The strategy of immersion of nanotechnology courses that prevails in the U.S. might become an impediment for professionalization so that Germany appears more probable in becoming a country where nanotechnologists will no longer be an 'exotic' group of professionals. This issue on professional development, however, cannot be answered here as there are still obstacles, also in Germany, to further professionalization (see 7.5).

8.3 Cultural Change and Professional Identities

The construction of an identity of nanotechnology takes place in relation to the process of institutional change that occurred with respect to nanotechnology and that has been addressed in the previous section. The interviews show how actors, as drivers of change, contribute to an identity by way of their notion and meanings of an advanced technology that has become part of their everyday work lives. The interview results are not merely summarized here, but applied to other interpretative contexts. The social constructivist perspective on the 'zone of interpenetration' (see Münch, 1984, pp. 200, 240, 1993a, p. 26) of politics and academic nanotechnology research revealed both expected and unexpected explorative hypotheses with regards to a noticeable reluctance toward nanotechnology and the simultaneous embracement of nanotechnology at universities in an institutional way. These hypotheses were also disclosed when asking about the experience of scientists with regards to public funding and the negotiation of expectations of politics for nanotechnology. This emphasized the role of individuals as mediators between the micro- and meso-level, which does not mean that individuals translate their interests one-to-one to the meso-level, but they rather induce change out of interests that do not necessarily match with political interests. Institutional change, in turn, affects cultural change which becomes effective in the academic working culture of nanoresearchers which is characterized by strategic handling of disciplinary-based professional identities on the one hand and Mode 2 based knowledge production favored by politics on the other.

Cultural change in nanotechnology is marked by ambiguity, vagueness, and reluctance which are translated into a self-categorization that remains disciplinary-based, but that, at the same time, allows to embrace the institutionalization of nanotechnology because long-held professional identities do not have to be given up so long as nanotechnology remains an important but not disciplinary strand of academic research and institutes. The embracement of nanotechnology is facilitated by the fact that is politically pushed and therefore the institutional visibility becomes valued, yet only if it does not touch the disciplinary structure of universities. This institutionalization speaks for the demarcation of a stable scientific community of nanotechnology. Still, the lack of a coherent cognitive, social, and historical identity (see Lepenies as discussed in 7.4) might remain permanent impediments to the development of a scientific community. Concerning the emergence of a profession of nanotechnology, the fact that nanotechnology career tracks are available in higher education institutions might support professionalization in the transition to the labor market (see also the 'Model of Intervening Mechanisms' in section 1.2). The identities namely that Lepenies (1981) found constitutive for scientific communities might be of less importance for professionalization in the market where other features play a role, as discussed in section 7.5.

In other words, the organizational analysis of the interview data shows how institutions, i.e., the cultural and structural constraints and related beliefs and norms, impact on individual definitions, identifications, and concepts on nanotechnology and strategies of actions concerning lines of research as well as applications for funding. In this field of tension, there are two, seemingly contradictory, paradigms at work, namely the political paradigm aiming at technology, innovations, and economic growth and the university-based rules of basic research as a public good and publications as a measure for success. These paradigms form an integral part of researchers' everyday lives and are constantly balanced within this field of tension where researchers as main actors manage this tension in a positive and prolific way to their own advantage by tapping into public funding. This balancing of differing interests leads to scientists' interpretation and strategy of what promises to be successful in present times. Therefore, the two paradigms and the resulting strategies of action are not mutually exclusive but juxtaposed or even 'exploited' in everyday situations. The influence of public funding comes to a halt when professional identities are addressed. Here, scientists remain 'conservative' in the sense that they stick to the academic disciplines they were trained in or that they switched to, since they are legitimated and constitutive in academe.

One can finally ask which mediation strategies in the triangle of science, the state, and the market lead to which patterns of identification among scientists. In short, the relationship with state bureaucracy, professorial autonomy, and long-term university structures makes scientists feel reluctant and cautious with regards to nanotechnology and consequently marks the identity of this advanced technology. In the context of third-party funding and public funding agencies, scientists are forced to embrace nanotechnology as a Mode 2 technology that is highly funded and that must be strategically handled in order to take advantage of this relatively new area of third-party funding. This explains the open stance of nanoresearchers toward the institutionalization of nanoinstitutes and the involvement in projects that are labeled with nanotechnology. When it comes to the market, issues of applicability and problem-solving are not unfamiliar to scientists who value their independency of pure market interests on the one hand, but who, on the other hand, know that alliances with industry are favorable for their reputation. In industry cooperation, nanotechnology is not always explicitly mentioned, above all if industry that applies nanotechnology does not stress this issue in their day-to-day business. Still, nanotechnology opens some doors for industry cooperation and thus, as done at PSU, constitutes a valuable strategy for industry collaboration.

The fact that reference to nanotechnology can facilitate grant application activities points to a larger and interesting phenomenon to be explained in future research: the discrepancy between the cutting-edge of scientific work and the necessity to be within the discursive norms of the wider public, whereby in the present study the wider public was limited to politics. This phenomenon is touched in the next section where the socially constructed notion of Mode 2 terms revealed by scientists is marked by that discrepancy as well: to do cutting-edge research, Mode 1 knowledge production must be followed; yet, to finance this sort of research, scientists must situate themselves within the norms of the wider public, such as the political norms that guide technology funding. Here, the importance of applicability as known from Mode 2 becomes evident.

8.4 Mode 2 Meets Mode 1: 'Clash' of Working Cultures?

There were two strands of findings with respect to Mode 2 and Mode 1 knowledge production. On the one hand, the multifaceted notion of Mode 2 criteria was elaborated in 7.2; on the other, nanotechnology was delineated as an organizational field where Mode 2 meets Mode 1 (section 7.1). The results about these two issues are summarized in that order as follows:

First, rather than interdisciplinarity, multidisciplinarity grasps best what informants defined as interdisciplinarity. Problem-solving was important to informants but always with reference to their home discipline. Departmental collaboration and research groups where several disciplines were involved could be found. However, these alliances have not yet reached a permanent state of interdisciplinary cooperation since disciplinary boundaries are still effective, and the involvement of several disciplines rather has the character of project-collaboration. Heterogeneity, in the form of projects where partners came from different home disciplines, could be noticed. Quality was still measured by publications, and graduate students, in particular those who worked with a 'star scientist,' were engaged in writing journal articles from the beginning. Patents were filed but rather represented a side-effect than a measure of quality. Applicability was mentioned as a justification for the kind of topic a researcher worked on. However, there were no clear criteria on what defines applicable research. Any relation to a future product served as a reason for pursuing one's research. Industry cooperation was not always seen as a must for applicable science. Accountability certainly played a role when talking about third-party funding. Yet, academic freedom and independence of stakeholders were highly regarded, above all by German professors whose autonomy is institutionally anchored in university hierarchies in case they are chair holders and thus in charge of larger fields of study, sometimes even whole disciplines (see chapter 5).

With respect to the first issue, one can conclude that ambiguity and vagueness characterize the notion of Mode 2 terms. This finding corroborates that Mode 2 policy has not been firmly anchored in academe or, in other words, has not replaced Mode 1 knowledge production. Mode 2 policy affects nanoresearchers without doubt, and they have to learn how to strategically deal with it. They must account for their research in Mode 2 policy terms. Similar to the identity of nanotechnology, this tension is not detrimental at all to scientists' working culture. This tension is a force that marks the working culture of nanoresearchers and enables them to solve the 'clash' of two different cultures of knowledge production by combining both modes of production in a symbiotic way. Nanoresearchers can proceed doing science, even if it is not merely nanotechnology-based, by tapping into federal grants for nanotechnology. Politics can realize their aims by helping the institutionalization of nanotechnology without infringing the discipline-based and basic science-oriented structure of academic organizations. Finally, nanoresearchers' work requires funding, and the ability to follow Mode 2 terms is indispensable for their research. On the other hand, giving up the Mode 1 knowledge production is not possible as academia still functions according to the logic of disciplines, publications, academic freedom, and, in some interview cases, scientists' curiosity.

Finally, and this leads to the second issue, what can be said about the organizational field of nanotechnology, politically conceptualized as a Mode 2 technology? How does it match with an academic culture of knowledge production, still following Mode 1 criteria to some extent? There are three findings that mark the organizational field of nanotechnology that finds itself in between the forces of Mode 2 and Mode 1. First, based on the interviews, a noticeable reluctance in nanoscientists' maxims of action to integrate the nanolabel into self-descriptions of professional identities can be traced in the interviews with German and U.S. nanoscientists. The reasons for this hesitancy are multi-faceted: the notion that nanotechnology comprises a field or, at least, a specialty came up in the political discourse (Schaper-Rinkel, 2010b) before it was constituted in the academic sector. The political discourse used a definition of size for nanotechnology, confining it to the scale from 1 to 100 nm. Nanoscientists, however, cannot operate adequately with that term as they conceive that definition as too broad and too vague. This occurrence elucidates the cross-technological character of nanotechnology that can be applied in a range of fields due to being a platform technology. To scientists, nanotechnology is either too broad, too narrow or merely a device or tool that can be applied in various ways.

Second, the consequence is that nanotechnology constitutes more and more a specialty that creates roles for scientists by virtue of nanoinstitutes and nano-degree programs. These have emerged in the U.S. and in Germany in the wake of substantial governmental funding of nanotechnology and the European higher education reform, the Bologna process, that created opportunities for forces of institutional change. Nanoscientists, nanostudents, and coordinators are needed to fill these positions. However, scientists have an 'opt-out clause:' By fulfilling several roles, and first of all by being members of a disciplinary scientific community at university, scientists only fulfill their role as a nanoscientist temporarily, in particular when applying for funds and projects. This explains why nanocenters and -institutes emerge, but no coherent identity for nanoscientists, who can replace traditionally trained scientists. Third, 'formal structures' are decoupled from 'work activities:' the affiliation to nanocenters by no means implies that scientists see themselves as a member of a nanocommunity. They still regard themselves as engineers, materials scientists, chemists or physicists.

9. Conclusions

This study followed a ‘heterogeneous’ perspective on the field of nanotechnology in the context of public funding. This work drew on an explorative perspective to deliver answers on the focal point of this study, namely the question: What can be said about the field of nanotechnology? Due to the breadth of this question, multiple perspectives have been adopted to look at this field. The main finding was that the field of nanotechnology is exposed to forces exerted by political actors and grant policies on the one hand and by reluctance and ambiguity toward nanotechnology within the scientific community on the other. In other words, a political Mode 2 conception of knowledge production concept meets a Mode 1 culture of university knowledge production. The result is tension, which represents the main characteristic of the field and which marks the production of an identity of nanotechnology that takes effect in academe. This tension is positively used by politicians and scientists who manage to pursue their own goals without infringing each other’s responsibilities. Scientists, the main actors interviewed for this study, are involved in both institutional and cultural change. They induce change through strategically handling the external political pressure or, more neutrally speaking, political interests by tapping into third-party funds and by simultaneously nurturing their working cultures, which are based on academic disciplines which they were formerly socialized in and which mark the reproduction of new scientists for their research groups. This cultural change becomes visible in the fact that an institutionalization of nanotechnology is possible without restructuring the disciplinary structure of universities and without turning scientists who apply or advance nanotechnology into mere nanotechnologists. Finally, in addition to structural institutional change in higher education systems, processes of institutionalization have been included: the definition of a scientific community via identity construction and professionalization. In the following, the main hypotheses are summarized after addressing shortly the limits of this study and opportunities for future research that could not be investigated in the present study.

The present study is innovative with regards to five aspects: First, it delivered a country comparison of Germany and the U.S., two countries leading in nanotechnology, by integrating the meso- and micro-level. Second, it left the field of scientometric studies using patents and publications as descriptors for the field of nanotechnology, but looked at the inner organizational life of nanotechnology instead. Third, it combined agent-based modeling and interviewing to gather both artificial and empirical data on nanotechnology in academia. It did so for the first time in case of agent-based modeling simulating research networks for an advanced technology. Fourth, it combined these explorative data to deliver detailed insights into the micro- and meso-level of the field. Thus, it did not stay on the macro-level, but followed a holistic and explorative approach. The study delivered insights into the inner organizational life of nanotechnology at universities by looking at individual actors to explore working culture in nanotechnology rather than to create macro-level data. The latter namely do not capture completely why nanotechnology has been successful and how it can be that nanotechnology has an institutionally fixed place in academe, but not in scientists’ self-categorization. Finally, it combined the Mode 2 concept with sociological neoinstitutionalism concepts to address the constitution of an organizational field that is affected both by Mode 1 and Mode 2 criteria of knowledge production. This combination helps to establish characteristics of the field from the perspective of sociological neoinstitutionalism. The findings of this unique approach toward the field of nanotechnology represent hypotheses that open up new fields for further research.

The exploration of the field of nanotechnology is important for two reasons. First, nanotechnology is a new advanced technology that is strongly politically pushed and that incites enormous institutional change, both on the structural and on the process-level, as shown by professionalization for instance. Second, an emphasis has been laid primarily on the development of patents and citations in nanotechnology so far. This study, by contrast, looks at nanotechnology from wholly new perspectives. For countries that stress advanced technologies as drivers for economic growth and measure for international competitiveness, knowledge about the constitution of a field is indispensable if a technology is supposed to be fostered in a successful and effective way.

Before turning to the opportunities for further research, the limits are addressed. As this study is explorative, the findings are not representative for Germany or the U.S. with a dataset from 33 interviews. Namely, this study did not test any theory that was applied. The VoC concept, Mode 2, and sociological neoinstitutionalism were used as heuristics and frames of interpretation of interview data. Further, the agent-based model is limited in terms of variables and country. Here, opportunities for an extension of the model arise e.g. by including civic actors or by incorporating other advanced technologies. Furthermore, this study did not look at the industry sector. Yet, this sector constitutes another promising perspective for a similar analysis of nanotechnology as an organizational field. A comparison of start-ups and large companies, as it was conducted for biotechnology using a firm-centered approach (e.g. Herrmann, 2009), might give additional insights into nanotechnology and on the effect of national policies. However, the findings show where nanotechnology as an academic organizational field is at the moment. As this study reveals impressively, the self-identification and recruiting of nanoscientists constitutes a challenge because all comes down to the still mooted question: Who is a nanotechnologist?

As already mentioned, several areas arise that are promising for future research. First, on a methodological level, network analysis and participant observation promise new and relevant results on the constitution of the new field of nanotechnology. With empirical data on research networks in nanotechnology, the agent-based model can be validated by inserting these empirical data. This way, the factors of the creation of research networks and for the diffusion of an advanced technology, as well as relevant variables for the question which kind of network is formed, could be more realistically derived. Participant observation can be used to get more insight into modes of knowledge production and modes of communication. In terms of knowledge production, the importance of research networks has been worked out in this study as well as the PI–student relationships and the reputation of PIs. Yet, more findings on the setup of research groups and their social relationships, their cooperation behavior and communication patterns, on implicit assumptions and body language could be gained from participant observation. Participant observation and network data might be able to give more insight into communication relations between nanotechnologists.

The presented agent-based model cannot answer the question if nanotechnology fits Crane’s theory of invisible colleges and organization of specialties in science. She found that these specialties follow a logistic, sigmoid-shaped curve, showing “low levels of communication and few links among researchers” at the beginning of the growth of a specialty, an increase of communication links along with the growth of the specialty forming a “highly coherent group,” and finally, a slow-down of growth with different outcomes concerning the state of the specialty near the end, be it a loose network or the polarization into schools (Crane, 1972, p. 76; Griffith & Miller, 1970, p. 137). The issue of communication links among nanoscientists and their distribution has, to the knowledge of the author, not yet been studied. Therefore, the analysis of nanoscience as a research specialty ought to be addressed in future research. What can be said, however, for the time being is that a scientific community where only nanotechnologists are included and which is autonomous from disciplinary communities has not evolved so far.

Secondly, with regards to the model, next to using empirical network data, more variables or further stakeholders (firms, consumers of products, citizens) could be included. The civic debate, for instance, has been left out here as the focus was on the academic sector of nanotechnology. The model presented here is not validated with empirical data. The small number of variables is also not sufficient to detect which variables are significantly influencing and explaining the spread of nanotechnology. This speaks for the limited influence of public funding and supports a realistic functioning of the model since the processes that are simulated are at least realistically portrayed, even though there are few of them.

Thirdly, further research using the Triple-Helix Model can be done. Still, the Triple-Helix relations do not seem to have equal status in the case of nanotechnology because the state or funding agencies remain the most important addressee for interviewees when it comes to third-party funding. Informants did not mention industry relations before being asked about them explicitly. Thus, further research is necessary in that respect. Fourthly, a firm-centered approach in nanotechnology can be taken to be able to compare nanotechnology to biotechnology. In the field of comparing nanotechnology and biotechnology more could be done to align these technologies next to each other. Lastly, other cases of disciplines and their history can be examined or consulted to compare them to the history of nanotechnology instead of using merely artificial intelligence or other advanced technologies, such as biotechnology, for comparisons. It would be interesting to see how biotechnology has been historically and institutionally incorporated into German universities.

This qualitative, explorative paper aimed at elucidating the socially constructed meanings and evaluations of nanotechnology from the perspective of academic scientists. For now, nanotechnology is not a discipline in the sense that it has a fixed number of actors or a clear profile or linear identity. Yet, it has been successfully institutionalized in Germany and the U.S. and characterized by a unique identity. This identity is based on the socially constructed interests of the central actors of the field, interests that meet at the point where these actors agree that public funding is indispensable to advance nanotechnology. It is the ability to withdraw from the field of nanotechnology into one's own scientific disciplines that allows scientists to accept the push for nanotechnology and to tap into nanotechnology grants.

Institutional change can be observed which does not affect the predominant disciplinary structure of universities that is based on chairs and departments or colleges. This finding runs counter to the Mode 2 argument that interdisciplinarity has become a feature of university knowledge production (Gibbons et al., 1994). The tension that arises from the prevalence of disciplines and the integration of nanotechnology into universities embracing several disciplines is necessary to enable institutional change. The security of discipline-based self-categorization gives researchers the freedom to risk change in the form of external formal structures without giving up their basic research orientation. As basic research is still the major portion that informants devoted their time to, the Mode 2 conception of nanotechnology is thus only partially valid due to the early stage of nanotechnology research. Scientists internalize Mode 2 symbolically, which leads to a hybridization of Mode 1 and Mode 2.

With these interview and simulation results, implications for higher education policy are derived. To give policy advice, however, the controllability of processes ought to be clarified. With the aforementioned influence of the state, one can derive from the simulation results that the way grants are distributed in scientific communities influences the spread of new disciplines and technological research. As the simulation results show a direct influence of funding schemes with other possible influential factors, i.e., random sample variances or 'noise,' ruled out. Public policy can influence science, however, only to a limited degree.

Still, implications can be drawn for higher education policy. The findings demonstrated how policy impacts organizational life in universities and how policy goals go hand in hand with scientists' interests. Policy and scientists' interests nurture each other. First, policy pushed the field of nanotechnology. Then, scientists' engagement in nanotechnology and their use of nanotechnology grants further pushed the field (Grodal, 2007). Since the goals of these two realms are nevertheless different from each other, tension arises. Yet, this tension does not slow down the rapid development of nanotechnology. It turns out to be fruitful for institutional change and the implementation of nanotechnology. The political conception of nanotechnology as a Mode 2 field, marked by interdisciplinarity and application/problem orientation, is confronted with the still dominant disciplinary and basic research orientation in university departments and faculties. This confrontation has turned out positive, as it opens opportunities for nanoresearchers to install new institutes, centers, and programs without giving up or fundamentally modifying their professional identities. The study shows that institutions and researchers are not influenced directly through policies, but institutions and scientists keep their autonomy. Yet, they use policies to their advantage by tapping into public funding. This in turn serves political interests, as by using nanotechnology grants, the field of nanotechnology is further advanced. Hereby, existing institutional structures channel change that is induced by social actors so that grant policies must take into consideration the, in VoC terms, institutional complementarities of a political economy and the working cultures of academic scientists that do not always follow Mode 2 lines.

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