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Cognitive and motivational effects of digital concept maps in pre-service science teacher training

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Abstract

University teaching deals with complex and miscellaneous knowledge and higher education should focus on sustained conceptual understanding of relevant topics. Guidance on how to construct adequate knowledge structures can support meaningful learning. But lectures, for instance, often are structured in linear sequence by a number of slides and are thus biased towards linear representations of knowledge that are not appropriate for most scientific disciplines.

In this study, a framework for concept maps was developed to complement lectures in human biology online. The course was aimed at student teachers at the undergraduate level. The work is based on recent theoretical research on the use of multimedia in learning environments and e-learning, knowledge structures perspectives of teaching and learning as well as theoretical assumptions of self-determination in educational processes. Each session (14 in total, e.g. human respiratory and circulatory system, physiology of senses, human anatomy) was supplemented by a digital concept map providing relevant concepts connected with linking words and continuative material attached via hyperlinks (e.g. images, web links, animations, video). Following each single lecture, students had free access to the concept maps to reinforce the latest topics and to prepare for the final examination. The objective of the study was to examine if the use of complementary concept maps (i) influences achievement and (ii) motivational variables. The students' (N = 171) concept map use was logged along with a documentation of their achievement and miscellaneous variables regarding their motivation (e.g. interest/ enjoyment, perceived competence, effort/ importance, value/ usefulness). The logfile-data allowed distinguishing learners according to the frequency and duration of their concept map use. Additionally, computer-related self-efficacy was documented as a moderating factor. Results reveal the benefit of additional concept maps for achievement and positive motivational aspects, moderating factors are discussed. The emphasize of further research should be on students' active engagement in structuring their individual learning by constructing adequate concept maps themselves, especially in science education courses.

Keywords: Science education; pre-service teacher training; digital concept maps; human biology; concept and content knowledge

1. Introduction

Learning at university level deals with complex and divers topics, with a meaningful, conceptual understanding of central ideas in order to promote domain specific problem solving (Sigler & Saam, 2006). Cognitive psychology

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introduces several processes by which schema, propositions, concepts or specific prototypes are formed (Anderson, 2004). Moderate constructivist approaches to individual learning are widely accepted in the scientific community, especially in science education (Mintzes, Wandersee & Novak, 2005), and implications of active knowledge construction are obvious.

In contrast, students' prior knowledge differs widely at the beginning of the tertiary educational level, which reveals difficulties in connecting scientific concepts to existing knowledge appropriately (Buntting, Coll & Campbell, 2004). Furthermore, students entering university use mostly learning strategies which worked well during their past experiences in school (*cf.* Merriam & Caffarella, 1999). But these learning strategies are often based on behaviorist learning paradigms in the context of a final examination and are often characterized by inadequate linear knowledge representation (*cf.* Kinchin, 2009). This false linearity of knowledge structures might even be emphasized by using Powerpoint slides in lectures (Kinchin, Chadha and Kokotailo, 2008) and thus students miss to reflect their individual achievement.

Therefore, Kinchin (2009) supposes to apply concept mapping as a means to develop a constructivist student-engaged pedagogy. Concept maps visualize a learners expertise, moving from a novice linear structure to an expert's network of a knowledge domain. Daley (2002), for instance, describes the use of concept maps to promote adult learners' insight into constructivist learning approaches and thus, their understanding of knowledge construction as an active linking of ideas or concepts into reliable and stable networks and schemes. Concept mapping techniques have been described to advance academic teaching in general (Ledermann & Latz, 1995, Kinchin, Hay & Adams, 2000, Sherborne, 2009, Kinchin, 2009), computer-based concept mapping has shown multiple positive effects in teacher education programs (Ferry, Hedberg & Harper, 1997, Countinho & Bottentuit, 2008). Buntting, Coll and Campbell (2006) focused the use of concept maps in introductory tertiary biology classes and their results point towards students' high acceptance of the method: Students found concept mapping enjoyable and useful to link concepts for meaningful learning.

Nevertheless adult learners are not familiar with the technique of concept mapping when they enter university, and thus, it has to be trained. Early work on mapping techniques showed evidence, that cognitive load exceeds individual resources if the learner is not used to the method (Holley & Dansereau, 1984). Even if adult students have used concept mapping successfully, one third of them stops mapping if it is not explicitly required (Daley, 2002). Kinchin (2001) also pointed towards a bias between an evidence-based potential of concept mapping to support and enhance students' learning and the actual use in secondary schools.

In general, user experience and satisfaction with a new technique are important criteria in the personal overall evaluation of that technique (Vennix & Gubbels, 1992). Allen and Tanner (2003) exemplify the problems while using concept maps for the first time. They point out the necessity to introduce the method carefully to avoid overstraining demand and thus a learners' refusal. Furthermore, according to the self-determination theory of Deci and Ryan (Ryan & Deci, 2008; Niemec, Ryan & Deci, 2009), the perceived competence while working with this technique or its perceived usefulness are important variables to apply it in future tasks.

In addition, self-efficacy moderates the application of a meta-cognitive technique like concept mapping. Self-efficacy can be defined as one's appraisal of his/her capabilities to organize and execute courses of action required to attain types of performances (Bandura, 1986, p. 391). Self-efficacy affects effort and persistence while using concept maps and people who believe they are capable are likely to participate. Recent self-efficacy is for example based on individuals' performances in a task as well on their observational experiences (Pintrich & Schunk, 2002).

The purpose of this study was to develop and to evaluate concept maps as supportive material for a traditional lecture in human biology for pre-service teacher training within large auditoriums. These supportive concept maps should be seen as low-threshold access to concept mapping during the further university education and, in the long run, to implement them in secondary schools.

2. Digital concept maps in biology courses

According to Novak (1998) a concept map is "a schematic device for representing a set of concept meanings embedded in a framework of propositions" (p. 15). Within a Novakian concept map, concepts and propositions are hierarchically structured. The most general ideas or concepts of a topic are represented at a higher level, whilst the more specific details are arranged below (Novak & Cañas, 2008). In literature, the potential applications of concept maps are in planning learning/ teaching and in curriculum development, as assessment tools (*cf.* Schaal, Bogner &

Girwidz, i*n press*) and as tools to support learning (*cf.* Lawless, Smee & O'Shea, 1998). Under a constructivist learning paradigm the construction of concept maps is an active process of personal meaning-making (Åhlberg, 2004, Novak, 1998). It helps students to organize and to structure their knowledge and thus affects their intellectual performance in general (Bransford, Brown & Cocking, 1999).

In the domain of biology, concept mapping offers broad and successful implementation in classrooms (*cf.* Kinchin, 2000). As 'biology is […] difficult to learn because it consists of […] unfamiliar concepts involving complex relations' (Schmid & Telaro, 1990. P.78), concept maps provide a coherent structure of the topic and thus expatiate on essential links between central concepts (Martin, 1994). Especially in complementary combination with traditional, objectivistic teaching approaches, concept maps might give new impetus to enrich students learning experiences and to develop teacher reflection "by encouraging them to think beyond linear sequences" (Kinchin, 2006).

In pre-service science teacher education concept mapping fosters science understanding and may decrease anxiety towards learning and teaching science (Czerniak & Haney, 1998). But not only active concept mapping promotes the learners' achievement, similar learning success in reproduction can be achieved working through an pre-structured expert's concept map (Jüngst & Bernd, 1999). Hence, a concept map can serve as summary tool in which a complex domain structure is coherently represented.

In combination with the potential of Kozma's (2003) reflections on multiple representations and their interpretation for deeper understanding in science education, digital concept maps have the potential to foster successful learning in the domain of science education. Dansereau (2005) differentiates three types of digital concept maps:

- *Information maps*: expert generated maps for presentation of information, orientation and navigation,
- *guided maps*: self-constructed novices' maps with adequate support, with e.g. pre-defined nodes or concepts,
- *freestyle maps*: user generated maps without constraints.

Neumann, Graeber & Tergan (2005) highlight the potential of *information maps* within a learning scenario of resource-based learning. They report positive effects in knowledge identification and interpretation using a digital structuring and presentation tool.

Consequently, digital concept maps provide access to content knowledge by offering further information resources to connect them successfully to the conceptual knowledge represented in a concept map (Tergan, 2005). Additional digital materials as, for instance, textual information, images, animations, audiovisuals or interactive simulations represent the information in multiple modes and codes. These resources help to integrate additional information in an individual's content knowledge aiding, for example, to construct individual mental models and images, analogies or metaphors (*cf.* Tergan, Keller & Burkhard, 2006, Alpert & Gruenenberg, 2000). In general, the potential of multiple representations and digital media to foster conceptual learning in science education is undoubted (an overview in Girwidz, Rubitzko, Schaal & Bogner, 2006).

For the recent study, a digital open-access concept mapping tool called CMap-tools was applied (Cañas et al., 2004) which provides free onscreen construction of a concept map so that concept map construction with nodes and labeled links is quick, simple and intuitive. Furthermore, the tool allows the user to connect further digital resources just by following pre-defined hyperlinks subsumed under an abstract concept (download http://cmap.ihmc.us). Within teacher training, Coutinho and Bottentuit (2008) reported successful implementations of Cmap-tools in web-based post-graduate training.

As conclusion for the present study, pre-defined expert maps serve as a first access to the "world of concept mapping" in teacher education, providing relevant *conceptual* knowledge about human biology in combination with digital resources to foster parallel *content* knowledge construction.

3. Methodology

3.1. Purpose

The main goal of the study is to investigate the cognitive effect of using pre-defined summary expert maps as supportive materials in pre-service teacher training for an elementary lecture in human biology. The first hypothesis is:

(i) Learners, who frequently use supportive concept map achieve better results with regard to the relevant concepts of human biology than learners who use them less.

Furthermore, according to the theory of self-determination, predictors for intrinsic motivation e.g. interest and enjoyment while working with the given concept maps, perceived competence and the perception of the method's usefulness affect learners' achievement and the access to the material. Thus, the second and third hypotheses are:

(ii) The frequency of concept map use is correlated with specific interest and enjoyment, competence and usefulness perception. Furthermore, the overall motivational disposition influences the use of concept map.

(iii) The computer-related self-efficacy affects the frequency of concept map use as a moderating variable.

3.2. 3.2 Procedure

This study was realized realized under ecological condition in regular lectures in human anatomy and physiology for pre-service teacher students at the University of Education in Ludwigsburg (southwestern Germany) during the winter and spring of 2008/2009. The lectures in human biology are obligatory for every teacher student and thus, the auditorium consists of more than one hundred students per session, which renders practical work impossible. In total, 14 90-minutes lectures were given by the same lecturer in traditional formats about the relevant human organic systems (*e.g.* human respiratory and circulatory system, morphology and physiology of senses, human anatomy), at the end of semester students were rated in a final exam.

Accompanying each reading students had online-access to the presentation slides and as well to a digital concept map of the specific topic (*e.g.* chemical senses), providing links to further web-resources, images and diagrams, videos or animations. The concept maps were constructed according to the guidelines of Novak and Cañas (2008). The access to the digital concept maps was logged for every student and on this basis the frequency of use was determined.

During the last session, students completed a *Computer User Self-Efficacy Scale (CUSE)* and the relevant items of the *Intrinsic Motivation Inventory (IMI)*. Finally, one week after the last session, a 30 minutes multiple-choice assessment with 14 items (each consisting of four declarations with three distractors) had to be completed. Along with the first online resources learners had access to an example of an exam test item that was logged too, and was used as an indicator of prior knowledge.

3.3. Sample

In total, N = 171 (of 249 lecture participants) student teachers for primary and secondary schools completed the whole test schedule and were considered in data analyses, their average study semester was 1.6±1.4 (mean±SD). Participation was voluntary, unpaid and anonymous, students' written consent was obtained.

3.4. Instruments

- The multiple choice achievement test consisted of one item each for the fourteen topics of the sessions. Each item consisted of four plausible (but only one correct) arguments from which the students were to choose according to the instructions. Furthermore, an anatomic drawing of the digestive system had to be labeled and each part had to be assigned to a specific function within the process of digestion. A total of thirty-six points could be scored. After the first session, students had online-access to three exemplary items of the test and the results were logged to get information about the prior knowledge, three points in total. This might be sufficient to reveal potential differences when user groups are classified to compare low- and high intensity concept maps users.
- Motivational variables were measured with a German version of the Intrinsic Motivation Inventory (IMI; see Plant and Ryan, 1985, McAuley et al., 1987, Ryan et al., 1990, German version see Schaal, 2006). The IMI is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity (Plant and Ryan, 1985; Ryan et al., 1990). Three dimensions of the scale were used: interest/enjoyment (eg. 'I thought using the digital concept maps was quite enjoyable'), perceived competence (eg. 'I am satisfied with my performance at learning with the concept maps') and value/ usefulness (eg. 'I believe doing this activity could be beneficial to me') of the concept mapping technique. Each item was rated on a five point lickert-scale (1

for completely true and 5 for completely false). Reliability of the three dimensions was between 0.89 and 0.92 (Crohnbach's α).

4. Findings

Students' concept map use differed widely from non-usage to approximately 100 accesses with an average of $M = 24.5 \pm 15.8$ accesses. The concept map use did not differ significantly from a normal distribution (Kolmog.-Smirn. $Z = .935$, $p > 0.3$).

Afterwards, students were assigned to three different user groups according to the access frequency: *low-intensity users* opened one time and less the additional concept maps ($N = 52$), *intermediate users* opened each of the concept maps up to two times ($N = 53$) and *high-intensity users* accessed each of the fourteen concept maps more than two times ($N = 66$).

Hypothesis (i) concerning better achievement of the *high-intensity concept map users* was determined using ANOVA. The average prior-knowledge of the three user groups was compared and a difference could not be found (M_{low}= 1.1±0.3, $M_{intermed}$= 1.0±0.3, M_{high}= 1.1±0.2, ANOVA $F_{102.3}$= 0.9, $p > 0.6$).

The comparison of the *achievement test* assessment revealed significant inter-group differences (see Tab. 1): The *high-intensity users* achieved significantly better (M_{high}= 25.4±6.1) and scored higher than the *intermediate* (M_{inter}= 22.6±4.9) and *low-intensity users* (M_{low}= 22.3±5.9). Hence the first hypothesis (i) can be confirmed.

Table 1. ANOVA scores of multiple-choice achievement according to the different user groups

N = 171	d.f.	Sum of Squares	Mean Square	F	Sig
Between groups	2	349.0	174.5		
Within groups	168	5496.5	32.7	5.33	0.006**
Total	170	5845.5			

Hypothesis (ii) expecting the correlation of the motivational variables *perceived competency* and *interest/ enjoyment* while using concept maps as well as the *perceived usefulness* of the technique was tested first (see Tab. 2). All three variables showed highly significant correlations to the frequency of digital concept maps use, which confirms the first assumption of this hypothesis.

Table 2. Correlations of motivational variables and the concept map use frequency

N = 171		Interest/ enjoyment	Competency	Usefulness
Cmap frequency	Correlation (Pearson)	0.375***	0.291**	0.399***
	Sig. (2-s.)	0.000	0.001	0.000

The second assumption of hypothesis (ii) and hypothesis (iii) were tested using GLM with the concept use frequency as dependent variable, the average of all motivational variables as factor and the *CUSE* as covariate, only main effects were respected. The results reveal a significant influence of the motivational variable, while an influence of the computer-related self-efficacy should be neglected (see Tab. 3). Therefore, hypothesis (iii) concerning the influence of self-efficacy could not be confirmed.

Table 3. Generalized linear model (GLM) with concept map use frequency as dependent variable, motivation as factor and *CUSE* as covariate. Corrrected $R^2 = 0.25$

N = 171		Sum of Squares (type III)	*df*	Mean Square	*F*	Significance
Constant Term	Hypothesis	1051,77	1	1051,77	5,669	,024
	Error	5695,33	30,7	185,54		
CUSE	Hypothesis	131,03	1	131,03	,718	,404
	Error	5290,89	29	182,44		
Motivation	Hypothesis	21773,27	49	444,35	2,436	,006
	Error	5290,89	29	182,44		

The results reveal different achievement levels for *low-* and *high-intensity concept map users* and concept map use might influence the learning outcome within the domain of human biology. Furthermore, motivational variables influence the concept map use while it is not affected by the potential difficulties in using digital concept maps. Of course, the coefficient of determination $R^2 = 0.25$ indicates, that the model applied fails to recognize some “hidden” variables and other parameters which influence the achievement. But as this field study was conducted under ‘ecological’, non-experimental conditions, some implications for entry-level lectures in human biology and for further research could be derived.

5. Conclusion

Tergan (2005) described the potential of digital concept maps to promote the construction of conceptual and content knowledge as well as to offer knowledge resources in an adequate visual representation. The findings of this study are in line with this assumption and indicate, that digital concept maps help students to get an adequate overview of the domain’s knowledge structure as well as to integrate further information resources into this network of concepts and relations. Dansereau (2005) suggested a guided mode of concept mapping within instructional settings like the lecture in human biology described in this paper. The findings of this recent study adds some further evidence to the insertion of the concept map technique in a more assimilative way.

Additionally, the findings described above are in line with earlier research results. Schaal & Bogner (2004) used digital representation of a knowledge structure within an interdisciplinary hypermedia learning environment about hibernation. They found that learners who often used this domain’s visual overview for navigation felt more competent and perceived the topic to be more useful and relevant for they everyday life.

In a next step, concept mapping techniques should be elaborated to a more constructive use by visualizing and generating conceptual knowledge within individuals’ own concept maps. But DiCerbo (2007) described a potential bias between the knowledge structures intended by the teacher and the actual structures within the concept maps constructed by the students. She suggests initializing learners’ reflections about their recent conceptualizations by using methods promoting conceptual change. This could be done within university courses within small groups and practical laboratory work to get further insight into human anatomy and physiology.

The final goal in the context of teacher education at universities could be the implementation of digital concept mapping to adhere the conceptual knowledge of the different scientific disciplines and to enrich it with further information resources as a complete portfolio of academic achievement. Especially a science teacher might profit from approaches to meaningful learning which he/she hopefully will implement into his/her own teaching practice.

The validity of the results is adequate for a fieldwork, but the data suggest further confounding variables for the achievement of human biology knowledge. For further research, prior knowledge and learning styles of pre-service teachers should be controlled and integrated into a more sophisticated, far-ranging model to quantify the effective influence of additional learning materials for achievement. Furthermore, a longitudinal research design should reveal if the stepwise implementation of concept mapping into science teacher education at universities could promote teacher students’ attitudes towards this visualization and learning technique and consequently, if it also influences its transfer into everyday science education classrooms. A first step has been made, but there is still a long way to go …

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