Specialization of competence development in mathematics and reading

Effects of education, interest, and gender on specialization of competence development in German secondary education

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Data note:

This paper uses data from the National Educational Panel Study (NEPS; see Blossfeld & Roßbach, 2019). The NEPS is carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Germany) in cooperation with a nationwide network.

Abstract

This dissertation provides insight into the specialization of competence development in reading and mathematics in secondary education. The first research aim of this dissertation project was the identification of specialized and generalized groups of competence development in reading and mathematics in secondary education. Papers 1 and 2 did not identify multiple profiles among students in lower (paper 1) and upper (paper 2) secondary education to a relevant degree. However, the studies also indicated an increased specialization throughout secondary education towards mathematical competences.

The second aim of this dissertation was the explanation of this specialization of competence development. Three main predictors were identified and ultimately tested in the third paper: Students' gender, their interest specialization, and vocational and tertiary education specialization. To test the effect of these predictors, competence development after Grade 9 was analyzed focusing on differences between predictor effects on reading and mathematics. Concerning gender, we showed developmental advantages for boys in reading and mathematics, with a large difference in effect size between the two domains. Specialization of interest and education positively affected competence development in the specialized domain.

This summary introduces the theoretical and methodological background as well as results of all three papers in a common context. Several aspects go beyond the three papers: An overview of the educational system is provided to explain how specialization of competences might increase over time. A short note on educational decisions and factors affecting these decisions expands on interactions between education and other predictors. Ultimately, some ideas for future research on the topic of developmental competence specialization are described.

1 Introduction

Which abilities humans need for success and where they can acquire them are fundamental questions for understanding basic interactions between individuals and society. Some abilities needed for success in society might differ by society and an individual's goals. For example, the ability to drive a car might be seen as a necessity in one society and not be required in another society. These abilities are not usually part of school curricula, thus requiring training outside of education. Meanwhile, some abilities are required for all individuals to participate in nearly all societies successfully. These abilities include basic reading competences and basic mathematical competences. Understanding written text (reading) is essential for many forms of knowledge acquisition and communication (e.g., OECD, 2003; Weinert, 2006). Likewise, mathematics is crucial for many work environments and higher education (Weinert et al., 2019). The importance of both competences is apparent in the attention they receive in formal education, starting in primary education.

While a certain level of basic competences must be ensured, modern society is also highly specialized. The division of labor required to keep modern societies running needs people to know how to be successfully employed in particular, highly specialized occupations. People in all kinds of occupations need to be at least able to read and do simple calculations. However, these occupations also require additional, job-specific skills that might not be needed in other jobs. For example, jobs based in science, technology, engineering, and mathematics (STEM) might require specific job-typical skills and an increased levels of mathematical abilities.

Skills, competences, and abilities required for occupations have to be acquired at some point in the life leading up to the job. Therefore, the labor market is highly dependent on the educational system. This is especially true in Germany. In addition to tertiary education, the German educational system includes a system of vocational education and training (VET), preparing more than half the students (Federal Institute for Vocational Education and Training, 2020) for specific careers. The VET system and tertiary education need to provide students with relevant qualifications to enter specific occupations and careers and the required competences and skills for that career.

Besides the necessity of a specialized workforce, individuals might see a necessity to specialize due to personal and individual reasons. For example, students might want to comply with gender stereotypes of high competences in either domain or with a higher interest in one domain. They may choose occupations in a specialized area as more attractive due to the labor market or personal incentives. Ultimately, students might specialize on one domain due to investing more of their leisure time in that area. No matter the reasoning or the learning environment (institutional or extra-curricular), students might be expected to specialize on either reading or mathematical competences in many ways.

Overall, the focus of this dissertation goes beyond average competence development to the specialization of that development. For example, knowing which students specialize on mathematics or reading during secondary education helps understand how intra-individual differences may arise among adults. Besides the previously mentioned job-specific education, internal student-specific aspects such as affective-motivational factors should be considered. Finally, socio-demographic aspects, such as parental socioeconomic status and especially students' gender, are relevant to identify specific reasons for specialization.

2 Theoretical background

This chapter gives information on the necessary theoretical and contextual background. First, competences, and explicitly reading and mathematical competences, will be described. The development and specialization of these competences were the dissertation's primary focus. Next, an overview of secondary, vocational, and tertiary education is provided. The final part of this chapter introduces reasons for differences in student specialization.

2.1 Competences

Students' competences in all areas are a significant topic of interest in current research. Some studies, such as the PISA studies (Programme for International Student Assessment; OECD, 2019)), report competences cross-sectionally and in international comparison. Others, such as the National Education Panel Study (NEPS; Blossfeld & Roßbach, 2019), look at competence development and focus on one country. Studies include a high number of different competence domains, such as reading, mathematical, scientific (tested in PISA studies - OECD, 2019), ICT (Information Communication Technology; Fraillon et al., 2014), and foreign language competences (e.g., Costa & Albergaria-Almeida, 2015). However, previous research has focused mainly on competences in reading in the native language and mathematics. As such, reading and mathematical competence are the focus of the research presented in this dissertation.

2.1.1 Reading and mathematical competences

Reading competences can be described as „understanding, using, reflecting on and engaging with written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society“(OECD, 2009, 14). As the ability to read can be seen as a necessity for learning, children are taught to read early in their education. At the end of primary education, nearly all students reach at least the lowest international benchmark set in PIRLS (Mullis et al., 2016) and can, among other activities, retrieve information and make straightforward inferences in simple literary and informational texts (Mullis et al., 2016, 53). With more than 75% of examined German students in Grade 4 at least at an intermediate benchmark (Mullis et al., 2016, 54), essential reading abilities can be assumed at the beginning of secondary education. Considering that most students (89% in Germany) do not reach the highest benchmark of reading competence (Mullis et al., 2016), plenty of additional competence development is possible in reading, which includes activities such as interpretation with text-based support, dealing with relatively complex texts and evaluating the text regarding the effect on the reader or the author's point of view.

Mathematical competences are the ability "to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD, 2003, 15). As mathematics is utilized in many classes offered in secondary education, from economics to science, basic mathematical operations are taught in primary education. Once students know some essential mathematical operations (addition, subtraction, multiplication, and subtraction), they can be introduced to more complicated topics like geometry, calculus, and stochastics. Ultimately, towards the end of secondary education, competence differences can be measured around understanding more complex mathematics concepts (Neumann et al., 2013). Many mathematical concepts and competences are beyond secondary education and are included in university studies of mathematics.

To understand how competences can be acquired prior to and within secondary education, knowledge about learning environments is crucial. Two of the most important learning environments for children and adolescents are the home and the school context. The home-learning environment can be divided into the home literacy environment and the home numeracy environment (e.g., Sénéchal & Lefevre, 2002; Skwarchuk et al., 2014). The amount of parental interaction with children as well as resources for learning and interaction with literacy and numeracy are essential, especially for acquiring early literacy and numeracy (e.g., Khanolainen et al., 2020; Sénéchal & Lefevre, 2002; Skwarchuk et al., 2014).

While home learning environments have an effect on student competence development all the way to early adulthood (e.g., Lehrl et al., 2019; Sammons et al., 2015), with increasing time in school, schools should gain importance as a learning environment. Reading and mathematical competences are taught in school through different means and classes. Early in German schooling (primary education), learning how to read and write is taught as a central part of the German curriculum. These basic competences are presumed to exist at the beginning of secondary education, with writing and analyzing more complex texts as an important part of German classes. Meanwhile, higher-level reading competences are also used and trained when acquiring information from texts in many other classes such as social studies or history or when learning a new foreign language. Mathematical competences are more easily connected to mathematics classes throughout education. These classes teach students most skills we can measure as mathematical competence. In addition to mathematics classes, the natural sciences are the main area where mathematical competences are applied and thus trained.

Both types of learning environments may differ from student to student. For example, the home learning environment is very individual and highly dependent on the students' parents, including their financial and cultural resources (related to parental education and occupation). Meanwhile, students' school learning environments depend on the specific school and course students attend. As will be explained later, this is more pronounced in secondary education, with students grouped into different tracks by parental decision and prior achievement. As parental background (through parental decisions) and student competences (through grades) are relevant for this tracking decision, differences in competence development might arise from compositional effects and institutional differences (e.g., Baumert et al., 2006). Students in 'higher' tracks will typically receive a 'higher' (or more difficult) level of instruction, which could lead to a higher level of competence development (institutional differences) (e.g., Baumert et al., 2006). Similarly, a higher average level of competences across the student body and a higher average social background could be connected to students developing faster due to student composition (compositional effects) (e.g., Baumert et al., 2006).

2.1.2 Relationship between reading and mathematics

Reading and mathematical competences correlate highly throughout education. Preliminary abilities, such as letter recognition and counting, are already related in preschool (e.g., Duncan et al., 2007). The competences in both domains stay correlated throughout education (e.g., Duncan et al., 2007; Hooper et al., 2010). Early competences and abilities are also predictive of later competences and competence development (e.g., Duncan et al., 2007; Hooper et al., 2010). Accordingly, competence development in both domains is highly correlated throughout secondary education (e.g., Adelson et al., 2015; Shin et al., 2013).

This strong relationship between reading and mathematical competences and development in the domains has several explanations. One substantial reason for their strong relationship is the importance of reading competences for mathematical competences. Overall, reading competence is essential for learning any skill (Weinert, 2006). For example, higher reading abilities among students with difficulties in mathematics can help them develop faster in mathematics (Jordan et al., 2002). In general, many studies show a positive relationship between cross-sectional reading competences and mathematical development (e.g., Chen & Chalhoub-Deville, 2016; Purpura et al., 2011; Shin et al., 2013) underlining the overall relationship. Language abilities might be especially critical for mathematical development in early secondary education when students attain mathematical reasoning skills and the ability to deal with complex mathematical procedures (Geary, 1994). In addition to the importance of reading for learning and competence development, reading abilities are also essential for competence testing in mathematics. Mathematical competence tests often use language-based questions (i.e., word problems), which are easier to answer for students with adequate reading abilities (e.g., Abedi & Lord, 2001; Korpershoek et al., 2014).

Reading and mathematical competences are also connected through independent predictors that affect development in both areas. For example, students' socio-demographic background or parents' socioeconomic status (abbreviated to SES) affects both domains. SES impacts cognitive abilities and pre-requisite abilities for both domains starting in preschool (e.g., Larson et al., 2015). This gap persists up to upper secondary education, with ninth-grade competences still highly dependent on students' backgrounds (e.g., OECD, 2019). The longitudinal effect of SES is less clear, with studies indicating mixed effects (Shin et al., 2013 provide an overview of studies on this topic). Connected to SES of the parents, home numeracy environment and home literacy environment are also highly connected (Napoli & Purpura, 2018). Overall, aspects of parental background and home characteristics typically affect both domains at the same time leading to potentially parallel development in the two domains.

2.1.3 Specialization of competences

However, while competences are highly correlated, student characteristics in multiple domains can differ within a student. From here on out, these types of within-student differences will be called specialization. One area where specialization of reading (or the German language) and mathematics exists, are affective-motivational factors of students, specifically, student interest and self-concept. The development of students' self-concept in mathematics and reading can be seen as negatively correlated (Parker et al., 2014), indicating specialization of self-concept over time. Additionally, Ehrtmann et al. (2019) analyzed interest to identify different student groups between mathematics, German, and vocational areas. While many students have overall high or low interest, some fit within specialized interest profiles in either German or mathematics (Ehrtmann et al., 2019). These results are relevant for competence development and potential specialization as interest and self-concept impact competences and development in the respective domain (e.g., Denissen et al., 2007).

Few analyses have been conducted prior to this dissertation regarding specialization in competences. However, some general expectations can be drawn from findings regarding higher and lower competences in different groups. Previous studies found groups with very low competences in one but not both competence domains. Jordan, Hanich, and Kaplan (2002) find such groups in their analysis of students in primary education with difficulties in one, both, or none of the domains. These groups can also be found in secondary education, as seen in PISA studies (OECD, 2016a).

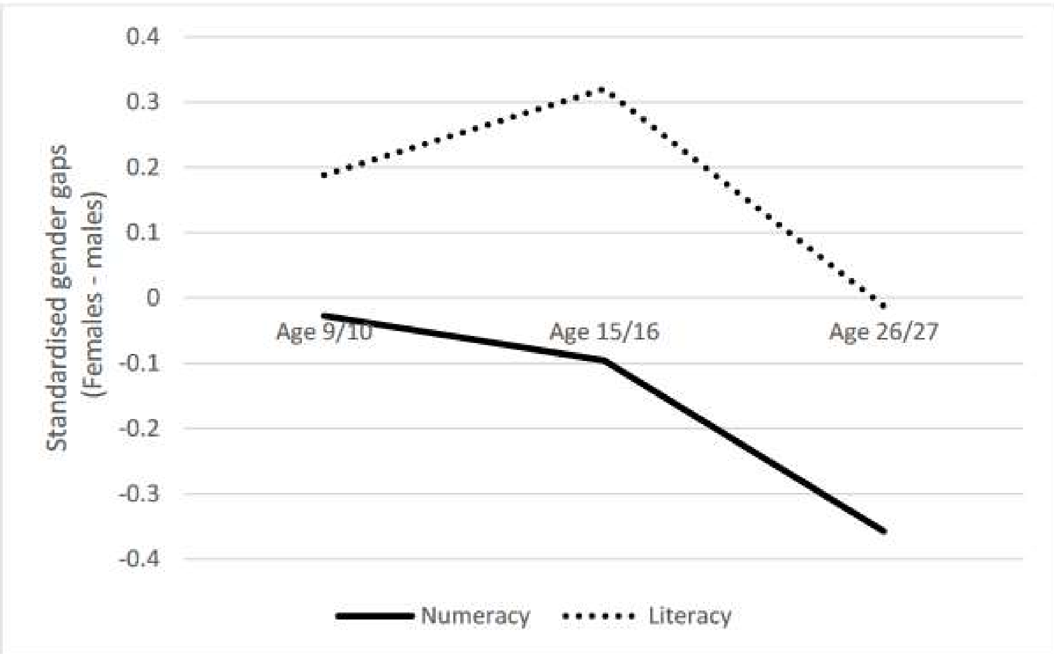

Figure 1: Evolution of gender gaps. (Borgonovi et al., 2018)

Differences between reading and mathematical competences can also be found for boys and girls. Male students often exhibit higher mathematical and lower reading competences than girls (Borgonovi et al., 2018; LoGerfo et al., 2006; OECD, 2016b; Robinson & Lubienski, 2011). From a cross-sectional perspective, boys could be interpreted as specialized on mathematics, with girls specialized on reading. However, this gender difference is more diverse in the competence development of students, as studies show either stagnating (LoGerfo et al., 2006) or decreasing gender differences in secondary education (Robinson & Lubienski, 2011). As Borgonovi and colleagues show in a study analyzing samples from three different educational stages (Grade 4, Grade 9, young adults), gender differences develop very differently in lower and upper secondary education (see Figure 1). Between Grades 4 and 9, gender differences grow distinctively towards the previously described cross-sectional differences in both domains. After Grade 9, mathematical gender differences stagnate while reading differences disappear between Grade 9 and adulthood.

2.2 Secondary education in Germany

For some level of specialization to occur, the educational environment of children and adolescents must allow them not only to attain abilities in reading and mathematics but also to focus their studies on one domain. As such, the German education system could be examined through multiple lenses: the general school concepts and curricula; the type of tracking that occurs; and the type of specialization possible through tracks or courses. The German educational system differs highly between federal states, though some commonalities exist across states. Overall, German institutional education can be divided into 5 phases: Preschool, primary, early secondary, upper secondary (including vocational), and tertiary education.

Prior to entering formal education, children may enter preschool institutions. Preschool education offers many options from type of institution to entry age. Typically, children then enter primary education at age 6. Primary education in *Grundschule* is obligatory and in mixed-groups, meaning all students have to attend *Grundschule* with no external tracking besides schools for students with special education needs and private schools. Educational tracking (differentiation of students in different schools according to their abilities) usually starts with the transition to secondary education in Grade 5. While lower secondary education offers general education (focusing on the attainment of general abilities and skills) in all school types, upper secondary education starting in Grade 10 includes more diversity in goals and forms of institutional education. Finally, after attaining specific graduation certificates, students may enter tertiary education. As education starts to diversify in Grade 5, especially after Grade 9, secondary and tertiary education are especially interesting for competence specialization.

2.2.1 General lower secondary education

The German educational system opens up into multiple separate tracks after primary education (usually after Grade 4 and Grade 6 in Berlin and Brandenburg). Historically, three main tracks could be differentiated: The *Gymnasium* as the track preparing for academic careers, the *Hauptschule* as a track preparing for vocational careers, and the *Realschule* between both tracks. Currently, only the *Gymnasium* exists across all German states. The tracks outside the *Gymnasium* may still include *Hauptschulen*, *Realschulen*, or a mixture of both school types but is far more diverse between the different German states. In addition to the typically tracked system, most states also include a system of comprehensive schools (usually *Gesamtschule* or *Gemeinschaftsschule*) offering all types of graduation certificates.

Despite the high diversity of different school types resulting from the federal structure of the German educational system, one focus of lower secondary education is the same across all schools: Offering students general education (KMK, 1993). This focus can be seen in the hours of mandatory schooling in German and mathematics being similar or identical for all school types across states (Avenarius et al., 2003, p. 94ff.). A high competence specialization in reading or mathematics seems less likely here than later in education. Students should exhibit basic abilities in both domains (the ability to read simple texts and use basic calculation methods) prior to lower secondary education. Towards the end of early secondary education, students should possess the competences and abilities needed to enter vocational or further academic pathways.

2.2.2 Diversified upper secondary and job-specific education

At the end of Grades 9 and 10, students may attain the first school graduation certificates, after which they may decide to leave general education (KMK, 2019). The following period offers very different paths with students either entering the vocational educational system or continuing with general education aiming for tertiary education. Students already in a *Gymnasium* or school with a track leading to university entry certificates ('Hochschulreife' or 'Fachhochschulreife') may remain within their school to attain these certificates. Other students aiming for tertiary education may enter a school including these tracks (i.e., *Gymnasium*, comprehensive schools, or schools offering Grades 10-12 or 10-13 with a vocational focus) to attain the same certificates.

Upper secondary general education offers significantly more opportunities to focus on specific areas than previous general education. In course selection, students have to choose based on some basic rules: Students need to attend classes in mathematics, German, one foreign language, physical education, history, and one natural science (KMK, 2019, p. 139). However, this still leaves students with many choices (KMK, 2019, pp. 138f): Which foreign language and natural science do they learn? What additional courses do they attend? What courses do they learn at an increased level? Students may, for example, choose to attend a high number of science classes or receive education in an additional foreign language. They may attend courses with increased difficulty in mathematics or German. These options and choices should increase the overall possibility of specializing in reading or mathematics and thus developing specialized competences.

Students choosing to leave general education in favor of vocational education and training (VET) may enter the dual VET system or in school-based VET programs (Fürstenau et al., 2014; KMK, 2019). The VET systems offer diverse career opportunities such as engineering, commerce, office work, preschool education, or health care. With such a diverse field of potential occupations to enter through the vocation system, the types of schooling also differ significantly. While some students are taught only in schools before entering the workplace for their on-the-job education, others spend roughly three-quarters of their time on the job (Fürstenau et al., 2014). What connects all apprenticeship programs is their character as a preparation for a specific job or career.

This connection to a specific job or career is why VET might be highly relevant for specialized competence development. Different jobs require very different abilities. While reading and mathematical competences are not necessarily occupational skills, they are necessities for many jobs. For example, high reading abilities can be connected to jobs in law, journalism, and literature, all of which require the ability to research and analyze complex texts. Regarding mathematical competences, careers in STEM (science, technology, engineering, and mathematics) require applying mathematical skills. Not only do some students lack mathematical or reading competences prior to entry into VET, but VET might also benefit development in both domains through other related competences. Examples of this are technical competences requiring and benefiting mathematical competence or different language competences (foreign language, writing) requiring and benefiting reading competence. Overall, the specialization of VET offers higher chances for the specialization of competences.

At the end of general upper secondary education, students remaining in general education can attain university entry certificates. Other students might gain access through the vocational system. Once students obtain entrance qualifications ('Fachhochschulreife' or

‘Allgemeine Hochschulreife’), they can enter tertiary education at either a university of applied science (*Fachhochschule*) or a regular university (*Hochschule*). Universities prepare students for an academic career in one specific area (e.g., medicine, engineering, law, language studies, economics, social studies, psychology, or informatics). Like courses in the VET, these specific fields of studies can be connected to specific competence requirements, including high mathematical or reading competences. For example, University courses in STEM areas (Federal Statistical Office of Germany, 2020) likely need high mathematical competences. Reading competences might be seen as a higher necessity for all university courses, as most information must be gathered from written sources. However, students from language and cultural studies (Federal Statistical Office of Germany, 2020) will likely need even higher reading competences. Overall, selecting a specialized field of study might lead to specialized competence development.

2.3 Inter-individual differences in students’ competence specialization

Previous chapters gave insight into the reasons for the existence of specialization in general. However, two central questions remain unanswered: which students specialize, and why do they specialize? The first part of this chapter provides an overview of student characteristics affecting competence development in reading and mathematics. The second part of this chapter focuses on the reason behind specialized learning and educational decisions.

2.3.1 Predictors of competence specialization

To determine which students specialize in one of the two domains, the effect of student characteristics on the development of both domains can be compared. A first step is identifying variables that affect development in the two domains differently. For example, some factors can impact mathematical competence positively and negatively impact reading competence. Relevant student characteristics could include socio-demographic characteristics, affective-motivational traits, and learning environments. While some characteristics should not affect competence development in reading and mathematics differently, other variables are likely predictors of both development and specialization.

Most socio-demographic aspects of students may affect competence and development in both reading and mathematics equally. For example, the parents' socioeconomic status (i.e., the parent's level of employment and education) should affect students' learning opportunities in both domains. Students with a high socioeconomic background may benefit from additional financial and cultural resources provided by their parents (e.g., Montacute & Cullinane, 2018) and from improved home learning environments (e.g., Zadeh et al., 2010). These resources and good home learning environments help development across domains, leading to potential advantages in reading and mathematical competences. However, parental occupation and parental education might factor into specialization when considering the parents' field of study and work. For example, parents from a mathematically focused field might offer a better home numeracy environment than home literacy environment.

A student's migration background might have a different impact on both domains. Language acquisition seems especially important for reading competences. Parents potentially not being able to speak the language of instruction fluently compared to parents of classmates could lead to problems in reading competence development. Previous research on students of different ethnicities in the United States (e.g., LoGerfo et al., 2006) does support this kind of argumentation - students of non-white ethnicity and English language learners struggle specifically with reading and not with mathematics. Similar analyses from Germany regarding migration background have differing results. These analyses show that students with a migration background have problems in mathematics and reading to a similar degree (e.g., Wendt et al., 2010; Guill et al., 2010). Overall, migration background cannot clearly be connected to developmental competence specialization.

Student gender can be seen as one critical factor for their specialized competences. Male and female students differ in their average interest in language and scientific fields (e.g., Ehrtmann et al., 2018) and their odds of entering mathematically focused education (e.g., World Economic Forum, 2017). Cross-sectional competences also differ between male and female students, as boys have higher mathematical competences than girls and girls have higher reading competences than boys (e.g., OECD, 2016b). Therefore, gender gaps in reading and mathematics might be expected to increase over time. However, gender differences increase between grades 4 and 9 and diminish until adulthood in reading while increasing further in mathematics (Borgonovi et al., 2018). This leads to a developmental advantage in mathematics for boys from Grade 4 to adulthood and in reading for girls between Grades 4 and 9 and boys after Grade 9. Overall, gender might be seen as a predictor of specialization for part of secondary education but not towards the end.

Finally, students could specialize due to their educational learning. Within education, students may differ both in the actual course and track selection and in the effort level they put into learning the competences. For example, the number of language and social study classes could be relevant for reading competence development in general education. Similarly, the amount of science and mathematics classes should affect mathematical development. VET preparing for work in a more specialized area could also lead to competence specialization in vocational education. Tertiary education ultimately fulfills a similar role to vocational education, preparing students for careers in academic fields, and can similarly be specialized on either mathematics (STEM) or reading (language and cultural studies). Besides formal education, hobbies (such as the number of books they read) may also offer another learning environment relevant for specialization.

2.3.2 Differences in choice for specialization

These last potential predictors of competence specialization, specialized individual focus within and outside of education, lead to another crucial question: Why do students decide to enter learning environments that are likely to lead to competence specialization? One theory that can help explain differences between students' choices for or against specialized education is the expectancy-value theory (Eccles & Wigfield, 1995). According to this theory, students' choices are dependent on their expectancies and values for either option. Task-specific expectancies (i.e., expectations for success) are increased by task-specific self-concept of domain-specific abilities and reduced by perceived task difficulty (Eccles (Parsons) et al., 1983). Meanwhile, task-values include attainment value, intrinsic value (interest), utility value, and cost (Eccles (Parsons) et al., 1983).

Regarding expectancy, students' expected success in specialized educational pathways depends on the required domain's perceived difficulty and their self-concept in that domain. For example, students with a high self-concept in mathematics and not in reading are more likely to choose a pathway that requires their mathematical competence and not their reading competence. Meanwhile, generalized and specialized educational pathways might feel equally doable for students with high self-concept in both domains. The self-concept should be connected to the actual competences, meaning actual intra-individual differences between the competence domains should also affect decisions.

Additionally, students should differ in their task values towards specialized and generalized educational pathways. For example, attainment values might be influenced by gender stereotypes. Students with high gender stereotypes likely see a high attainment value in choosing a pathway that fits the stereotypes of their gender. In addition, students' domain-specific interests are a central part of the intrinsic value of any choice. Thus the connection between specialized interest and specialized educational decisions is quite clear. Overall, whether they affect the students' expected chances of success or their values regarding a pathway, student characteristics like gender, stereotypes, interest, or life goals all likely affect students' decisions for or against specialized education. As we expect specialized education to increase the likelihood of specialized competence development, each of these characteristics should indirectly affect the specialization of competence development.

3 Research Questions

Several research questions can be asked based on the previously described theoretical background. The three manuscripts described later examine each of these research questions somehow. Intra-individual differences in competence development form the base of this dissertation. Thus, the first research question regards differences in students' competence development specialization. Even though development in reading and mathematics is expected to be highly correlated overall, previous research indicated that some students specialize on mathematical or reading competence development. Therefore, one primary goal was to explain the overall distribution of competence specialization through identified groups with similar intra-individual differences. Specifically, we looked for groups with specialized competence development leading to the first research question:

RQ1: Can groups with a specializing competence development be identified?

Assuming specialization of students can be found either in specific groups or the overall distribution of students, the second primary goal of this dissertation lies in predicting this specialization. By identifying predictors and testing their effect on specialization, the explanation of competence specialization might be enhanced. Thus, the second research question concerns the identification of potential predictors:

RQ2: What factors affect the competence specialization of students?

The potential predictors of competence development identified in the theoretical background include students' gender, affective-motivational factors, and specialized education. While the manuscripts highlight all of these aspects, the main focus of the final two research questions is on educational effects. As mentioned before, secondary education in Germany includes differing levels of competence specialization opportunities between early secondary education and upper secondary education. As such, we could propose an increasing level of specialization towards the end of secondary education:

RQ3: Does the number of students with specialized competence development increase throughout secondary education?

Beyond looking at the overall change between early and upper secondary education, we need to look specifically at the attendance of specialized education. Specialized education includes specialized vocational training, courses within the general secondary educational system, and university studies in tertiary education. Identifying how attendance of specialized education affects specialized development is the basis for the final research question:

RQ4: Does attendance of specialized education increase the likelihood of specialized competence development?

4 Research design

This chapter provides the necessary background information for the manuscripts described as part of the results of this dissertation. In addition, information on the National Education Panel Study (NEPS; Blossfeld & Roßbach, 2019) and the specific sub-samples is included. This chapter also explains the coding of all utilized variables, including competence measures, predictors, and control variables. Finally, the underlying methodology of growth modeling, mixture modeling, and regression analysis will be specified.

4.1 Sample

The articles use two datasets from the NEPS. The NEPS aims to collect "longitudinal data on educational processes and individual competence development across the entire life span from early childhood to late adulthood" (Blossfeld & Roßbach, 2019, p. V). Currently, the NEPS has six different 'starting cohorts' (short SC) sampled initially as babies (SC1), kindergarteners (SC2), students in Grade 5 (SC3) and Grade 9 (SC4), students entering university (SC5), and adults at different points of their life (SC6). The SC3 and SC4 were sampled in a multi-stage stratified cluster design (Steinhauer et al., 2015) using schools and classes for clustering. Once sampled, the SCs were followed longitudinal, with competence tests and questionnaires administered regularly.

The sub-sample used in the first paper is the SC3 of the NEPS. Students were first sampled at the beginning of secondary education (Grade 5). As of the writing of the first manuscript, the datasets included information on reading and mathematics tests of Grades 5, 7, and 9. The 5,201 students relevant for our analysis were 10.9 years old on average (*SD* = 0.53). Of these students, 48% were female, 19% had a migration background, and 46% visited either a *Gymnasium* or the equivalent track of a comprehensive school.

The second and third manuscripts were both based on the NEPS SC4. This cohort of students was initially sampled and tested in Grade 9 in both domains, with subsequent competence tests in Grade 12 and three years after Grade 12. Initially, the 15,012 students relevant for our studies were 15.2 years old (*SD* = 0.6). Half the students were female, 21% had a migration background, and 36% attended either a *Gymnasium* or an equivalent branch of the *Gesamtschule*.

4.2 Instruments

The variables required to conduct the analyses of the manuscripts included competence measures in reading and mathematics and students' background variables such as gender or migration background. The information was attained through competence tests and questionnaires answered by the students, parents, and teachers.

4.2.1 Competence values

The competence values used in all three studies are based on competence tests explicitly created for use in the NEPS. Reading and mathematical competences were assessed in Grades 5, 7, 9 (SC3), 9, 12, and three years after 12 (SC4). The only deviation from testing in the same wave is in Grade 9 (both SCs), where students took the mathematics test in the winter of Grade 9 and the reading test in the spring of Grade 9. All tests until Grade 12 were paper-based, with the final measurement post-school computer-based. Students had 28 minutes to answer each test.

Reading competence in the NEPS was measured using three different comprehension requirements (finding information in text, drawing text-related conclusions, and reflecting and assessing) and five text functions (commenting, information, literary, instruction, and advertising; Gehrer et al., 2013). The tests of SC3 consisted of 33, 29 or 30, and 32 or 33 items in Grades 5, 7, and 9, respectively (Krannich et al., 2017; Pohl et al., 2012; Scharl et al., 2017). Tests in SC4 included 31, 28, and 23 or 27 items in Grades 9, 12, and three years after Grade 12, respectively (Haberkorn et al., 2012; Gnambs, et al., 2017; Rohm et al., 2019). All tests had at least good marginal reliabilities of .78, .72, .81 (Grades 5, 7, and 9 in SC3), .81, .80, and .77 (Grades 9, 12, and three years later in SC4).

Mathematical competence similarly had a framework with four content areas (quantity, change and relationship, space and shape, and data and chance) and six cognitive components (mathematical communication, mathematical argumentation, modeling, using representational forms, mathematical problem solving, and technical abilities and skills) used to create items (Neumann et al., 2013). Tests included 25, 23, 23, 22, 21, and 21 items (SC3 Grades 5, 7 and 9, SC4 Grades 9, 12, and three years after 12 respectively) with marginal reliabilities of .78, .72, .81, .81, .77, and .75 (Durchhardt & Gerdes, 2012; Durchhardt & Gerdes 2013; Fischer et al., 2017; Gnambs, 2020; Schnittjer & Gerken, 2017; van den Ham et al., 2018).

The competence tests of each wave and domain were modeled using item response theory (Pohl & Carstensen, 2012) to estimate proficiency scores as weighted likelihood estimates (WLE; Warm, 1989). To compare competences across times, the WLEs were linked (Fischer et al., 2016). The linking of reading competences used independent linking studies, while the linking of mathematical competences used anchor items used in multiple waves. Finally, the WLEs were z-standardized according to the mean and standard deviation in the first wave (Grade 5 for Paper 1, Grade 9 for Papers 2 and 3).

4.2.2 Predictors of competence specialization

As predictors of the specialization of competence development, three variables were elaborated in the articles: gender, interest, and education. Gender, as used in our analyses, is coded as a dichotomous variable differentiating only between boys and girls. Meanwhile, interest and education were coded as the specialization of interest and education as a predictor of specialization.

Specialized interest was based on two scales of domain-specific interest adapted from Baumert and colleagues (1997). Students were asked how interested they were in four topics for both the German language and mathematics. These scales ranged from 1 “does not apply at all” to 4 “does completely apply” and had high internal reliabilities (.83 for German and

.85 for mathematics). The scales were z-standardized to create a score of specialized interest, and the interest in German was subtracted from the interest in Mathematics.

Similarly, education was assessed more for its amount of specialization than for its overall level. While some specialization exists in general education in areas such as course selection, we focused on vocational and tertiary education. Vocational and tertiary education prepare for future careers and future jobs and thus can more easily be connected to one of the domains. All vocational and tertiary education episodes that could be seen as mathematically specialized or reading specialized were summed up to two scores. Episodes of mathematically specialized education include vocational education for future careers in STEM jobs (defined by the Federal Employment Agency of Germany, 2019) or tertiary education in mathematics, natural sciences, and engineering (Federal Statistical Office of Germany, 2020). Episodes of reading specialized education were vocational education for careers in law, print media, and libraries, and tertiary education in language and cultural studies. After adding up durations of singular episodes (ending – start in months), students were divided into students with at least six months in reading specialized education, students with at least six months in mathematically specialized education, and students with less specialized education or sufficient time in both specialized types.

4.2.3 Control variables used for imputation or prediction

In addition to the predictor variables, several control variables were needed for the imputation model and to control the effects of the predictors. Similar to domain-specific interests, students were also asked about their self-concept in German and mathematics (adapted from Kunter et al., 2002). The reasoning ability of students (Lang et al., 2014) was tested to control for the effects of another ability on the two competence domains. Migration background (coded as existing if one of the parents or the student immigrated) and a scale on interaction language in different contexts were used to control family immigration history. The highest occupational prestige according to the International Socio-Economic Index of Occupational Status (ISEI; Ganzeboom, 2010), and the highest number of educational years according to the Comparative Analysis of Social Mobility in Industrial Nations (CASMIN; Lüttinger & König, 1988) were used to control for socioeconomic background. Finally, the age of students, school type (dichotomized into students in *Gymnasium* or equivalent track and all others), and school-attendance information in former West- or East-Germany were included. It should be noted that not all variables were part of all three studies.

4.3 Methodology

To operationalize development in reading and mathematics, linear latent growth models (LGM; McArdle, 1988)) were used for the first and second papers. These linear latent growth models use the actual competence values in all waves to generate an initial competence value (intercept) and a developmental value (slope) for every student. As intercept and slope in both domains were identified in the same model in Mplus (version 8.2, Muthén & Muthén 1998-2017), this model was a dual-process LGM.

Based on the LGM, an underlying mixture of subgroups within the overall distribution can be located through mixture modeling. LGM and mixture models are combined in latent growth mixture models (LGMM; Muthén et al., 2006; Muthén, & Shedden, 1999). In the first paper, profiles were identified once based on all developmental parameters (intercepts & slopes) and once based only on the slopes. In the second paper, only the slopes were relevant for profile identification. Several criteria were used to interpret the different models, most notably the Bayesian Information Criterion (Schwarz, 1978), the Lo-Mendel-Rubin Likelihood Test (Lo et al., 2001; Vuong, 1989), and the size of the profiles. A minimum size of 5% for each profile was set to generate replicable results.

The third paper changed the growth model from a linear LGM to a latent change score approach (LCS; Klopack & Wickrama, 2020). This model also generates latent intercept and slope parameters similar to an LGM. However, this model does not require strictly linear development as it adds a proportional growth factor β, which indicates the impact of earlier competences on students' competence development. With the inclusion of β, the slope can be interpreted as the development between two time-points for a student with previous competences of 0 (in our case, average Grade 9 competences). Linear regression was conducted to test competence development predictors for each of the two intercept factors and slope factors.

5 Summary of the conducted research articles

Based on the described methods and the theoretical background, the three manuscripts will be described in the following section. The specific focus is on the questions each article set out to answer and the article's results. The articles will be described in order of conception, not by publication date. The first and second articles aim to find competence development profiles in early secondary education (paper 1), upper secondary education, vocational education, and early tertiary education (paper 2). The third article remains within upper secondary and tertiary education to analyze predictors of competence development in this diverse age group.

5.1 **Manuscript 1:** Profiles of competence development in mathematics and reading in early secondary education

The first paper focused on the identification of competence profiles in early secondary education. A high number of students in general profiles of competence development (parallel development in both reading and mathematics) was expected due to reading requirements for mathematics (e.g., Abedi & Lord, 2001; Geary, 1994; Weinert, 2006), high correlations between the two domain (e.g., Adelson et al., 2015; Hooper et al., 2010; Shin et al., 2013), and common predictors such as cognitive skills (Alloway et al., 2006; Bull et al., 2008; Knievel et al., 2010). Additionally, as noted before, early secondary education does not offer many opportunities for individuals to focus on either domain. However, the paper also predicted the existence of specialized profiles of competence development (higher development in one domain) due to the previous specialization found in cross-sectional competences (Jordan et al., 2002; OECD, 2016a), differences between groups (e.g., gender: LoGerfo et al., 2006; OECD, 2016b; Robinson & Lubienski, 2011) and specialization of interest (Ehrtmann et al., 2019) as a connected characteristic.

Overall, we derived at least three profiles with two specialized profiles and one generalized profile of competence development. For identification of profiles of competence development, Latent Growth Mixture Models (LGMM; Muthén et al., 2006; Muthén, & Shedden, 1999) with a different number of classes were compared. Criterions used to decide the eligibility of models were entropy above .70 and minimum profile size above 5% of the overall sample. Criterions used for selection among acceptable models include the lowest Bayesian Information Criterion (Schwarz, 1978) and the last significant Lo-Mendell-Rubin likelihood ratio test (Lo et al., 2001, Vuong, 1989). Additional subgroup analysis was conducted with students attending *Gymnasium* or the equivalent track of comprehensive schools to check for reliability of results.

Due to many missing values, specifically in Eastern Germany (based on the transition from primary school being after Grade 7 in the states of Berlin and Brandenburg) and among students with lower competences, missing values had to be computed. These missing values of competences were estimated using full information maximum likelihood (FIML; Enders & Bandalos, 2001) estimation in Mplus. Auxiliary variables included characteristics of students (self-concept, interest, reasoning, age, gender), their background (migration background, CASMIN and ISEI of the parents, interaction language), and their school (type of school and location of the school in East or West Germany). The basis of these control variables were theoretical decisions and attrition analysis. Based on the estimated competence values, latent growth variables (intercept: initial competence; slope: competence development) in both domains were estimated using Latent Growth Models (McArdle, 1988). Models with multiple profiles were interpreted according to these average slope parameters.

Table 1 shows means, standard deviations, and correlations of competences prior to missing value estimation. The mean values of competences indicated roughly a mean development of .35 per grade in mathematics and .28 in reading among data without missing values. The Standard deviation of these competences prior to FIML remained consistently around 1 (resembling the distribution of competences in Grade 5). Correlation within mathematics competences of different grades was constantly high. However, correlations between reading competences of different grades and correlations between the two domains were distinctively lower. The correlations across domains also do not point to an increased effect of early reading competences on later mathematical competences.

Table 1. Means, standard deviations, and correlations of competences across grades.

	Grade	*N*	*M*	*SD*	Correlation					
					Mathematics			Reading		
					5	7	9	5	7	9
Mathematics	5	5,193	0.0	1.0						
	7	3,829	0.7	1.1	.74					
	9	2,854	1.4	1.0	.71	.74				
Reading	5	5,193	0.0	1.0	.64	.58	.57			
	7	3,833	0.6	1.1	.55	.60	.58	.61		
	9	3,116	1.1	0.9	.53	.52	.58	.59	.64	

Note. Competence scores were z-standardized within domain with respect to Grade 5.
Source: Freund, Gnambs, et al., 2021

Once missing values for competences in higher grades were estimated, models with increasing number of profiles were examined (up to a maximum of 6 profiles). The model criterion (BIC, LMRT) indicated multiple profiles in all tested models. However, profile size functioned as a baseline criterion with a minimum of 5% in the smallest profile. None of the models with multiple profiles included more than 5% of students in their smallest profile. Overall, these results indicated that the basic Latent Growth Model was better than any model with multiple groups.

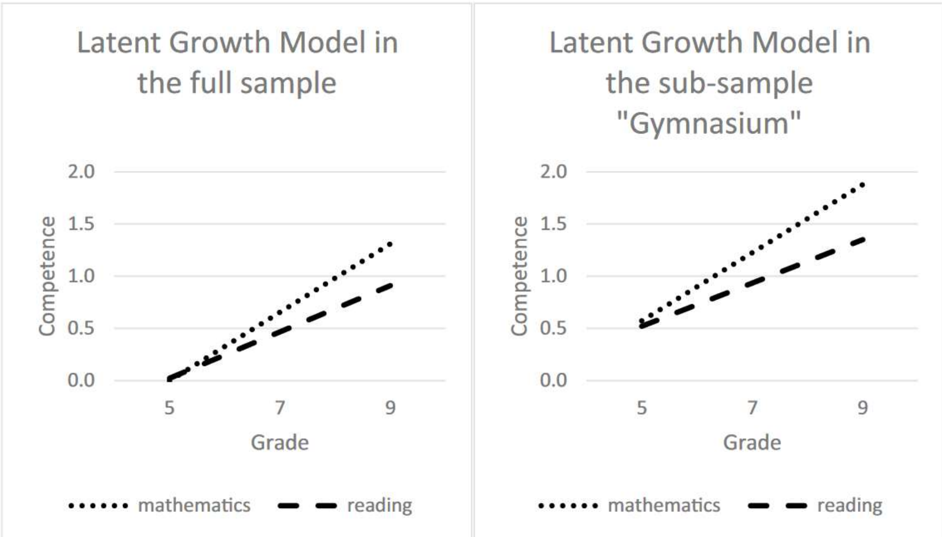

Figure 2. Growth trajectories in the full sample (left) and the sub-sample "Gymnasium" (right). (Freund, Gnambs, et al., 2021)

Finally, the development of competences in the one-class solution (the basic Latent Growth Model) was interpreted. Figure 2 shows this model in both the overall sample and subsample. For the full sample, the average intercepts were roughly 0 in both domains with standard deviations of .90 (mathematics) and .84 (reading). These intercepts corresponded to the competence values in Grade 5, which we standardized according to their mean and standard deviation. Slope in both domains was found at .33 (SD = .11) in mathematics and .22 in reading (SD = .10). Following this article's definition of specialized competence development (difference in slopes larger than the average development in halve a year of education), the overall development was described as generalized.

The initial competences (intercepts) were highly correlated across the two domains, indicating a high cross-sectional connection (.86). Meanwhile, the slopes of the two domains were moderately positively correlated (.42), indicating a moderate longitudinal connection of the two domains. Finally, correlations of intercepts and slopes were negative, with very slight negative correlations of intercepts (MA: -.16; RE: -.05) with the mathematical slope and moderately low correlations (MA: -.39; RE:-.37) of intercepts with the reading slope.

Overall, the sub-group of students in the *Gymnasium* started with higher initial competences and showed similar competence development, as seen in Figure 2. Initial competences (intercepts) were found at .57 (SD = .67) for mathematics and .52 (SD = .67) for reading. They were only moderately correlated (.35), indicating a higher potential for students with specialized competences in this group. Latent slopes were estimated at .33 (SD = .09) for mathematics and .21 (.08) for reading. The correlation between the slopes of roughly 0 indicated no overall relationship between the two slopes. However, the mean development of students was very similar to the overall sample. Finally, correlations between intercepts and slopes were smaller than in the overall sample.

5.2 **Manuscript 2:** Determinants of profiles of competence development in mathematics and reading in upper secondary education in Germany

The second article used the argumentation of generalized and specialized profiles of competence development from article one as a baseline. Due to the small specialized profiles found in the first manuscript, we argued that the educational system of early secondary education was too generalized, with all tracks aiming for the general education of their students. This changes after Grade 9, with general education offering additional course selection opportunities and many students entering vocational or tertiary education after graduation. This second article had two central goals: identification of profiles of competence development in upper secondary education and testing predictors of these profiles. As in article one, at least three profiles were hypothesized (one generalized, two specialized). In addition to specialized education, differences in learning focus indicated by student interest were assumed to affect competence specialization.

As a sample, starting cohort 4 of the NEPS was used for this study, with competence measurements in Grades 9, 12, and 3 years after Grade 12. LGMM (Muthén et al., 2006; Muthén & Shedden, 1999) with different numbers of profiles were compared according to LMRT (Lo et al., 2001, Vuong, 1989) and BIC (Schwarz, 1978). Models were still required to have a minimum profile size of 5% and entropy above 0.7. Multinomial regression analysis could have indicated the effects of predictors and control variables. Ultimately testing the predictors was not possible due to a lack of profiles. Before estimating profiles, missing values were imputed using a multiple imputation approach (Rubin, 1987).

Table 2. Means, Standard Deviations, and Correlations of Competences of Competence Tests.

	Grade	*M*	*SD*	Correlations					
				Mathematics			Reading		
				9	12	12+3	9	12	12+3
Mathematics	9	0.00	1.00						
	12	0.56	0.92	.70					
	12+3	0.77	1.00	.68	.68				
Reading	9	0.00	1.00	.54	.44	.47			
	12	0.21	0.81	.56	.50	.53	.65		
	12+3	0.32	0.77	.55	.51	.59	.58	.65	

*Note***.** Competence scores were *z*-standardized within domain with respect to grade 9. All correlations are significant at a 99.9% significance level. (Freund, Wolter, et al., 2021)

Table 2 includes basic statistics of competences in Grades 9, 12, and three years after Grade 12 from the imputed dataset. Mean competences indicate reduced increases in both domains after Grade 12 with distinctively higher competence development in mathematics than reading. The variance of student competences stayed high in mathematics and dropped in reading competences, indicating consistent homogeneity between students in mathematical competences and increasing homogeneity in reading competences. Correlations of competences within mathematics were the strongest, with correlations of competences within reading tests slightly lower and just higher than correlations between reading and mathematical competences. Overall, correlations can be considered moderate to moderate-high between all tests.

Regarding profiles of competence development, the results were very similar to previous analyses in lower secondary education in the first article. While the fit criterion indicated a two-class solution, the second profile was deemed too small at only 1.6% of students. Therefore, an additional LCGA (Latent Class Growth Analysis) was used as quality control. This approach uses variances and covariances within each class fixed to zero (Jung & Wickrama, 2008). While the LCGA did find solutions with multiple relevantly sized profiles (up to 4 profiles), the model fit criterion indicated a better fit of the basic latent growth model (LGM) than any LCGA.

Table 3. Means, standard deviances, and correlations of the latent intercepts and slopes

		M	*SD*	Correlation			
				Mathematics		Reading	
				intercept	slope	intercept	slope
Mathematics	Intercept	0.06	0.77				
	Slope	0.13	0.02	-.27			
Reading	Intercept	0.03	0.71	.83	-.33		
	Slope	0.05	0.04	-.40	.65	-.73	

Note: All correlations are significant at a 99.9% significance level. (Freund, Wolter, et al., 2021)

As the best fitting model, the LGM is described in more detail in Table 3. In this model, the average initial competences resembled the competences in Grade 9, with mean intercepts roughly at 0 and standard deviance being near 1 (though distinctively not at 1). The slope parameters indicated reduced development in mathematics and significantly slowed development in reading compared to lower secondary education. Indeed, using the same criterion as in the first study, average development is specialized on mathematics. Both cross-sectional competences (intercepts) and longitudinal competence development (slopes) correlated positively. However, correlations between the initial competences and the competence development can be seen as slightly negative (mathematics) or strongly negative (reading).

5.3 **Manuscript 3:** Predictors of reading and mathematics development of adolescent students in Germany: The effect of gender, interest, and educational specialization

The first and second papers did not find profiles of competence development, which lead us to a change of strategy. Following the goal of predicting specialization of competence development, the third paper aimed at predicting reading and mathematical competence development in upper secondary, vocational and tertiary education. The sample of paper two was selected as more specialization was expected in this age group and previous results showed an overall more specialized development.

The theoretical background of Paper 3 built on the previous argumentation on the prediction of specialization. Interest and job-specific education were included as aspects of different learning environments. A third predictor in this paper was gender, with previous results by Borgonovi et al. (2018) indicating growth advantages for male students in both domains. The theoretical background indicated that specialized interest and job-specific education positively affect competence development in the specialized domain. Meanwhile, the effect of gender was not expected to differ between both domains.

The imputation model of this analysis resembled the model from the second manuscript. Four regression analyses tested the effects of the predictors (gender, specialization of interest, and specialization of education) on intercept and slope of reading and mathematics - additional control variables included reasoning ability, HISEI, school type, and migration background. Due to the poor model fit of linear growth models, slopes and intercepts were estimated using latent change score analysis (LCS; Klopack & Wickrama, 2020). In contrast to the LGM, LCS includes an additional β-coefficient indicating the effect of earlier competences on competence development. The coefficient β was introduced to take initial competences into account, meaning slope parameters were interpreted as development for students with initial competence of 0.

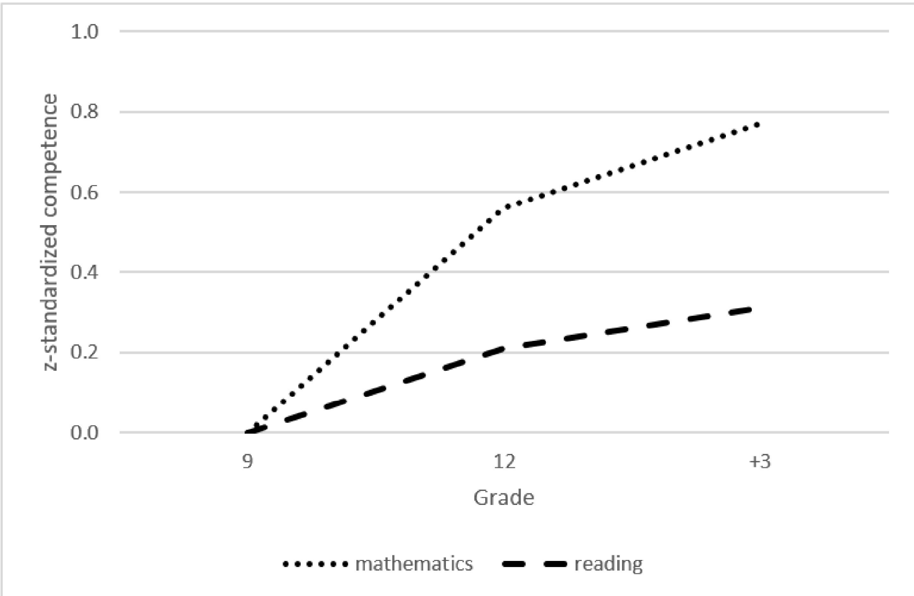

Figure 3. Competence development in reading and mathematical competence in and the 6 years following Grade 9. (Freund, Gnambs, et al., 2022)

As shown in Figure 3, competence development in upper secondary education slows down greatly after Grade 12. This development showed in the LCS parameters. Initial competences followed the z-standardized parameters with a mean of 0 and variance of 1 in both domains. Students on average exhibited constant development over 3 years of .23 (Var = .14) in reading and .57 (Var = .26) in mathematics. The difference between parameters of

LGM parameters in Paper 2 and of LCS underlined the non-linearity of development. The proportional growth factor β also indicated such non-linear growth with a β of -.64 in mathematics and -.62 in reading. Overall, these parameters showed that students with higher initial competences developed slower until Grade 12, and students with higher competences in Grade 12 developed slower after secondary education.

Table 4. Regressions of Growth Parameters

Independent variables	Dependent variables			
	Intercept in…		Slope in…	
	Reading	Mathematics	Reading	Mathematics
Gender[1]	-.15* (.02)	.25* (.02)	.04* (.01)	.22* (.02)
Specialization of interest	-.15* (.01)	.10* (.01)	-.05* (.01)	.07* (.01)
Mathematical education[2]	-.14* (.03)	.07 (.04)	-.05* (.02)	.14* (.02)
Generalized education[2]	-.17* (.03)	-.09* (.03)	-.05* (.02)	-.02 (.02)
Reasoning ability	.30* (.01)	.26* (.01)	.10* (.01)	.17* (.01)
Highest ISEI	.08* (.01)	.09* (.01)	.07* (.01)	.07* (.01)
School type	.62* (.02)	.87* (.03)	.26* (.02)	.34* (.02)
Migration background	-.30* (.02)	-.19* (.02)	-.11* (.02)	-.16* (.02)

Note. Standardized effects. Standard errors in brackets. [1]Coding: 0: girls; 1: boys. [2]Reference category for both variables is reading specialized education. * $p < .01$. (Freund, Gnambs, et al., 2022)

Table 4 displays the results of 4 different regression analyses with the two latent intercepts and the two latent slope parameters as dependent variables. All effects of metric predictors were standardized to allow comparison. As expected based on previous research (e.g., OECD, 2016b), gender differences in Grade 9 pointed to boys having initial advantages in mathematics and girls having advantages in reading. Specialized interest was positively and significantly related to the domain of specialization. Students that entered specialized education have higher initial competences in the domain of specialization. However, this effect was not significant for the mathematical intercept, indicating that students entering mathematically specialized education were not significantly better at mathematics than students entering reading specialized education.

The control variables affected intercept in both domains to a similar degree. Students not entering specialized education had the lowest competences in Grade 9. Students' reasoning ability had a (relatively) high positive effect on both domains indicating a high impact of cognitive abilities on these competences. Students from *Gymnasium* had distinctively higher initial competences, which fit the results of Paper 1 that students in a *Gymnasium* start with higher competences in Grade 5 and keep that advantage through parallel development at least until Grade 9. Finally, students with a higher social background and no migration background had higher initial competences in both domains.

Effects of the predictors on the linear development fit our expectations. Specialization of interest and education each positively affected the domain students specialized on. Meanwhile, specializing through education in one domain did not lead to disadvantages in developing the opposite domain compared to unspecialized education. Boys developed faster in both domains in this age group. However, effect sizes pointed to a much higher gender effect for mathematics. This gender effect thus fit both previous cross-sectional research of initial gender differences and fit the previous results by Borgonovi et al. (2018) of a developmental advantage for boys in both domains in this age group.

Higher reasoning ability also significantly affected students' development, with a slightly more substantial effect on growth in mathematics. For students with initial competences at zero, a higher social background had a positive, and migration background had a negative effect on both domains. This result showed that background characteristics still play a role in competence development when the effects of initial competences are controlled. The same was also true for school types, with students in *Gymnasium* developing faster when controlling for initial competences.

6 Discussion

Finally, these results must be interpreted regarding overall trends, previous research, and the formulated research questions. This interpretation is divided into three parts, first looking at overall development and specialization, then at predictors of this specialization, and finally at the impact of the diversified secondary education. In addition to examining the results, several changes and additions are proposed for future research.

6.1 Development of reading and mathematical competences

The first manuscript showed a high overall development in both domains. However, the second manuscript saw a developmental decrease in upper secondary education, with lower average development in both domains. Additionally, development of reading competences was distinctively lower than development in mathematical competences. While development in early secondary education seemed linear, this changed significantly in upper secondary education. Development of reading competences slowed down after Grade 9 and even further after Grade 12. Development in mathematics slowed down after Grade 12.

In addition to the growth of reading competences, variance in reading decreases throughout secondary education. While the seventh-grade variance was above the fifth-grade variance, the ninth-grade variance was lower. After ninth grade, the variance of reading competences decreased much faster, with variance in Grade 12 being only at .65 and variance three years later being down to .60. This effect is even more substantial considering that this group is standardized according to competences in Grade 9, which should have lower variance than fifth-grade levels.

Table 5 shows the mean and standard deviance of competence throughout secondary education. In this comparison, competences of upper secondary education were standardized according to competence distribution in Grade 9 of Starting Cohort 3 (used in the first manuscript). This table visualizes the development from Grade 5 to three years after Grade 12 with the caveat that two different populations are likely not fully comparable. Interpreting this estimated overall development confirms the previous expectation of a decreased growth in upper secondary education in both domains. In addition, it supports the drop in reading development found previously. Finally, this simulated dataset also indicates that variance in mathematical competences stays near Grade 5 levels, while heterogeneity of reading competences decreases significantly in adolescence.

Table 5. Means, standard deviation and growth per year of competences from Grade 5 to after secondary education.

	Grade	*M*	*Growth per year*	*SD*
Mathematics	5	0.00	-	1.00
	7	0.56	0.32	1.07
	9	1.32	0.34	1.04
	12	1.90	0.19	0.95
	12+3	2.12	0.07	1.03
Reading	5	0.00	-	1.00
	7	0.55	0.27	1.08
	9	1.00	0.23	0.89
	12	1.19	0.06	0.72
	12+3	1.28	0.03	0.69

*Note***.** This table uses competences in grade 5, 7 and 9 from the first manuscript (based on Starting Cohort 3) and for the last two measurements from the second manuscript (based on Starting Cohort 4) corrected for standard deviance and mean in Grade 9 from Manuscript 1.

These observations point to a ceiling effect in reading after Grade 9 and mathematics after Grade 12. The bottom end of the reading distribution closes in on the top end, leading to decreasing variances. The ceiling in reading would also point to general education reaching its goal of teaching the essential abilities needed to survive in modern society. The average development also slows down towards the end of schooling for mathematical ability.

However, heterogeneity stays high, indicating that some students leave school without basic mathematical competences or that some students have even higher than needed mathematical competences. This could be an early indicator of the effects of occupational specialization. While a certain level of reading competences is necessary across careers, different mathematical competences might be necessary for different careers, leading to higher remaining variances.

Due to the higher competence development in mathematics than in reading, the overall development in secondary education was increasingly specialized on mathematics. This specialization resulted from higher initial mathematical competence development for the average student and an earlier decrease in reading growth over secondary education. As will be indicated by the predictors in the following chapters, some students are more likely than others to specialize on mathematics. On the other hand, other students are more likely to develop at least as fast in reading as in mathematics. However, latent groups of differing specialization could not be identified.

The non-existence of profiles did not fit with previous studies finding differently specialized groups of students in cross-sectional education (e.g., Jordan et al., 2002; OECD, 2016a), groups of students with opposite differences in competences (gender: e.g., OECD, 2016b) and specialization of affective-motivational characteristics (i.e., interest: Ehrtmann et al., 2019; motivation: Parker et al., 2014). Ultimately, while specialized development did not lead to profiles of competence development, these results do not rule out a variance of specialization. Indeed, the results only showed that the overall distribution of competence development in reading and mathematics was explained best by one overall distribution of students. This distribution still differed in its degree of specialization between students. Nonetheless, the first research question can be answered negatively: different groups could not be identified.

6.2 Predicting student-specific development trajectories

The differences in specialization can be analyzed to see which predictors influence specialization. Student characteristics that would likely lead to specialized development can be identified by predicting development in reading and mathematics. The regression analyses conducted in the third manuscript showed which characteristics affect initial competences and development in both domains. Characteristics that positively affect one domain and do not affect the other positively can be seen as predictors of specialization. Comparing predictors on initial competences helps identify cross-sectional predictors of competence specialization; comparing predictors of competence development indicates groups with developmental competence specialization.

Some factors affected both domains to a similar degree. As noted before, the parental background of students and other mutually relevant abilities could all be seen as factors resulting in general development. The parental background was previously shown to affect competences throughout educational careers (Larson et al., 2015; OECD, 2019). Therefore, it is no surprise that the third study showed a high ISEI (i.e., parental occupational status) having a nearly identical effect on both domains. Furthermore, students with higher social background have a higher mean competence in both domains in Grade 9.

The developmental effect of increased development for students with higher social background might be more surprising. However, the specifics of the model may explain the existence of this effect as the model takes previous competence differences into account. Students with a higher social background seem to have an advantage over students with a lower social background with the same initial competences. While it would be reasonable to assume that parental background has decreasing effects on competence development later in educational pathways, it is also reasonable that parental background is still relevant for development in any competence domain.

Abilities such as working memory (e.g., Peng et al., 2020), reasoning ability (e.g., Peng et al., 2020), or fluid intelligence (e.g., Peng et al., 2019) could also be argued to affect competence in both reading and mathematics. The regression analyses of the third manuscript take one of these abilities into account by looking for the effect of reasoning ability on both domains. As expected, reasoning abilities affect competences in both domains to a similar degree in Grade 9. However, over time, the effect of reasoning ability on mathematical development is more substantial, indicating that mathematical learning might require reasoning ability more than the development of reading competences. Nonetheless, reasoning – and likely other underlying student abilities – is relevant for competence development in both domains.

Gender was previously argued to have differentiated effects between Grades 5 and 9 and similar effects after Grade 9 (Borgonovi et al., 2018). The effects of gender on development between Grades 5 and 9 were not examined in the first manuscript (the only study focusing on this age group). However, initial gender differences among Grade 9 students suggest that girls develop faster in reading and boys faster in mathematics at some point prior to Grade 9. Similar effects of gender were already seen on competences in Grade 5 (in the attrition analysis of paper 1). It is thus unclear whether the gender differences develop during or prior to lower secondary education.

The effects of gender on competence development indicated an advantage for boys in reading and mathematical competence development when considering initial competence differences. However, boys develop only slightly faster in reading than girls with similar initial reading competences. Meanwhile, boys develop much faster in mathematics than girls with the same initial competences. This result could be significant for analysis and policy towards mathematical gender differences among adults as neither the mathematically specialized occupations nor the higher interest of boys in mathematics explains the effect.

Finally, interest is closely connected to competences in any domain (e.g., Denissen et al., 2007). As such, specialized interest (as found in Ehrtmann et al., 2019) should be connected to a more specialized competence and development. Indeed, the higher a student's reading interest compared to their mathematical interests were in Grade 9 (or the more specialized a student's interest in reading), the higher their initial reading competences were. Furthermore, the specialization of interest was still relevant for the development of competences, though to a distinctively lesser degree. Overall, the effects showed that specialization of interest is connected to the specialization of competences. Specialized interest was thus one of the factors identified to affect student specialization, along with gender and (see below) specialized education.

6.3 Education as a factor for specialization

Beyond student characteristics, this dissertation was interested in the effect of education on competence development. This educational specialization increases in upper secondary education, leading to the third research question of whether specialization of competence development also increases throughout secondary education. Indeed, a minor mathematical specialization found in the average development between Grades 5 and 9 turned into an explicit mathematical specialization after Grade 9. However, very few students specialized on reading. Instead, students ranged from generalized to highly mathematically specialized development. Overall, this result answers the research question: While groups of specialized development do not materialize throughout secondary education, the overall development becomes more specialized.

Educational effects on specialization should also be examined in lower and upper secondary education. In lower secondary education, differentiation (and thus the potential for specialization) can mostly be found in different school tracks. However, students in a higher track (*Gymnasium*) were not expected to develop differently (regarding specialization) from students in a lower track (e.g., *Hauptschule*, *Realschule*) due to all tracks being based on general education goals. Indeed, the subgroup analysis in the first manuscript showed a similar development of students in the highest track and the overall sample. External tracking did not change developmental trajectories. Germany's small amount of internal tracking within schools explains why neither track allowed for specialization.

Tracking in upper secondary education has very different characteristics. Students in different tracks are either in vocational or in general education. It is quite obvious, that this kind of tracking did make a difference in competence specialization. Students in specialized vocational did develop faster in their domain of specialization, indicating an effect of tracking and of specialized education. A reason for the overall specialization on mathematics might be found in the differences in the number of specialized courses for mathematics and reading. When looking for specialized courses, VET training, study areas, and vocations, it was much easier to use the existing definition of STEM than to find a definition of reading specialized learning environments.

Regarding reading specialized education, another factor must be considered: Most reading specialized education students were initially in *Gymnasium*, as most reading specialized learning environments were university courses (language and cultural studies). Thus, while students in reading specialized education did develop significantly faster than other students, this might be due to these students being more likely to attend university than the other two groups. Meanwhile, STEM-focused VET is quite common, leading to roughly the same ratios of students in mathematically specialized education among students initially in *Gymnasium* and other school tracks.

These analyses showed that mathematically specialized learning environments affect mathematical development. This is also true for reading specialized learning environments affecting reading competence development, though with a smaller effect size likely due to the type of education and initial competence differences. Meanwhile, specialized learning environments do not negatively affect development in the opposite domain. Analyses from lower secondary education showed that different general education tracks do not differ distinctively in student specialization. The results could answer the fourth research question: Students in specialized education are more likely to develop in a specialized manner.

6.4 Areas of improvement for future studies

Many potential changes and improvements could be made throughout the three manuscripts described in this dissertation. Changing these aspects might help answer the additional questions relevant for this research, they might help improve the result's precision, or further research by looking at these topics through a different lens. These changes include changing the dataset, the model, or different operationalization of the variables.

An obvious approach to changing the setting of future research is using a different dataset. While the NEPS has extensive and well-crafted longitudinal datasets, different datasets could offer an interesting extension to the present results. Using data from a different educational system or even international data from multiple systems would increase the knowledge of educational effects on specialization. For example, systems with internal tracking (i.e., students within a school being sorted by ability in each class) could offer entirely different specialized learning environments. As a result, students with initially specialized competences might be more easily able to specialize even further in these systems. Another chance for future research would be analyses based on the entire secondary education in one sample. An analysis of the entire secondary education or even all education (from kindergarten all the way to tertiary education) would help visualize at what points specialization emerges. Similarly, a dataset with more regular competence tests (e.g., one per school year) would show a more in-depth look at the intricacies of competence development.

Any study similar to the present studies might also change the competence development model. The third study shows that a linear approach to competence development can be questioned, at least in upper secondary education. Non-linear approaches (including an additional quadratic growth factor or a latent change score analysis) might improve the overall model fit. One interesting approach to visualizing the development of competence specialization could include latent transition analysis (Lanza et al., 2013), specifically a transition analysis between specialized and unspecialized profiles.

One variable that could be coded differently is specialized education. The variable did predict development in reading and mathematics differently. However, we did not include all aspects of specialized education. Specialized education within general education (i.e., course selection or the focus of schools) could not be analyzed with the current dataset due to missing information or substantial differences between states. Future studies should focus on the specialization opportunities within general education. Future studies might also want to differentiate between specialized education in vocational and tertiary education. For example, high reading competence might be more of a necessity across university courses than across vocational education courses. Finally, a more objective approach to the categorization of job-specific education could be applied. For example, one might take a competence-based approach, first analyzing which competences are needed in the actual jobs and then categorizing the jobs by the needed competence structure.

Outside of education, interest was used as a proxy for learning environments and learning focus outside of school. While domain-specific interest has its own reasons for affecting competence specialization, out-of-school learning environments might be approached more directly. Relevant aspects include homework effort, hobbies, leisure-time activities, topics of books read by the students, and the specialized cultural capital of the parents. If a complete analysis of these factors goes too far, the current analysis might also be enhanced by including domain-specific motivation or self-concept as affective-motivational factors beyond students' interests.

Changes to the assessment, scaling, and selection of competences could advance the current research. For example, while the NEPS competence tests have a high quality, they are overall relatively short. Utilizing more extended tests would help differentiate competence distributions at both distribution ends. Adaptive competence tests could also add further precision to current competence measurements. Finally, the selection of reading and mathematics competences could also be questioned for future studies. While reading and mathematics are essential competences necessary for many problems, domains, and learning environments, they may not be the main focus of upper secondary education. It could be argued that different competence domains, such as foreign language, writing skills, scientific skills, or ICT ability, should be chosen and compared instead.

Finally, the comparability of any two competence domains can always be questioned. As noted previously, competences in reading and mathematics were both standardized on the initial competences and the initial competence distribution in Grades 5 and 9. Whether these distributions are comparable is not certain. Longitudinally, any linked competences are linked based on the initial variance, meaning an overall improvement of 1 indicates an improvement of the entire sample of one Standard Deviation. Ultimately, this dissertation cannot answer how to improve this comparability with a different approach to competence operationalization. As of now, the results have to be interpreted as development relative to the initial distribution. This interpretation does still allow for the interpretation of specialization. However, specialization must be interpreted relative to the overall initial student population.

7 Conclusion and Outlook

The central aim of this dissertation project was to increase the current knowledge of competence specialization. Competence specialization was analyzed in reading and mathematics through secondary education and early adulthood. The first approach was to identify latent profiles of competence development in lower and upper secondary education. Such latent profiles could only be identified at insufficient sizes, concluding that the students' development was best explained as one overall group. With increasing time, this overall group could be described as increasingly specialized on mathematical competences. Reasons for the non-identification of multiple profiles might lay in the overall general educational system up to Grade 9 or the high ratio of students in unspecialized education after Grade 9. Additionally, the relationship between specialized education and specialized initial competences might mean that specialized development is more challenging for initially specialized students.

Overall, profiles would require a substantial deviation from the mean development of a large population. While some students focus more on one domain than the other or develop more quickly or slowly overall, these students do not form sizeable groups. This homogeneity of development might be a positive aspect of the German educational system. After all, students need to reach a basic level of competence to compete on the labor market and join the modern society. These minimum abilities should be acquired in general education, leading to a goal of similar and unspecialized development.

This overall homogeneity does not mean that specialization does not exist. On the contrary, the overall sample trends towards specialization. Competence development standardized on a z-standardized test might not be comparable across domains. However, even with this restriction, a higher development in mathematics – relative to the initial competence distribution – can be interpreted as overall specialized development. Within this group, some students develop even more specialized on mathematics, some unspecialized, and some specialized on reading.

The second approach to describing specialization was predicting these differences within the overall group. This approach allows for identifying student characteristics typical for students that develop faster in one domain and thus develop in a specialized way. Specialized education and specialized interest were identified as characteristics affecting development in the two domains in opposite directions. Gender exhibited differing effect sizes in the same direction, with male students having a slight advantage in reading and a considerable advantage in mathematics. The effects of specialized interest and education might be seen as a success of the educational system. While the overall student population should not develop faster in one domain due to generalized goals of education, students that want to specialize should be able to. Being more interested in one domain and choosing education specialized on that domain shows that a student wants to focus on that domain or topics related to that domain.

Overall, the German educational system does prepare students for a modern, specialized labor market by setting a general minimum competence while allowing students to specialize through job-specific education. This educational focus fits with the specificities of the German labor market - a market with entry difficulties but strong labor protection. A specialized job-specific education prepares students for one specific job in which they have clear paths to employment. However, in the case of career changes due to changing market situations, digitalization, or globalization of work processes, the German system provides students with a level of general competence that likely is not sufficient for free job selection. When other applicants are trained for a specific job, students with only general education might not be competitive when applying for that job.

Besides the educational system, the results also showed some conclusions regarding gender differences. While male students closing the gap in reading competences might be an overall desired outcome, male students strongly expanding their advantage in mathematical competences likely is not. These male advantages are especially problematic from the perspective of male and female access to STEM occupations. Women are still clearly underrepresented in STEM studies and occupations (e.g., Ertl et al., 2019; Jacob et al., 2020; Federal Ministry of Education and Research (BMBF), 2015; Quaiser-Pohl, 2012), leading to disadvantages on the labor market. Decreasing the gender differences in competence specialization could be one way to improve women's access to STEM careers. Future research should focus on the reasons, mechanisms, and outcomes of male mathematics specialization (including educational decisions).

Future research might also investigate cross-sectional specialization or specialization as a predictor of further outcomes. The analysis of transitions between profiles of cross-sectional specialization offers one possible way to identify longitudinal specialization. For example, if some students start with generalized competences and end up specialized, the reasons and influences on these changes should be analyzed. On the contrary, students with initially specialized competences that develop towards generalized profiles could offer interesting insights. Meanwhile, regarding specialization as an outcome, adults with specialized competence profiles could differ in life satisfaction or labor market success from adults with more distributed competence profiles. Finally, future research might focus on educational decisions leading to these specialized profiles and using the potential benefits of specialization.

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Profiles of competence development in mathematics and reading in early secondary education

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Abstract

This article examines the development of reading and mathematical competence in early secondary education and aims at identifying distinct profiles of competence development. Since reading and mathematical competences are highly correlated both cross-sectionally and longitudinally, we expected to find a generalized profile of competence development with students developing parallel in reading and mathematical competences. Moreover, previous research confirmed individuals' specific focus on one of the two domains, for example, in their interest, self-concept, or motivation. Also, differences in competence levels between both domains were found in cross-sectional studies. Therefore, we hypothesized that additional to the generalized profile, there are specialized profiles of competence development with students developing distinctively faster in one of the two domains. To identify both types of profiles, latent growth mixture modeling was used on a sample of 5,301 students entering secondary education from the German National Educational Panel Study. To demonstrate the robustness of the results, these analyses were repeated using different model specifications and subgroups with higher homogeneity (with students belonging to the highest track, i.e., "Gymnasium"). The results indicate only small to non-existent specialized profiles of competence development in all conditions. This finding of roughly parallel development of reading and mathematical competences throughout early secondary education indicates that potential specializations are less important at this point in students' educational careers.

Keywords Competence development · Reading competence · Mathematical competence · Competence profiles · Latent growth modeling · Mixture modeling

Introduction

Language and mathematical abilities are the key competences for successful participation in modern society. Competences in the native language, including the ability to handle written language efficiently, are critical for learning and communication (OECD,

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2003a; Weinert, 2006), and basic mathematical competences are indispensable for higher education and many work environments (Weinert et al., 2019). Therefore, the causes and conditions of competence development have been subject to intense research and debate. Numerous studies highlight the importance of, for example, individuals' socio-economic background (e.g., Morgan, Farkas, & Hibel, 2008) and gender (e.g., LoGerfo, Nichols, & Chaplin, 2006) for the development of domain-specific competences. Furthermore, cross-sectional findings show that mathematical and reading competences are correlated and, thus, seem to share a common core (e.g., Shin et al., 2013).

Based on the literacy approach as defined, for example, in PISA, reading competence refers to the "understanding, using, reflecting on and engaging with written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society" (OECD, 2009, 14). Mathematical competence encompasses "an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgments and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD, 2003b, 24). Till date, the association between the two competence domains has rarely been analyzed in a longitudinal context to evaluate similarity and uniqueness in their developmental trajectories. Little is known about how reading and mathematics competences develop in relation to each other within students, and it is still an open question whether the development in reading and mathematics is parallel in most students or whether there are groups of students who specialize in reading or mathematics. Therefore, this study focuses on the joint changes in students' mathematical and reading competences across a period of 4 years. Particular emphasis is placed on the identification of characteristic change profiles to uncover students exhibiting similar change trajectories in both domains (parallel development) and students showing more pronounced changes in one compared to the other (specialized development).

This might allow the identification of unobserved risk groups of students that exhibit weaknesses in specific competence domains (e.g., students falling behind in one domain in comparison to another domain or students falling behind in both domains due to overall slow development) or groups that exhibit increased development in one specific competence domain with average development in the other domain. A person-centered approach with analyzing profiles of competence development in lower secondary education allows to estimate the impact on later educational and career decisions as well as development in other areas and by that to discuss practical implications and interventions to provide educational equity. Students falling behind in one or both domains might need further support to keep up with their classmates. On the contrary, students with an increased development in one domain might utilize further fostering in that domain to build on their strengths. Against the background of person-environment fit theories (e.g., Kristof-Brown, Zimmerman, & Johnson, 2005), a certain level of specialization might be helpful for later career success in specific areas of the labor market; however, it might also be hindering for an unconstrained access to other fields of study or at the labor market.

Moreover, identified profiles might later be analyzed to find out which student characteristics (e.g., gender, migration, and socio-economic background) might affect the specialization of students and how the specialization of student competences in return might affect student decisions. However, any analyses of such groups require prior identification of profiles. As such, the goal of this article is to identify distinct profiles of competence development. To account for profiles being observed only due to different school types, subgroup analyses also examine competence development among students from the highest track of the German education system (i.e., "Gymnasium" or the equivalent track of the comprehensive school).

Competence development in mathematics and reading

Most studies show a consistent, if not steady, increase in mathematical and reading competences during different stages of students' educational careers (e.g., Rescorla & Rosenthals, 2004; Shin et al., 2013). Consistent development has been shown throughout elementary and secondary education, for example, between third and tenth grade (Rescorla & Rosenthals, 2004) and between fourth and seventh grade (Shin et al., 2013). Moreover, the relationship between reading and mathematics has been well documented (Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Jordan et al., 2002). Studies report that competences in reading and mathematics are already related in preschool age (Duncan et al., 2007) and the correlation remains high throughout the educational career (Hooper et al., 2010).

It has also been shown that the development of reading and mathematical competences influence each other. For example, Shin et al. (2013) reported a cross-sectional correlation between competences in reading and mathematics with $r=0.90$ at Grade 4 and a correlated change up to Grade 7 with $r=0.55$. Interestingly, this study also shows that initial competences in both domains are slightly positively correlated with development in mathematics but slightly negatively correlated with development in reading. In a study by Adelson et al. (2015), mathematical competence was found to increase between 0.39 and 0.46 standard units for one unit change in reading competence between Grade 3 and Grade 11.

There are multiple explanations for the correlation between mathematical and reading competence. Reading competence is necessary to make progress in mathematics. Reading and language competences influence mathematical competence because they are not only important for any kind of learning (e.g., Weinert, 2006), but also necessary for mathematical problem-solving in more specific ways (e.g., Abedi & Lord, 2001; Korpershoek, Kuyper, & van der Werf, 2014). The ability to comprehend the language used in mathematical problems (e.g., statements expressing the relation between variables) affects a student's ability to solve them (Lewis & Mayer, 1987). Moreover, understanding number of words or verbal counting strategies facilitates solving mathematics tasks (Jordan et al., 2002). As noted by Geary (1994), language is especially important for mathematics in the middle school years when students have to develop mathematical reasoning skills and master complex mathematical procedures. Consistent with the view that language and reading competences are preconditions for solving mathematical tasks, many studies show that initial reading competence impacts mathematical competence development (e.g., Chen & Chalhoub-Deville, 2016; Jordan et al., 2002; Purpura, Hume, Sims, & Lonigan, 2011).

Furthermore, both mathematical and reading competences are influenced by the same underlying abilities or skills. Cognitive skills such as short-term memory, working memory, and executive functioning are important preconditions for both reading and mathematical competences (e.g., Alloway, Gathercole, & Pickering, 2006; Bull, Espy, & Wiebe, 2008; Knievel, Daseking, & Petermann, 2010). Additionally, the socio-demographic characteristics of students are related to competence. One of the main socio-demographic characteristics, the socio-economic background, affects educational attainment through primary effects (Boudon, 1974), which involves the initial differences in competence levels between students from high and low socio-economic backgrounds at the beginning of education.

These primary effects of socio-economic background strongly affect both mathematics and reading competences (e.g., OECD, 2019).

Moreover, the development of reading and mathematical competences might also be affected by schooling. A central aspect of the German education system is tracking students into school types based on achievement and, in some states, parental choice after Grade 4 (Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany, 2015). Therefore, the level of schooling in German and mathematics should not differ within a school, as additional tracking within schools is rare. Similarly, the hours of mandatory schooling for both German and mathematical education is similar or identical in all school types across the German states (Avenarius et al., 2003, p. 94ff.). Finally, while composition effects might affect the development of competences (e.g., Kiss, 2013), the ability level of classmates in German and mathematics should be more homogenous than between classes from different school tracks. All these factors additionally point to a common development of reading and mathematical competences in secondary education. Thus, reading and mathematical competences seem related through cognitive skills, socio-economic background, and schooling, pointing to parallel development of mathematical and reading competences in early secondary school.

Typologies of competence development

While the overall mathematics and reading abilities of students seem highly correlated, some students might still show intra-individual differences in the development of the domains. Cross-sectionally, some students can be described as better in mathematics or reading (e.g., Jordan et al., 2002; OECD, 2016a). Jordan et al. (2002) show different groups in a sample of second graders, with learning difficulties in both reading and mathematics (23% of students), learning difficulties in only one of the domains (25% in reading, 26% in mathematical difficulties), or without learning difficulties (26%). The results of the Programme for International Student Assessment (PISA) of 2015 (OECD, 2016a) also imply that some students are low performers in only one of the domains. As these differences between domains exist cross-sectionally, these students must specialize in their competence development at some point in education.

Although longitudinal studies showing groups of students specializing in one domain are scarce, several cross-sectional studies show groups of students with specialized competences. Gender-based differences in both mathematics and reading can be shown (e.g., OECD, 2016b), with 15-year-old boys in most countries having a higher average competence in mathematics than girls, whereas girls have a higher competence in reading than boys. Longitudinally, multiple studies show that this gender-based difference in competences either increases in primary education and stagnates (LoGerfo et al., 2006) or decreases (Robinson & Lubienski, 2011) in secondary education.

Regarding the ethnicity of students, empirical studies in the education system of the USA imply a larger disadvantage of students of color in reading competence development than in mathematical competence development (LoGerfo et al., 2006). However, students with a migration background in Germany show roughly the same initial disadvantage and faster development in both reading (Wendt et al., 2010) and mathematical (Guill et al., 2010) competences between fourth and eighth grade. Overall, results on both gender and ethnicity might imply that some students specialize in either mathematical or reading competence (leading to a change in the overall group); however, the limited results on migration background in Germany regarding intra-individual differences of students in reading and mathematics do not imply a specialization.

Specialization of affective-motivational factors

While research showing intra-individual differences regarding competences is rare, expectations on specialization might be drawn from research in related fields. Research on affective-motivational factors (e.g., self-concept, motivation, and interest) points in the direction of some specialization. Domain-specific motivation (e.g., McElvany et al., 2008; Stanat, & Kunter, 2002; Wolter, Braun, & Hannover, 2015), self-concept (e.g., Gogol et al., 2017; Wolter, & Hannover, 2016), and interest (e.g., Denissen, Zarrett, & Eccles, 2007) are all highly correlated with competence. However, there are also intra-individual differences in self-concept, motivation, and interest for mathematics as compared to reading, which indicates a specialization towards one of the domains. For example, some students can be seen to have a specialized interest profile (Ehrtmann, Wolter, & Hannover, 2019). Similarly, Parker et al. (2014) show a negative correlation between the development of self-concept in mathematics and reading between seventh and 11th grade in Australian high school students, signifying a specialization in one of the domains.

Based on previous research showing the relationship between affective-motivational student characteristics and competence in mathematics and reading (Denissen et al., 2007; Gogol et al., 2017; McElvany et al., 2008; Stanat, & Kunter, 2002; Wolter et al., 2015; Wolter, & Hannover, 2016), we argue that if students differ in domain-specific self-concepts, motivation, or interest, this would be reflected in domain specificity in their competence development. It is plausible to presume that a student who is highly motivated in reading rather than in calculating (and other mathematical tasks) will invest more time and effort in reading and writing than in mathematics. This additional time and effort might come in either the students' leisure time with activities such as reading a book or solving a puzzle or at school with a higher effort in class or with additional tasks such as homework. Additional effort should then lead to a higher gain of competence in this domain. This higher competence development could, in turn, lead to a higher self-concept and motivation for reading and language studies compared to mathematics (e.g., Denissen et al., 2007).

Research question

The study aims to identify generalized and specialized profiles of competence development in mathematics and reading in lower secondary education. Based on the empirical background, we expected both generalized and specialized competence development. Overall, we expected to identify three profiles of competence development: one generalized and two specialized profiles. Students in the generalized profile of competence development show similar development in mathematics and reading. Conversely, students in the specialized profiles of competence development develop distinctively faster in either reading or mathematics.

Methods

Sample and procedure

Participants were part of the German National Educational Panel Study (NEPS; Blossfeld et al., 2011) that follows representative samples of students across their life courses. Students were sampled based on a multi-stage stratified cluster design (Steinhauer, Aßmann, Zinn, Goßmann, & Rässler, 2015) and then tested in grades five, seven, and nine between the winter of 2010/2011 and the spring of 2015. The sample included $N = 5{,}201$ students (48% girls) to provide a valid response to at least one mathematical or reading competence item in Grade 5. On average, the students were 10.90 years old ($SD = 0.53$). About 46% attended the highest secondary school track ("Gymnasium") in Germany. The tests were administered in the students' school classes by trained test supervisors. Details on the administration procedure can be found on the NEPS homepage at https://www.neps-data.de.

Instruments

Mathematical competence was measured with paper–pencil tests specifically developed for use in the NEPS. The underlying framework of the tests differentiates between four mathematical content areas, that is, quantity change and relationship, space and shape, data, and chance, and six cognitive components, that is, mathematical communication, mathematical argumentation, modeling, using representational forms, mathematical problem solving, and technical abilities and skills (see Neumann et al., 2013). The mathematical tests were administered at the beginning of Grades 5, 7, and 9 and included 25, 23, and 23 items respectively, requiring either multiple choice or short constructed responses. The test duration was limited to 28 min for all tests in all waves. All tests were scaled using models of the item response theory (Pohl, & Carstensen, 2012) and linked across grades with the help of overlapping items to allow for meaningful longitudinal comparison (Fischer et al., 2016. Students' proficiencies were derived as weighted maximum likelihood estimates (WLE; Warm, 1989) and *z*-standardized according to the mean and standard deviation in fifth grade. Marginal reliabilities for the students of Grades 5, 7, and 9 were 0.78, 0.72, and 0.81, respectively. Further details on the psychometric properties of the administered tests are given in Duchhardt and Gerdes (2012) for fifth grade, Schnittjer and Gerken (2017) for seventh grade, and van den Ham et al. (2018) for ninth grade.

Reading competence was measured with paper–pencil tests comprising five text functions, that is, commenting, information, literary, instruction, and advertising, and three comprehension requirements, that is, finding information in text, drawing text-related conclusions, and reflecting and assessing (Gehrer, Zimmermann, Artelt, & Weinert, 2013). The tests were administered at the beginning of fifth and seventh grade and towards the end of ninth grade (half a year after the mathematical test). In Grade 5, the test comprised 33 items (Pohl et al., 2012). Seventh grade onwards, branched testing was used that assigned different test versions depending on previous performance. The tests comprised of either 29 or 30 items in seventh grade (Krannich et al., 2017) and either 32 or 33 items in ninth grade (Scharl et al., 2017). Again, the test duration was limited to 28 min for all tests. Reading tests were linked using independent linking studies, which included items from two grades (Fischer et al., 2016). The marginal reliabilities for the students of Grades 5, 7, and 9 were 0.77, 0.79, and 0.79, respectively. Students' proficiencies were derived as

WLEs (Warm, 1989). For the sake of comparison, these were *z*-standardized according to the mean and standard deviation in fifth grade.

Auxiliary variables included socio-demographic and educational information such as gender, age (in years), school type, and region of schooling (former West or East Germany), as reported at the first measurement point in Grade 5. Parental background variables at the first measurement point included the International Socio-Economic Index of Occupational Status (ISEI-08; Ganzeboom, 2010), and the highest number of years of education (Comparative Analysis of Social Mobility in Industrial Nations (CASMIN); König, Lüttinger, & Müller, 1988) of the parents. Migration background was taken into account by noting whether the student or at least one parent was born in a country other than Germany and by the dominant language spoken in different contexts. Finally, domain-specific self-concept and interest as well as reasoning skills were acknowledged. A detailed description of these variables is given in Tables 1 and 2 of the supplement.

Statistical analyses

Change analyses

Changes in mathematical and reading competences across 4 years were analyzed using latent growth models (LGM; McArdle, 1988). In these models, the development of students' competencies can be described by the mean (*M*) and standard deviation (*SD*) of their initial competence (i.e., the intercept) and the development over time (i.e., the slope). Both competences were analyzed in a single model specifying a dual-process LGM and estimating two slopes and two intercepts at the same time (see Fig. 1 in the Appendix). The analyses were conducted in Mplus version 8.2 using a robust maximum likelihood estimator (Muthén, & Muthén, 1998–2017). The respective syntax is available in an online repository (online at OSF: https://www.osf.io/5h2v3/?view_only=f5ec8677be66491eb798c5cc8467b47f).

Mixture modeling

Profiles of competence development were identified using latent growth mixture models (LGMM; Muthén, Asparouhov, & Rebollo, 2006; Muthén, & Shedden, 1999). This method helps identify groups of students differing in their slope or intercept. Since the focus was on the development of students, Model 1 used only the mean slopes of mathematical and reading competences to allocate profiles of competence development. The intercepts in both domains were constrained across all profiles. To examine how strongly competence development depended on initial competence levels, the intercepts were no longer constrained in Model 2. Both models were examined twice: once with all students as described in the sample and once only with students attending the highest educational track in the German educational system (i.e., 2,369 students attending "Gymnasium" or an equivalent track of the comprehensive school). Similar subgroup analysis for other school types is very difficult, as these types (i.e., Hauptschule, Mittelschule, and Realschule) are far less homogeneous across the German federal states.

Missing values

These were acknowledged using a full information maximum likelihood procedure (FIML; Enders & Bandalos, 2001), which uses all observed information for model estimation. To improve the accuracy of the algorithm, a number of auxiliary variables were included. Attrition analyses showed that all included auxiliary variables except gender predicted the likelihood of dropping out (see Table 3 in the supplement) because the theory-guided variable selection considered only predictors which were expected to be correlated with dropout propensity or competences scores. In addition to the auxiliary variables, the competence scores themselves were also included in the estimation of missing values, as students with initially lower competence are generally more likely to drop out.

Model selection

Three criteria were used for model selection. Lower values of the Bayesian Information Criterion (BIC; Schwarz, 1978) indicate a better model and, thus, help identify the true number of profiles (Nylund, Asparouhov, & Muthén, 2007). The Lo-Mendell-Rubin likelihood ratio test (LMRT; Lo, Mendell, & Rubin, 2001; Vuong, 1989) checks whether a model with k profiles fits the data significantly ($\alpha = 0.05$) better than a model with k-1 profiles. Finally, only models with group sizes including at least 5% of the entire sample were considered, since smaller groups are difficult to interpret and replicate in other samples. Entropy was not used as a selection criterion but can help in measuring the quality of the identified profiles.

Interpretation of profiles

The difference between the slopes of mathematics and reading was taken to interpret the meaningfulness of domain-specific competence development. Profiles with a difference between mathematics and reading slopes smaller than the average development of students in a domain within half a school year (roughly 0.137 as seen in the LGM) were interpreted as generalized profiles. Profiles with a larger difference were interpreted as specialized.

Results

Descriptive analyses

The mean, variance, and correlation of the competence measures are provided in Table 1. From the figure, it can be seen that both domains developed by more than one standard deviation over 4 years. The growth between Grades 5 and 7 and between Grades 7 and 9 was mostly equal, with each domain indicating relatively linear growth on average. The standard deviation in both domains was relatively stable over time. Table 1 also shows that reading and mathematics scores were highly correlated at each of the three measurement points, with a slight decrease of the correlation from Grade 5 ($r = 0.64$) to Grade 9 ($r = 0.58$). Furthermore, the stability of inter-individual differences over time was substantial in both domains, ranging from $r = 0.71$ to $r = 0.74$ for mathematics and $r = 0.59$ to $r = 0.64$ for reading.

Table 1 Means, standard deviations, and correlations of competences across grades

	Grade	*N*	*M*	*SD*	Correlation					
					Mathematics			Reading		
					5	7	9	5	7	9
Mathematics	5	5,193	0.0	1.0						
	7	3,829	0.7	1.1	.74					
	9	2,854	1.4	1.0	.71	.74				
Reading	5	5,193	0.0	1.0	.64	.58	.57			
	7	3,833	0.6	1.1	.55	.60	.58	.61		
	9	3,116	1.1	0.9	.53	.52	.58	.59	.64	

Competence scores were *z*-standardized within domain with respect to Grade 5

Latent growth modeling

Overall development in the full sample

Based on the z-standardization, the LGM for the entire sample showed initial competence levels (intercepts) with 0.02 logits ($SD = 0.84$) in reading and − 0.00 logits ($SD = 0.90$) in mathematics. The development of the domains can be described with average slopes of 0.22 logits ($SD = 0.10$) per year for reading and 0.33 logits ($SD = 0.11$) logits for mathematics. Overall, the LGM showed a higher competence development for mathematics than for reading. Importantly, for the further interpretation of profiles, average development in the domains in half a year was 0.11 logits (in reading) and 0.16 logits (in mathematics) for an average of roughly 0.14 logits (after rounding off). All the profiles with a difference between the slopes smaller than 0.14 are to be interpreted as generalized profiles. The LGM can be interpreted as a generalized profile with a difference of 0.11.

Regarding correlations between the model variables, the slopes of reading and mathematical competence showed a low correlation, while the cross-sectional measurements were highly correlated (see Table 2). The correlations between the slopes and the intercepts were small and negative, indicating a slightly decreasing development for higher initial competence levels.

Table 2 Means, standard deviations, and correlations of latent intercepts and slopes

		M	*Var*	Correlation			
				Mathematics		Reading	
				Intercept	Slope	Intercept	Slope
Mathematics	Intercept	0.00	0.90				
	Slope	0.33	0.11	− 0.16			
Reading	Intercept	0.02	0.84	0.86	− 0.05		
	Slope	0.22	0.10	− 0.39	0.42	− 0.37	

Overall development in the sub-sample "Gymnasium"

For students attending the highest secondary school track (i.e., "Gymnasium" or equivalent track in comprehensive schools), the initial competence levels were distinctively higher, with intercepts of 0.52 logits (SD = 0.67) in reading and 0.57 logits (SD = 0.67) in mathematics. The mean slopes of the students were roughly the same as in the overall sample (reading: M_{slope} = 0.21, SD = 0.08; mathematics: M_{slope} = 0.33, SD = 0.09) (Fig. 2 in the Appendix).

Latent growth mixture modeling

Model 1 in the full sample

To identify the number of profiles, different solutions with different number of latent classes were compared using information criteria (see Table 3) in Model 1, using only the mean slopes and constraining the intercepts across all profiles. The BIC and the LMRT indicated a two-profile solution with two different generalized profiles of competence development. However, we considered small profiles including less than 5% of the sample as unreliable and irrelevant for our interpretations. Since the larger of the two profiles include over 98% of the sample, the second profile with less than 2% of the sample was deemed irrelevant. Thus, only a single profile of generalized competence development was observed.

Model 1 in the sub-sample "Gymnasium"

In the sub-sample (i.e., "Gymnasium" or equivalent track in comprehensive schools), both criteria indicated two profiles (see Table 4). While the first profile was similar to the generalized development profile in the overall sample, the second profile was even smaller than in the previous analyses and included only seven students (0.13%). Thus, again, only a single profile of generalized competence development emerged.

Model 2 in the full sample

While the BIC suggested a five-profile solution (see Table 5), the LMRT indicated four profiles in Model 2, in which the intercepts were unconstrained. Similar to the previous

Table 3 Model fit and profile sizes for slope-only model in the full sample

Groups	*BIC*	*Entropy*	*LMRT*	Group size (based on estimated model)					
				P 1	P 2	P 3	P 4	P 5	P 6
1	55,725	1.00		5,201					
2	**55,712**	.92	**.010**	5,112	89				
3	55,721	.89	.093	5,021	90	90			
4	55,729	.85	.099	4,889	119	103	89		
5	55,742	.84	.093	4,794	158	144	101	4	
6	55,759	.67	.339	3,965	849	203	125	55	4

Bold values indicate the best model; underlined values are below the threshold for acceptable entropy (> .70) or profile size (> 5%)

Table 4 Model fit and profile sizes for slope-only model for higher secondary students

Groups	*BIC*	*Entropy*	*LMRT*	Group size (based on estimated model)					
				P 1	P 2	P 3	P 4	P 5	P 6
1	26,914	1.00		2,369					
2	**26,913**	.99	**.041**	2,362	7				
3	26,927	.89	.629	2,278	51	39			
4	26,937	.82	**.020**	2,163	135	67	3		
5	26,950	.79	.368	2,094	132	72	68	3	
6	26,969	.69	.349	1,807	369	125	62	3	1

Bold indicates best values for a criterion; underline indicates values being below our set threshold for acceptable entropy (> .70) or profile size (> 5%)

Table 5 Model fit and profile sizes for intercept and slope model in the full sample

Groups	*BIC*	*Entropy*	*LMRT*	Group size (based on estimated model)					
				P 1	P 2	P 3	P 4	P 5	P 6
1	55,725	1.00	/	5,201					
2	55,660	.86	**< .001**	4,965	236				
3	55,610	.89	**< .001**	4,885	241	74			
4	55,580	.67	**< .001**	3,008	1,891	223	78		
5	**55,566**	.63	.065	2,697	1,857	363	210	74	
6	55,570	.66	.794	2,703	1,880	312	199	74	33

Bold indicates best values for a criterion; underline indicates values being below our set threshold for acceptable entropy (> .70) or profile size (> 5%)

analyses, most specialized profiles of competence development in Model 2 fell below the set criterion of a size of at least 5% of the sample. For the four-profile solution (preferred by the LMRT), only about 6% of the students (distributed over two profiles with 4.2% and 1.5% students) were identified as having specialized competence development. Overall, this leaves us with the LGM because additional profiles in multi-profile models ended up too small.

Model 2 in the sub-sample "Gymnasium"

Model 2 could not be replicated with the sub-sample (i.e., "Gymnasium" or equivalent track in comprehensive schools). In all solutions with more than two profiles, the mathematics and reading slope had a correlation above 1, showing an improper model solution. The two-profile model had one specialized class of competence development with only 54 students (2.3%) not reaching the minimum size of 5%.

Discussion

The main goal of this study was to identify profiles of competence development in mathematics and reading in early secondary education. Previous research (e.g., Shin et al., 2013) suggested that students, on average, develop similarly in mathematics and reading competences. Considering studies on the relative specialization of groups of students (e.g., LoGerfo et al., 2006), and on domain-specific affective-motivational factors (e.g., Parker et al., 2014), not all students were expected to fit this description. These studies led to the hypothesis of a generalized (parallel development of the domains) and two specialized (one domain developing faster) profiles of competence development in mathematics and reading.

Regarding the correlation of reading and mathematical competences, our results are in line with previous research showing moderate correlations between reading and mathematical competences cross-sectionally and longitudinally (e.g., Duncan et al., 2007, Hooper et al., 2010, Shin et al., 2013). Competences were shown to be developing in a rather continuous manner from Grade 5 to Grade 9. Interestingly, the results of the latent growth model (LGM) did not point to a high correlation between the two slopes for mathematical and reading competences. Meanwhile, the intercepts (cross-sectional competences) were moderately correlated. This shows that students who are good in one domain are also, on average, better in the other domain but students who develop better in one domain do not necessarily develop better in the other domain as well.

Both reading and mathematical competence developments were negatively correlated to their initial competence level. This shows that in our study, students with a higher initial competence do not on average profit from a Matthew effect (see also Schneider & Stefanek, 2004). Conversely, the results point to a slightly slower growth in reading and mathematical competences for students who show higher competence levels in Grade 5 compared to those with lower competence levels in Grade 5. This might also imply the possibility of non-linear or non-continuous development with some students developing faster than their peers prior to Grade 5 and then having a period of slow development in lower secondary education. Including a larger timespan could help both with checking the linearity of development and whether this negative correlation holds when analyzing students, for example, between kindergarten and completion of lower secondary education.

Our findings confirmed the existence of one generalized profile of competence development in reading and mathematics throughout early secondary education. The results did not confirm additional specialized profiles of competence development. However, the findings showed that development over 4 years in mathematical competence was slightly higher than in reading competence. This slightly higher increase of mathematical competence compared to reading competence might be explained by the curriculum for early secondary education: Mathematics and German are the main subjects in secondary education in Germany, and educational standards specify the competences that students should have developed in these subjects (Köller, 2009); in mathematics, the educational standards correspond partly to the contents and requirements of the NEPS mathematics tests, whereas the reading competence test (text comprehension) represents the competencies that students acquire in the subject German (such as writing, spelling, or language use) to an even lesser extent. Therefore, the curricular content of mathematics and its teaching is slightly better reflected in the NEPS mathematics test compared to reading competence, which is not much in the focus of teaching in German lessons in lower secondary school anymore.

Additionally, the larger development in mathematics might be explained by an earlier plateau of competences in reading. Both reading and mathematical competences seem to exhibit a peak or plateau according to the negative correlation between intercept and slope in both domains, meaning that at least students with on average higher initial competences develop less in early secondary education. However, this effect might be stronger in this sample for reading competences, as the acquisition of basic reading competences can be seen as a central focus of primary education, while several basic mathematical operators are only taught in secondary education (e.g., geometry, algebra besides basic calculation). Whereas the tests on reading competence used in the present study go beyond the basic ability to read, and are based on the ability to understand complex texts, it is still plausible that this ability might exhibit an earlier plateau than mathematical competences.

While students differed in their initial competence level and their development, few students belonged to a specializing profile of competence development as defined in our study, with a difference of an average development of half a year in each domain. This indicates that only little specialization in the development of reading and mathematical competences can be found in early secondary education. As all German school tracks provide general education in early secondary education (Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany, 1993), this seems to lead to similar development of competences in both mathematics and reading. The lack of specialization of competence development also shows that results demonstrating specialization in affective-motivational factors cannot easily be transferred to the field of competence development.

This sample is representative for students in German lower secondary education. However, in previous studies, these students have been found to be less specialized at least cross-sectionally than in other developed nations (e.g., Gladushyna et al., 2020). Different results might be found for countries allowing within-school tracking, as students might be stimulated differently according to their levels. Students in a more advanced course in one domain and a less advanced course in the other domain could be more likely to develop faster in the domain that they are attending advanced classes for. Meanwhile, the German education system with its focus on the acquisition of basic competences in lower secondary education is not designed to foster specialization in either domain.

Limitations

Despite the many advantages of a longitudinal dataset, there were also some limitations to our study. Although the competence scores (weighted likelihood estimates) had no predefined maximum value, the administered competence tests had difficulty differentiating in the tails of the proficiency distribution (i.e., between very high or between low competences). Given the severe time constraints faced in educational large-scale assessments, the NEPS only allowed administering short instruments that measured more precisely at medium ability levels. Consequently, these tests might not have been able to identify reliable changes for students with very high or low initial competences. Future research might benefit from longer tests that allow more precise estimates of competence development across the entire proficiency range.

Outlook

The overall results of this paper suggest that it is plausible to assume that students do not have many opportunities to specialize in their competence at general education level within the school system in lower secondary education. In Germany, across all school types, mathematics and German are main subjects in lower secondary school with a similar number of school lessons (Avenarius et al., 2003, p. 94 ff.). Perhaps, the opportunities to specialize in a certain domain become relevant later in upper secondary school or educational career. Assuming that competence development displays a different degree of specialization, once the possibilities for individuals to choose their educational courses increase, analyzing the same research question in upper secondary education would be of interest for future research. In Germany, during upper secondary education, students can choose to either leave general education to follow up into vocational training or continue in the equivalent high school track. For students remaining in general education until the end of upper secondary education, the level of differentiation in different classes also increases substantially due to the course system of the final school years. As such these added opportunities for differentiation might increase the likelihood of specialization. Additionally, profiles of competence in upper secondary school might be interesting to understand how school prepares students for the competences they need in their later careers (cf. person-environment fit) since specialization might be beneficial for pursuing one career but also hindering the access to another field which was less pronounced in an individuals' competence profile.

Appendix

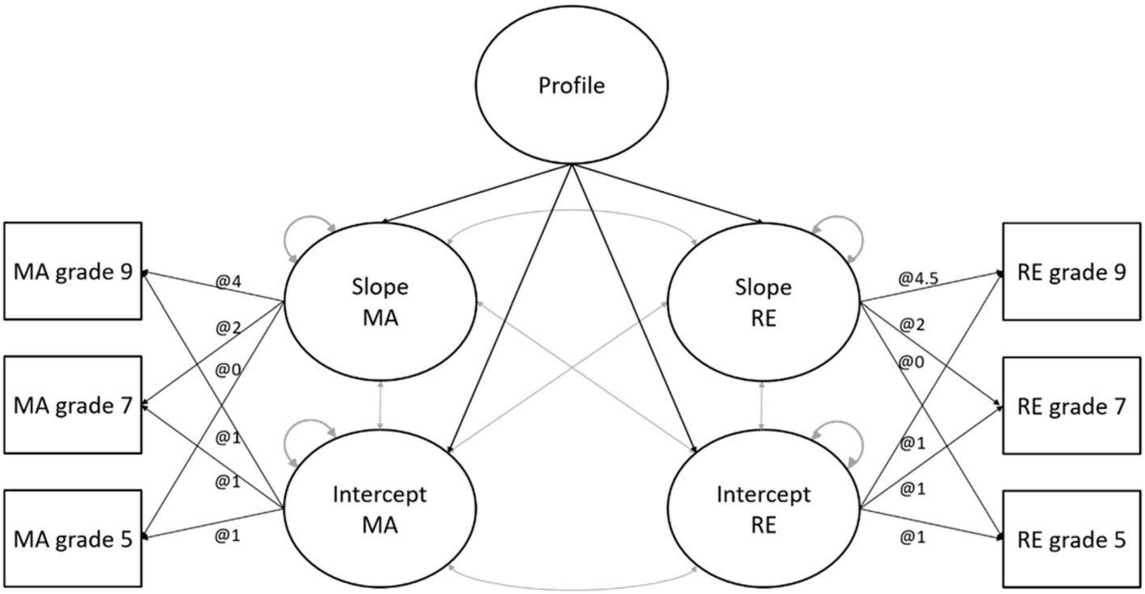

Fig. 1 Dual-process latent growth model for competence development in mathematics (MA) and reading (RE). Note. Constrained parameters are indicated with "@"

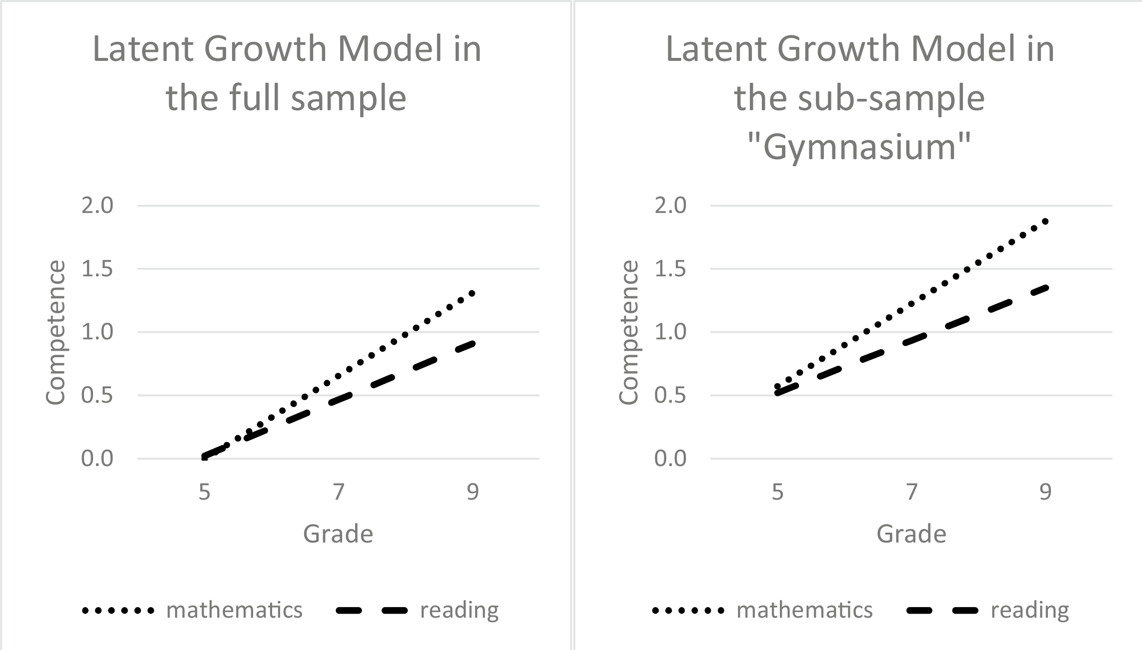

Fig. 2 Growth trajectories in the full sample (left) and the sub-sample “Gymnasium” (right)

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Author contribution - Micha Freund: Conceptualization, data curation, formal analysis, writing (original draft), and writing (review and editing).

- Timo Gnambs: Conceptualization and writing—review and editing
- Kathrin Lockl: Conceptualization and writing—review and editing
- Ilka Wolter: Conceptualization and writing—review and editing

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Availability of data and material All data can be attained by eligible researchers after prior conclusion of a Data Use Agreement with the Leibniz Institute for Educational Trajectories (LIfBi).

Code availability The code used for data preparation can be found at https://www.osf.io/5h2v3/?view_only=f5ec8677be66491eb798c5cc8467b47f

Declarations

Conflict of interest The authors declare no competing interests.

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Current themes of research:
- Micha-Josia Freund:
Profiles of competence development in secondary education in reading and mathematics, predictors of specialization in competence development, specifically specialized interest, gender and education.
- Timo Gnambs:
Personality and competence measurement, including computer-adaptive and web-based testing, longitudinal large-scale assessments, and meta-analytic methods.
- Kathrin Lockl:
Development of metacognition, relationship between language and metacognitive development, self-regulated learning, competence development.
- Ilka Wolter:
Self-concept and academic achievement, competence development, reading competence and text comprehension, gender stereotypes and identity, gender-specific learning environments.
Most relevant publications in the field of Psychology of Education:
Publication in the same project and with the same group of authors (and the only current publication by the corresponding author):

Freund, M.-J., Wolter, I., Lockl, K., & Gnambs, T. (2021). Profiles of competence development in upper secondary education and their predictors (Registered report protocol)**.** *PLoS ONE, 16* (1). https://doi.org/10.1371/journal.pone.0245884

Short list of recent publications by one or more of the **authors** that are very relevant to the specific topic of this article – for a full list of all publications in the field of psychology of education by these authors you might want to consider their publication lists found online:

Ehrtmann, L., **Wolter, I.,** & Hannover, B. (2019). The interrelatedness of gender-stereotypical interest profiles and students' gender-role orientation, gender, and reasoning abilities, *Frontiers in Psychology, 10:* 1402. https://doi.org/10.3389/fpsyg.2019.01402

Gnambs, T. (2021). The development of gender differences in information and communication technology (ICT) literacy in middle adolescence. *Computers in Human Behavior*, 114. https://doi.org/10.1016/j.chb.2020.106533

Kosel, C., **Wolter, I.,** & Seidel, T. (2020). Profiling secondary school students in mathematics and German Language Arts using learning-relevant cognitive and motivational-affective characteristics. *Learning and Instruction, 73,* https://doi.org/10.1016/j.learninstruc.2020.101434

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Thums, K., **Gnambs, T.,** & **Wolter, I.** (2020). The impact of gender-stereotypical text contents on reading competence in women and men. *Zeitschrift für Erziehungswissenschaft, 23*, 1283–1301. https://doi.org/10.1007/s11618-020-00980-8

Weinert, S., Artelt, C., Prenzel, M., Senkbeil, M., Ehmke, T., Carstensen, C. H. & **Lockl, K.** (2019). Development of competencies across the life course. In H.-P. Blossfeld & H.-G. Roßbach (Eds*.), Education as a Lifelong Process* (pp. 57–81). Wiesbaden: Springer VS.

Wolter, I., Braun, E., & Hannover, B. (2015). Reading is for girls!? The negative impact of preschool teachers' traditional gender role attitudes on boys' reading related motivation and skills. *Frontiers in Psychology, 6*:1267. https://doi.org/10.3389/fpsyg.2015.01267

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RESEARCH ARTICLE

Determinants of profiles of competence development in mathematics and reading in upper secondary education in Germany

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Abstract

The registered report was targeted at identifying latent profiles of competence development in reading and mathematics among $N = 15{,}012$ German students in upper secondary education sampled in a multi-stage stratified cluster design across German schools. These students were initially assessed in grade 9 and provided competence assessments on three measurement occasions across six years using tests especially developed for the German National Educational Panel Study (NEPS). Using Latent Growth Mixture Models, Using Latent Growth Mixture Models, we aimed at identifying multiple profiles of competence development. Specifically, we expected to find at least one generalized (i.e., reading and mathematical competence develop similarly) and two specialized profiles (i.e., one of the domains develops faster) of competence development and that these profiles are explained by the specialization of interest and of vocational education of students. Contrary to our expectations, we did not find multiple latent profiles of competence development. The model describing our data best was a single-group latent growth model confirming a competence development profile, which can be described as specializing in mathematical competences, indicating a higher increase in mathematical competences as compared to reading competences in upper secondary school. Since only one latent profile was identified, potential predictors (specialization of vocational education and interest) for different profiles of competence development were not examined.

1 Introduction

The introduction with the theoretical background and the method description are reproduced *verbatim* from the Registered Report Protocol [1]. All modifications to these sections are listed in the online supplement.

Language and mathematical competences significantly impact academic and professional success. Basic language competences (including reading competence) are at the core of learning and communicating [2], while basic mathematical competence (or mathematical literacy) is defined by the Organization for Economic Co-Operation and Development (OECD) ([3],

Data Availability Statement: As we work with secondary data, this dataset cannot be shared. However, the data is accessible to scientists fulfilling all necessary requirements of the national education panel study (NEPS) once they have concluded a Data Use Agreement with the Leibniz Institute for Educational Trajectories (https://www.neps-data.de/Data-Center/Data-Access). Once a scientist has access to the data, the data will be available on the NEPS-homepage (https://www.neps-data.de/Mainpage).

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p.15) as the ability "to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen". Both competence domains are basic skills necessary for everyday life, which is why both reading and mathematical competences are often analyzed in educational research.

Students in secondary education display consistent development in reading and mathematical competences with a reduced growth rate towards the end of compulsory education [4–6]. The two domains are highly correlated in cross-sectional data in both lower [4] and upper secondary education [7]. Previous research on the relationship between the development in reading and mathematical competences demonstrated substantial correlations between the change trajectories in both domains throughout secondary education [4, 8]. However, at the end of mandatory education (i.e., in the years following Grade 9 in Germany), research on domain-specific competence development and especially on the relationship between the two domains through a longitudinal perspective is scarce.

Against this background, this paper aims to analyze the longitudinal trajectories of mathematics and reading competence by identifying profiles of competence development of students in Germany at the beginning of upper secondary education, commencing in Grade 9 until age 21/22. We expect these profiles to be either generalized profiles of competence development (i.e., similar development in both reading and mathematical competence) or specialized profiles of competence development (i.e., a higher development in either domain). In a previous study with students at the beginning of lower secondary school in Germany (Grades five to nine), we were unable to confirm specialized profiles of competence development in those domains [9]. However, based on the manifold options the German educational system offers in upper secondary school, a higher level of specialization is expected in this period of schooling. If the expected profiles of competence development are found, potential predictors of profile-membership are also analyzed.

1.1 Individual's characteristics as determinants of competence development in reading and mathematics

Certain student characteristics can influence the development of reading and mathematical competence development of all students. Some of these explain the high correlation between mathematical and reading competences. In this context, research has shown that underlying abilities such as working memory [10–12] and reasoning ability [13] impact both domains. For example, several studies discovered working memory to be substantially correlated to both language and mathematical competences [14–16]. In a recent meta-analysis by Peng et al. [17], working memory and reasoning abilities together accounted for over 50% of the variance in the relation between language and mathematics. Additionally, the correlation between mathematical and reading competences can be traced back to the fact that general language and reading competences are important for learning in general but also for acquiring mathematical knowledge and solving mathematical problems [2, 17–19].

Previous research has additionally shown that socio-demographic characteristics of the students impact their competence development. Mathematical and reading competences are highly correlated to the socio-economic status of students' parents even before elementary education [20] and throughout secondary education [21]. As a summary of studies by Shin and colleagues [4] shows, the gap between students from high and low socioeconomic backgrounds was displayed as an increase, a decrease, or a stagnation depending on the model, tests, and sample that were used. Hence, analyzing specific longitudinal effects of social background on profiles of competence development are difficult to work out. Nonetheless, the socio-economic background can be seen as a determinant of both competence domains simultaneously, further indicating generalized profiles of competence development.

Moreover, differences in reading and mathematical abilities were confirmed for male and female students. Cross-sectional studies in this field depict that, on average, boys have higher mathematical and lower reading competence in Grade 9 compared to girls [22]. These inter-individual (between-student) differences imply intra-individual (within-student) differences between the domains at least cross-sectionally. The pattern of the development of gender differences from a longitudinal perspective is less clear, with studies showing that gender differences decrease [23] or stagnate [24] in secondary education. Thus, while the effect of gender on cross-sectional competence differences seems quite clear, longitudinal effects are difficult to predict.

Socio-demographic characteristics are not the only individual determinants of competence development implying potential specialization. Affective-motivational (e.g., motivation [25, 26], interest [27]) or socio-cognitive (e.g., self-concept [27]) factors, which substantially vary between the domains [27, 28] and are related to the frequency of school-related or leisure time activities [29], also have impacts on competence development in mathematics and reading. For example, Ehrtmann, Wolter, and Hannover [28] showed that many sixth-grade students' interest in German and mathematics (as well as further vocational interest domains) can be classified as generalized high or low, but some students are located in a profile with high interest in mathematics and low interest in German, or a profile with high interest in German and low interest in mathematics. As aforementioned, due to the correlation of interest and frequency of activity in a domain, we expected that students more likely belong to a profile of specialized competence development if they are distinctively more interested in one of the domains than the other. The existence of both generalized and specialized profiles of interest overall implies the existence of these profiles in competence development as well.

1.2 Context characteristics as determinants of competence development in reading and mathematics

Finally, the learning context also plays a role in competence trajectories. That is, competence development in both domains is affected by the characteristics of teaching in the classroom and the type of school a student attends [30] but also by students' choices during their educational career. Variations in the development of mathematical and reading competences in upper secondary school might be enforced by specific characteristics of the German educational system. With the end of lower secondary school and compulsory schooling after the ninth grade, the German system offers multiple pathways in either further general education towards a university entrance certificate or vocational training and associated exams [31].

The German school system is best described as a highly tracked school system [32]. Starting mostly in Grade 5 with entering lower secondary education all school types (mainly: Hauptschule, Realschule, Mittelschule, Gesamtschule, Gymnasium) focus on providing their students with general education until the end of compulsory education after Grade 9. These school types, however, differ mainly in their overall level of curricula but similarly focus on mathematics and reading competence. Starting with upper secondary education after Grade 9 some students decide to aim for a university entrance certificate, whereas other students leave the general education system and enter vocational training or alternative paths. Additionally, even students staying in general education have more options to decide between basic and advanced courses [33], which also determines parts of their exams at the end of schooling.

Students in vocational training [34] are already selecting their occupations and should more likely show specialized competence development. Hence, their competence profiles are expected to be specialized on either mathematics or reading competence throughout their vocational training due to the focus of their apprenticeships on job-specific skills. Similarly, after finishing upper secondary education with a university entrance certificate, students entering university can decide on a university course focusing on either predominantly language- or reading-related competences (e.g., arts or language studies) or mathematical competences (e.g., science, technology, engineering, or mathematics; i.e., STEM) [35]. We thus expected that students in specific vocational training or university study programs are more likely to be specialized in their competence development in reading and mathematics than students not in specific vocational training or university courses. Overall, the increased variety and larger number of choices on pathways and courses in upper secondary education further strengthens the argument that there are specialized profiles of competence development throughout the course of upper secondary education.

2. Hypotheses

Against this background, we expected to identify not only a generalized profile of competence development with a similar trajectory for mathematical and reading competence but also specialized profiles of competence development at the beginning of upper secondary education. More specifically, we expected two specialized profiles of competence development, which are differentiated into a predominantly mathematical competence and a predominantly reading competence profile.

Hypothesis 1: *There are one generalized and two specialized profiles of competence development*.

Learning environments of students after Grade 9 should have an impact on their likelihood of belonging to either specialized or generalized profiles of competence development. Specialized interest can be interpreted as a higher likelihood of investing leisure time to acquire either mathematical or reading competences which in turn leads to higher competences in the specific domain. Similarly, students might focus more on one domain through further education. Vocational education after Grade 9 and higher education after Grade 12 can prepare for a career in a specific work sector or job. Since that work sector or job might demand a higher competence level in either reading or mathematics, a high specificity of vocational or higher education could lead to a higher likelihood of ending up with a specialized profile of competence development.

Hypothesis 2: *Students with interests predominantly in one domain*, *reading or mathematics*, *are more likely to specialize in that domain than students with an unspecialized interest*.

Hypothesis 3: *Students who choose an occupation or a university program in a STEM field in school more likely belong to a specialized profile in mathematics than in reading*. *Corresponding to this*, *students who choose an occupation or a university program identified as reading-centered are more likely to belong to a specialized profile in reading than in mathematics*.

3. Materials and methods

3.1 Sample

The study used data from a sub-sample (starting cohort Grade 9) of the German *National Educational Panel Study* (NEPS [36]), which examined representative samples of students from secondary schools across their educational careers. The National Educational Panel Study is a study "collecting longitudinal data on educational processes and individual competence development across the entire life span from early childhood to late adulthood" [36] in Germany across different age groups in multiple datasets. In NEPS, students were sampled in a multi-stage stratified cluster design [37]. They were examined via questionnaires and were tested with standardized competence tests [38]. Additionally, both educators and teachers were asked to answer questionnaires to contribute additional information. The present study (N = 15,012), focused on students who were initially tested in mathematics and reading in grade 9 (age M = 15.2 years, SD = 0.6) and, subsequently, received competence tests in mathematics and reading at three-year intervals. The sample included 49.8% female students and 21.2% students with a migration background. Finally, 36.3% of students attended the higher school tracks (i.e., Gymnasium or the equivalent branch of a comprehensive school).

3.2 Knowledge of data

The lead author had not previously worked with this dataset. All theories and hypotheses, as well as details on the methodological approach, were based on a thorough literature review and prior research on other samples of the NEPS, including a currently unpublished paper with a similar aim in a mutually exclusive dataset with students in lower secondary education. The co-authors had previously worked with the dataset, albeit on topics unrelated to the present research. All publications using NEPS data published by the authoring team can be found at https://www.neps-data.de/Project-Overview/Publications (filtering for starting cohort 4). Furthermore, the co-authors had also contributed to some unpublished papers, which used the present dataset. However, none of the authors conducted analyses pertaining to this pre-registration, including identifying profiles of competence development, or identifying profiles across multiple domains in upper secondary education. The authors thus had no knowledge of the results of this study prior to publishing this report. All information used in the protocol was derived from the documentation available online (https://www.neps-data.de/Data-Center/Data-and-Documentation/Starting-Cohort-Grade-9/Documentation).

3.3 Instruments

In ninth grade, mathematical and reading competences were measured in a class-context, whereas later assessments were conducted individually in the students' private homes by trained test supervisors. Information on students' backgrounds, as well as on predictor variables, was taken from a questionnaire answered by the students.

3.3.1 Mathematical competence. Mathematical competence tests with items from four content areas and six cognitive components were specifically developed for use in the NEPS [39]. The mathematical tests at the beginning of Grades 9, 12, and three years after Grade 12 consisted of 22, 21, and 21 items, respectively [40–42]. They included simple and complex multiple-choice items as well as short constructed responses. Item response theory was used for scaling the tests [43]. Weighted maximum likelihood estimates (WLE) [44] and linking across grades with the help of overlapping items were used to attain student proficiencies [45]. Reliabilities of the WLEs in the three grades were .81, .77, and .75, respectively. To compare the competences in the two domains, the WLEs were standardized according to the mean and standard deviation in Grade 9.

3.3.2 Reading competence. Reading competence tests in NEPS were constructed according to a theoretical framework with three cognitive requirements and five text types [46]. These tests were administered at the end of Grade 9, beginning of Grade 12, and three years after Grade 12. They consisted of 31, 28, and either 23 or 27 items, respectively. The number of items in the last test differed because of different difficulty-tiered booklets depending on prior reading competence levels [47–49]. The different tests were placed on a common scale using an anchor-test design [45] to allow for valid longitudinal change analyses. Reliabilities of the

WLEs for reading competence were .81, .80, and .77, respectively. The WLEs were standardized according to the mean and standard deviation in Grade 9.

3.3.3 Additional variables. To test hypotheses two and three, we included further variables in our analyses. To measure students' interest in academic domains (mathematics and German) in NEPS, a scale was adapted from Baumert and colleagues [50]. Students were asked four items per domain in Grade 9 on their interest in spending time on mathematics and literature. The four questions for each domain were then turned into a scale. After z-standardizing the scales, a difference score between the interests in the two domains was calculated and used as a metric scale to indicate specialization of interest.

Additionally, to analyze whether students spent significant time in reading or mathematically specialized education, all episodes of schooling, training, or studying that were at least six months long were considered. Each of these episodes was classified as either language specialized, mathematics specialized, or generalized (i.e., not specialized to either domain). Vocational trainings that were defined as STEM (science, technology, engineering, or mathematics) occupations by the Federal Employment Agency of Germany [51] and university programs in the fields of mathematics, natural sciences, and engineering [35] were coded as specialized in mathematics. Vocational trainings in the area of law, print-media, archives, and libraries as well as university programs in the fields of language and cultural studies, were coded as specialized in reading. All other episodes were coded as generalized (or unspecialized) episodes. Once every episode was coded, students were checked whether they spent significant time (at least six months) in only one of the two specialized areas (thus being specialized) or in both or in none (being generalized). This was ultimately combined in two separate dichotomous variables, each indicating one of the two specialization areas and both being mutually exclusive.

In addition to these predictor variables, several additional variables were necessary that were used for imputation in addition to competence and predictor variables. These variables included unique identifiers for the student and their school. Gender was already available in the dataset. The age of students was calculated in months by subtracting the month and year of the test in Grade 9 from their birth month and year. The highest occupational prestige of the parents (defined as a parent questioned in a questionnaire and their partner) using the International Socio-Economic Index (ISEI) of Occupational Status [52], and the highest number of years in education of the parents using the CASMIN (Comparative Analysis of Social Mobility in Industrial Nations) classification [53] were used as social background characteristics of students. To create a variable accounting for the type of school in Grade 9, all schools leading to university entrance qualification (i.e., Gymnasium, and the equivalent branch of comprehensive schools) were differentiated from all other types of schools.

Migration background was recoded to compare students with a first- or second-generation migration background (i.e., either students themselves or at least one parent born in another country) to all other students. A scale of interaction language in different contexts was created by taking the average of six variables on a students' interaction language: with their mother, with their father, with their siblings, with their best friend, at the schoolyard, and of the parents with each other. The domain-specific self-concept of students was also considered using variables adapted from Kunter and colleagues [54]. This questionnaire included 10 items on the self-concept of students in German and mathematics (five items each). Finally, a test on reasoning abilities [55] was included in the dataset. The original test included 12 items and examines if students can identify the right element to complete a given figural sequence. An overview of all variables can be found in Table 1.

Table 1. List and description of all variables used in this study.

Variable		Necessary transformation	Range of values
Competence			
Reading competence	Grade 9	z-standardization	-∞ to +∞
	Grade 12		
	Grade 12 + 3 years		
Mathematical competence	Grade 9		
	Grade 12		
	Grade 12 + 3 years		
Predictors			
Specialization of interest		Creation of scale	-∞ to +∞
Specialization of education		Creation of scale	-1, 0, 1
Controls			
Gender of the student		-	0, 1
Migration background		Dichotomization	0, 1
Type of school in grade 9		Dichotomization	0, 1
Highest CASMIN of parents		Creation of scale	9 to 16
Highest ISEI of parents		Creation of scale	16 to 90
Interaction language of students		Creation of scale	0 to 3
Additional auxiliary variables (for imputation)			
Age of students at first testing		Calculation	0 to +∞
Self-concept in German		-	1 to 4
Self-concept in mathematics		-	1 to 4
Reasoning ability of students		-	0 to 16

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3.4. Statistical analyses

An overview over the planned statistical process, including the used datasets and variables at each step, can be found in Fig 1.

3.4.1 Latent change analyses. Longitudinal competence development was analyzed using linear latent growth models (LGM) [56]. The basic model provided information about the initial competence (intercept) and development (slope) of all students. Specifically, a dual-process LGM (with two slopes and two intercepts) was specified to acknowledge both mathematical and reading competences. This model was estimated in Mplus version 8 [57] using a maximum likelihood estimator with 4,000 initial stage starts and 1,000 final stage optimizations. The constraints for the slope parameters were zero, three and six years for the three waves respectively. Then, latent growth mixture modeling (LGMM) [58, 59] identified the different profiles of competence development. As the focus of this study was on the development of students (and not initial competence levels) our model only used the mean LGM slopes of mathematical and reading competences to allocate profiles of competence development. As such, the intercepts in both domains were constrained across all profiles.

3.4.2 Dealing with missing values. To account for the dropouts in the data of NEPS, we used a multiple imputation approach [60]. We imputed missing values 30 times using predictive mean matching in the Stata-package ICE [61]. For imputation, we used age, type of school in grade 9, interaction language of the students, migration background, reasoning abilities, the domain-specific self-concept in German and mathematics, the highest ISEI and the highest CASMIN of the parents in addition to the competence tests in mathematics and reading for each grade and the aforementioned predictor variables (gender, specialization of further educational paths, and specialization of interest in mathematics or reading).

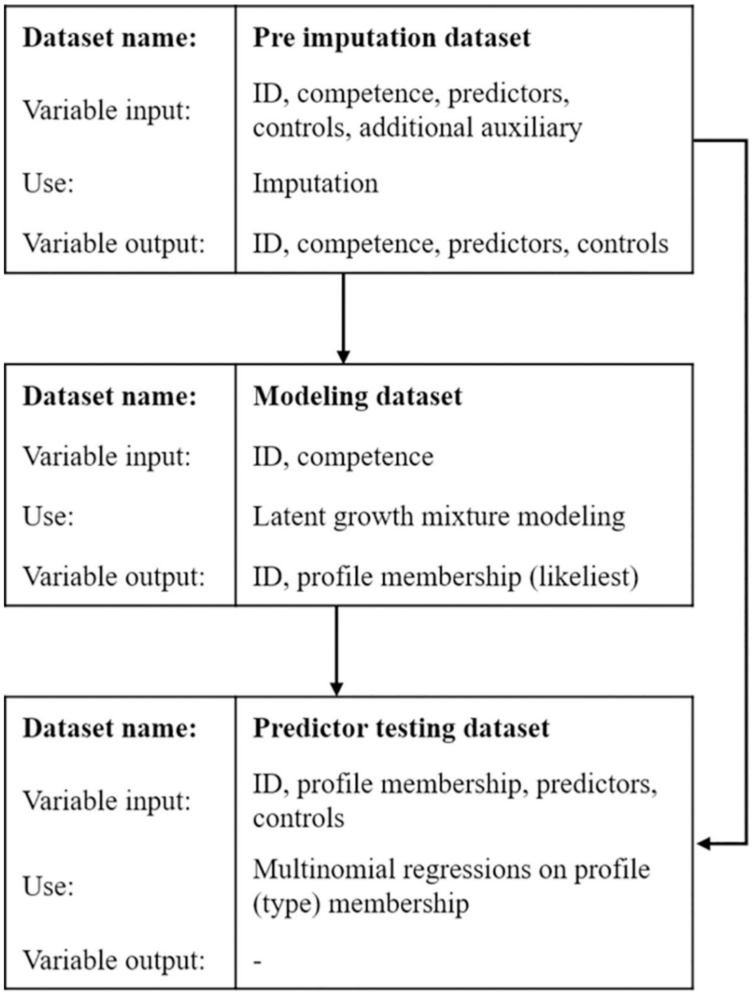

Fig 1. The three statistical steps, necessary datasets and variables.

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3.4.3 Model selection. To identify the optimal number of profiles, we fit different LGMMs with 1 to 10 classes. Then, we excluded models with profiles including less than 5% of the students. Smaller profiles are likely difficult to replicate and seem to have negligible practical relevance. In a next step, the model with the best fit was chosen using the Bayesian Information Criterion (BIC) [62] and the Lo-Mendel-Rubin Likelihood Test (LMRT) [63, 64]. The model with the lowest BIC and a significant LMRT can be interpreted as the model with the best fit. A significant (α = .05) LMRT indicates that a model with *k* profiles provides a better fit than a model with *k*-1 profiles. All criteria for model selection are summarized in Table 2.

Table 2. Criteria for model selection.

Name	Type of criterion	Decision making process
Profile size	Exclusion criterion	Profile size of every profile at least 5%
BIC	Fit index	Lowest BIC indicates best fit
LMRT	Fit index	Last significant LMRT indicates best fit

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3.4.4 Interpretation of profiles. The basic LGM acted as a baseline to interpret the profiles of the other models. We took the sum of both slopes in the LGM and divided it by 4. This resulted in a threshold of 0.045 which served as a criterion for interpretation. If the difference between the two slopes in a profile was greater than this criterion, students differed more in their development between the domains than the average student develops within half a year. Profiles with a higher difference were interpreted as specialized profiles of competence development while profiles with a lower difference were interpreted as generalized. All profiles fit into one of these three types of profiles, as only this difference between the slopes (and not the absolute level of slopes or intercepts) was relevant for profile interpretation.

However, it was possible, that this classification resulted in several profiles of the same type. For example, it was conceivable that two specialized profiles appear that simply differ in their degree of specialization (i.e., the amount of difference in slopes). However, differences within profile types were not the focus of the present study. Therefore, for the prediction analyses, if more than one profile of a type was identified, these profiles were then merged into a single profile type. For example, two generalized profiles, two profiles specialized in mathematics and one profile specialized in reading would be condensed into three profiles, each containing all original latent profiles of their type.

3.4.5 Testing predictors. If we identified both generalized and specialized profiles, we were able to test the influence of the predictors on the likelihood of belonging to each class via a three-step approach [65]. In this approach, the most likely latent class and the measurement errors for each student (calculated in step one in the LGMM) are saved as manifest variables (step two). The effect of the predictors on the likelihood of class-membership is then tested via multinomial regression (step three). In this regression, both predictors and several additional control-variables were used (see Table 1). As an inference criterion for the effect of interest and educational pathways, we used an a priori significance level of 1%.

3.5 Open practices

Details on the study material and the assessment procedure are available at https://neps-data.de. The analyzed data is owned by a third party and can thus not be accessed through direct means. However, it is freely available to scientists after signing a data use agreement and is provided at http://dx.doi.org/10.5157/NEPS:SC4:11.0.0. The computer code used to generate the reported results can be accessed at https://osf.io/x67bh/?view_only=77d0d99f497f43c3a2eb466f9b072553. The study was preregistered at [1].

4. Results

4.1 Descriptive analysis

In Table 3, the means, variances, and correlations of the imputed competence scores (*z*-standardized in reference to the mean and standard deviation in grade 9) are provided. Mathematics competence exhibited a substantially stronger increase across the six years (d = 0.77) as compared to reading competence (d = 0.32). However, in both domains, competences increased more strongly in Grades 9 and 12 (up to graduation from secondary education) as compared to the three years following Grade 12 (after leaving school). This might question the assumption of linear growth during the observational period. The standard deviations in mathematics changed very little in the six years following Grade 9, while the standard deviations in reading showed a slight but consistent decrease after Grade 9. Thus, individual differences in reading abilities decreased across the six years. Correlations between the two domains were moderately high across domains and measurement occasions.

Table 3. Means, standard deviations, and correlations of competence tests.

	Grade	*M*	*SD*	Correlations					
				Mathematics			Reading		
				9	12	12+3	9	12	12+3
Mathematics	9	0.00	1.00						
	12	0.56	0.92	.70					
	12+3	0.77	1.00	.68	.68				
Reading	9	0.00	1.00	.54	.44	.47			
	12	0.21	0.81	.56	.50	.53	.65		
	12+3	0.32	0.77	.55	.51	.59	.58	.65	

Note. Competence scores were *z*-standardized within domain in reference to Grade 9. All correlations are significant at a 99.9% significance level.

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4.2 Latent growth modeling

4.2.1 Latent growth analysis. The LGM showed average initial competence levels (intercepts) of 0.06 (*SD* = 0.82) in mathematics and 0.03 (*SD* = 0.78) in reading. Development of reading competences can be described with an average slope of 0.05 logits (*SD* = 0.05) per year, while the average development in mathematics was distinctively larger at 0.13 logits (*SD* = 0.03). Since the difference of the two slopes within the LGM was 0.08 and, thus, distinctively larger than our criterion for inferring specialization (0.045), the overall development of the students is interpreted as specializing in mathematics. The standard deviation of the two slopes was very small, which also implies that most students developed similarly with only small inter-individual differences.

The correlations between the latent growth factors (see Table 4) indicated a large relationship between both domains and their development across time. The two intercepts correlated at .83 and, thus, showed that reading and mathematics were cross-sectionally substantially associated. Additionally, both slopes were negatively related to the respective intercepts, -.27 and -.73 for mathematics and reading, respectively. This might indicate that especially in reading initial differences in competence reduced over time.

4.2.2 Latent growth mixture model. To identify the number of profiles, LGMM solutions with 1 to 5 profiles were compared (see Table 5). Both the LMRT and the BIC suggested a two-profile solution in which both profiles were specialized in mathematics. However, this solution did not meet our threshold of a minimum profile size (5%). The smaller (and more specialized) profile was estimated to include only 1.6% of the students. This led to only 70 students (0.5%) exhibiting this profile as their most likely profile. Due to the profile size criterion, a single profile solution, that is, the aforementioned LGM was preferred over any LGMM solution.

Table 4. Means, standard deviation, and correlations of the latent intercepts and slopes.

		M	*SD*	Correlation			
				Mathematics		Reading	
				intercept	slope	intercept	slope
Mathematics	Intercept	0.06	0.77				
	Slope	0.13	0.02	-.27			
Reading	Intercept	0.03	0.71	.83	-.33		
	Slope	0.05	0.04	-.40	.65	-.73	

Note: All correlations are significant at a 99.9% significance level.

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Table 5. Model fit and profile sizes of the LGM and LGMMs.

Groups	*BIC*	*Entropy*	*average LMRT*	Group size (based on estimated probabilities)				
				P 1	P 2	P 3	P 4	P 5
1	191,161	1.00	-	**15,012**				
2	**191,120**	0.93	**0,001**	14,770	242			
3	191,123	0.92	0,075	14,616	232	164		
4	191,145	0.89	0,174	14,308	323	195	187	
5	191,166	0.90	0,302	14,251	316	230	197	18

Note. Bold indicates best values for a criterion, underlining indicates values being below our set threshold for acceptable entropy (> 0.7) or profile size (> 5%).

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To examine whether these results were specific to our chosen modeling approach, we also estimated respective latent class growth analyses (LCGA). A summary of these results can be found in the online supplement. While these models exhibited profiles of useful size up to a 4-profile solution, the model fit of these models were distinctively worse than the model fit of the LGM and LGMMs. Thus, while profiles might be found using LCGAs, they were much worse at explaining the overall variance of competence development than the LGM, which simply allowed students to differ without specifying qualitatively distinct groups.

4.3 Prediction of latent growth

The second and third hypotheses outlined in the Registered Report Protocol [1] referred to predictors of students' most likely profile membership. However, as only one relevant profile was identified, these hypotheses cannot be addressed further.

5. Discussion

This present study aimed at identifying profiles of competence development in German upper secondary education and potential predictors for these profiles. The expectation of finding at least one generalized profile that is characterized by a similar competence development for reading and mathematics was based on high correlations between competence domains and their development identified in previous research [4, 7, 8]. Meanwhile, longitudinal specialized profiles were expected, among other reasons, due to specialization found in domain-specific interest [27, 28] and in vocational training [34] or areas of higher education–both factors that can be connected to competence development.

Similar to most studies analyzing the longitudinal relationship between competences in mathematics and reading [4, 8], the two domains were substantially correlated in this present study. With respect to the cross-sectional distributions, competences within and across waves were moderately to highly correlated to each other. Similarly, in the LGM competences were cross-sectionally highly correlated and also showed correlated change. These moderate to high correlations were expected since many factors (such as working memory [14–17], reasoning ability [17], and parental background [20, 21]) have an overlapping impact on reading and mathematical competences to a certain degree.

In the LGM, the two latent intercepts as well as the two latent slopes were correlated with each other. However, initial competence levels (i.e., intercepts) were negatively correlated to competence development (i.e., slope) both within and across domains. This result shows that students with initially higher competences improved slower on average. The negative relationship was especially pronounced within reading competences. This finding suggests that towards the end of secondary education, students with higher competences cannot expand or keep up their competence advantage, especially in reading competences.

The LGMM did not provide a solution with more than one profile having a relevant size (at least 5% of the sample). Due to this, the LGM was chosen as the model with the best overall fit. Hypothesis 1 of finding multiple profiles of competence development was therefore rejected. Hypothesis 2 and hypothesis 3 were not tested, because the hypothesized multiple profiles were not identified. The confirmation of only one latent profile with specialized development in mathematics is also in line with the high correlations between the two competence domains. The findings also indicate that prior group differences (such as cross-sectional gender differences [22]), vocational specialization for some students, and specialization of affective-motivational determinants (e.g., interest [27, 28]) show a different (potentially indirect or long-term) impact on competence development than expected.

The results of our study confirm that the overall development in upper secondary school can be described as specialized in mathematics, with students developing faster in mathematics than in reading competences. The average development in mathematics every year is quite substantial, whereas reading competence develops to a slower degree at the end of secondary education. Even though the expected profiles of competence development were not confirmed in this study, there is a specialization towards mathematics throughout upper secondary education and this type of difference between the two domains can be partially attributed to a higher focus of vocational education on mathematics-related as compared to reading-related tasks. While only about 955 (6%) of the students in this study were found studying or training in reading specialized fields, specialized education in mathematics (i.e., STEM fields) was much more common with 4620 of the students (31%).

5.1 Implications and limitations

Future research on the development of competence profiles should focus on the specialization on mathematics in upper secondary, and tertiary education. Even though the findings of this study suggest a beneficial development in the area of mathematics for all students, minority students or women are still confronted with multiple challenges regarding their access to and persistence in STEM fields (e.g., [66]). There is an ongoing discussion and need for interventions regarding the access of women and minority students [67], especially since STEM fields are characterized by higher prestige and income (e.g., [68]). Therefore, the results lead to certain practical implications for researchers and educators interested in the cognitive development of adolescents. On one side, it is clear, that reading and mathematical competences are highly correlated. Hence, it can be argued that both reading and mathematical competences (or the understanding of complex texts and the understanding of complex mathematical problems) must be fostered to a similar degree. On the other side, the higher development in mathematical competence might point us in a different direction as students use their previously acquired competences in reading and mathematics to further improve in mathematics while reading competences might already reach a plateau throughout upper secondary education. This finding suggests a higher focus on promoting mathematical education to support students especially in this period of rapid improvement. Yet, students struggling with reading should be promoted regardless their improvements in mathematics. However, regarding any focus on mathematical or reading competence development, it is especially important to monitor the progress of all students. This includes not promoting gender stereotypes (as previously seen in interest-profiles [28] or in gender differences in competences [22]), helping students that start out with low competence in mathematics, and enabling all interested students to enter courses and fields that are focused on mathematics.

Also, future research might learn from a methodological point of view from this study. While multiple (relevantly sized) profiles cannot be found with the used data, different aspects such as different tests and more test repetitions can be seen as potential improvements for future studies. Using different approaches in test development might be favorable for this research question as the high correlation between reading and mathematical competences can partly be explained by the high *language* parts within the mathematical test. Many mathematical questions are presented as text-based questions and thus correct answers are partially conditional on reading competence. Moreover, additional measurement points for competence tests in both domains would allow for an analysis of exponential growth in addition to linear growth or additional linear growth factors that were modelled in the present study. Potentially, these additions would help to better describe the actual competence development of students than within the framework of one linear factor as used in this study.

Furthermore, the longitudinal development of cross-sectional competence profiles using a latent transition analysis might also be an interesting approach to analyze how initial competence levels and later competence levels are correlated within specific groups of students. Additionally, the effects of predictor variables might be analyzed with a different method (e.g., a linear regression on the growth parameters of the LGM) to analyze whether the variance can be explained by different factors and predictors. While the variance in specialization is not distinctive enough to identify profiles of competence development, the growth parameters can still be used as a dependent variable in linear regression analysis. Finally, such a prediction of the Latent Growth Model can also help explain the difference in growth between reading and mathematical competence by explaining which predictors affect one of the domains stronger than the other one.

Finally, the results of this paper might be seen with several drawbacks and limitations. The analyses might be hard to generalize due to the context of the German educational system. The German education system is tracked and one of the very few developed nations with vocational education as part of upper secondary education [32]. This vocational education system in Germany and the high proportion of mathematics-related work fields might be the reason for the overall specialized development in mathematics. Another limitation might be the high number of missing values in the sample. Due to the nature of a transitory educational phase (students leaving general education for vocational education), many students exited the study between the first and the second wave. We tried to keep the sample representative through multiple imputations using several additional auxiliary and control variables. However, the fact that students' characteristics changed severely before and after imputation indicates selective dropout. While this dropout is addressed through the imputation, it is always possible that the imputation model does not include all necessary variables and leaves out observed or unobserved variables that account for dropout.

6. Conclusion

Overall, our findings show that even though students differed in their initial competence and their competence development, the best way to explain the competence development of German upper secondary education students is to view them in an overall growth model. This model can be described as overall specialized in mathematics, yet, there is no indication of a generalized profile of similar development in mathematics and reading, or a profile of specialized development in reading. The results of this study differ from our previous research identifying one main generalized profile in lower secondary education [9] with a similar development in both domains. However, it adds to the previous finding, that even though there are intra-individual differences within students, they are not resulting in distinct profiles of competence development. Future research should confirm the robustness of these findings in different contexts (i.e., educational systems) and samples.

Supporting information

S1 File. Online supplement: Contains all supporting tables.
(DOCX)

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Predictors of reading and mathematics development of adolescent students in Germany: The effect of gender, interest, and educational specialization

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Abstract

Various student characteristics might affect the development of reading and mathematics competence in different or similar ways in upper secondary education. In this study, we investigated the role of students' gender, specialization of their interests, and educational decisions. We expected gender to affect competence development similarly as boys close the gap in reading competences and expand their advantage in mathematical competences. Furthermore, specialized interest and education were expected to increase competence development in the respective domain. The present study used a longitudinal sample of N = 15,012 students from the German National Educational Panel Study that provided three measurements from age 15 to 21. The results showed differential effects of all three predictors. Specialized interest and education increased development in the students' specialized domain, while boys showed more substantial increases in mathematics and, less strongly, in reading than girls.

Keywords: competence development, reading competence, mathematical competence, vocational education, latent change score modeling

Introduction

The development of competences from primary to the end of secondary education can be viewed as a critical determinant for students' chances in their prospective professional careers. The end of secondary education is a critical phase in countries with segregated upper secondary education that include a continuing academic track and a transition to vocational education. Germany, for example, is one country where upper secondary education includes a parallel system of either general education leading to university entrance qualifications or vocational education, which prepares students for specific jobs or careers (Munch, 1995). The competence development in such a diversified educational period is, as of yet, an underexplored aspect of competence development.

Two influential competence domains shaping future educational and professional success are language competences (specifically reading competences) in the native language and mathematical competences (e.g., Adelson et al., 2015; Peng et al., 2020; Rescorla & Rosenthal, 2004; Shin et al., 2013). These domains can be seen as crucial throughout the life course. Native language competences, such as reading competences, are needed whenever students want to acquire new knowledge or communicate (e.g., OECD, 2003; Weinert, 2006). Similarly, basic mathematical competences have to be applied in higher education and work (Weinert et al., 2019). As such, this paper tries to add to prior research and focuses on the development of these two competence domains.

Developmental trajectories in both reading and mathematical competences are, on average, characterized by a gradual growth throughout primary and secondary education (e.g., Rescorla & Rosenthal, 2004; Shin et al., 2013). However, towards the end of secondary education (i.e., after Grade 8), this growth seems to slow down (Rescorla & Rosenthal, 2004). Additionally, the development of the two domains is substantially correlated (e.g., Adelson et al., 2015; Freund, Gnambs, et al., 2021; Freund, Wolter, et al., 2021; Shin et al., 2013), indicating that students who improve stronger in one domain also improve stronger in the other domain. However, this correlation does not necessarily imply that all students exhibit identical growth rates in both domains. Due to the diversified nature of upper secondary education in Germany (Becker et al., 2017), some students might specialize in one of the domains to prepare for future careers. Analyzing this type of specialization and, in particular, what factors might affect this type of competence specialization is the focus of this study. In this study, we pursue the question of which student characteristics can differentially predict changes in reading and mathematical competences. We will focus on three essential attributes of students: Their gender, their interest in language and mathematical topics, and their education after Grade 9.

Development of competences at the transition between upper secondary to vocational or tertiary education

When looking at competence development in ninth grade and the following years, it is essential to understand what abilities or skills are still subject to a substantial change in this educational stage. Concerning reading competence, students usually have mastered basic reading skills in primary school, and learning to read in terms of reading fluency does not play a major role for most students in upper secondary school (cf. Perfetti et al., 2005). Instead, the ability of students to comprehend texts from various text functions and themes (Gehrer et al., 2013) becomes more important, and development can be found in understanding increasingly complex texts (Berendes et al., 2013). In mathematical competences, analysis of competence development is similarly possible due to the increasing complexity of mathematical problems that students can solve (Neumann et al., 2013). These problems may also refer to different content areas and cognitive components.

While much is known about cross-sectional distributions of competences in reading and mathematics (based on datasets such as the PISA studies; OECD, 2019), competence development has rarely been analyzed in this age group. The studies that analyzed students up to this age group longitudinally (e.g., Rescorla & Rosenthal, 2004; Abedi et al., 2005) usually focused on students from a country with a system of comprehensive schools (e.g., the United States) and often did not follow students after graduation from secondary education.

One of the crucial aspects differentiating the German educational system from the educational system in most other developed nations is vocational education as part of upper secondary education. Those students that do not aim to study at university (i.e., tertiary education) may spend their last years of formal education learning and training at vocational school and (sometimes) at the workplace to prepare for an occupation in a specific area (Fürstenau et al., 2014, KMK, 2019). In preparation for their future occupations, students might more specifically acquire competences needed in their future professions and competencies needed for life in general. Meanwhile, students remaining in general upper secondary education until Grade 12 or 13 can enter either tertiary education at university or vocational education in the dual system after leaving school. This period of the German educational system should provide ample opportunities for students' competence specialization.

Student characteristics predicting competence development

Most studies analyzing the relationship between reading and mathematical competence showed a large correlation (e.g., Adelson et al., 2015; Shin et al., 2013) and a relatively parallel development (Freund, Wolter, et al., 2021) between the two domains both cross-sectionally and longitudinally. Bidirectional effects between the two domains might partially explain this large correlation because competences in one domain are beneficial for learning in another (e.g., Bailey et al., 2020; Erbeli et al., 2021; Grimm, 2008). However, the correlation might also result from similar underlying factors that affect both competence domains to a similar degree. These underlying factors include the social background of students (e.g., Larson et al., 2015; Wang et al., 2017) and basic abilities such as working memory (e.g., Peng et al., 2020) or fluid intelligence (e.g., Peng et al., 2019). While these factors influence competence development at earlier stages in students' educational trajectories, research on upper secondary education is scarce.

Another factor that might predict competence development after Grade 9 is gender. However, the influence of gender on competence development is complex and needs to be considered in greater detail for different age groups. On one side, studies showed cross-sectional advantages for girls in reading and slight advantages for boys in mathematics at the end of lower secondary education (e.g., OECD, 2016). Therefore, against the background of gender-stereotypical competence patterns (e.g., Steffens & Jelenec, 2011), it might be reasonable to assume that girls continue to increase their advantage in reading, whereas boys increase their advantage in mathematics.

However, Borgonovi et al. (2018) analyzed student competences at ages 9-10, 15-16, and 26-27 in different samples across several countries. They showed that the gender gap in numeracy, while hardly existing at the beginning of secondary education, grew throughout secondary education and towards adulthood. Meanwhile, the initial advantage of girls in literacy increased within lower secondary education and diminished by the time the students reached age 26 (Borgonovi et al., 2018). Thus, male students seemed to have a developmental advantage in both domains in the transitional years starting in upper secondary education. Both their mathematical and reading competences increased more than girls' during this educational stage. This effect implies that boys should have higher competence development in both domains in this particular age group.

Specialization of interest and educational decisions

While the gender of the students might not affect the growth of the two domains differently during this educational stage, some student characteristics and educational decisions might promote specialization of competences. For example, one way students might have a higher competence development in one domain compared to the other is by putting more time and effort into that domain. Thus, student characteristics that indicate students' specialization might explain differential competence development in mathematics and reading.

Among student characteristics that might foster this higher engagement in one domain, affective-motivational factors (e.g., interest) should be considered. Students' interest indicates their commitment to putting effort into one domain, and the correlation between interest and competence development has been shown in prior research. For example, Denissen et al. (2007) reported that students between Grades 1 and 12 exhibited a positive longitudinal coupling between their interest, self-concept of ability, and achievement in a domain. Additionally, Ehrtmann et al. (2019) previously identified several interest profiles, including two latent profiles with either high interest in reading and low interest in mathematics or high interest in mathematics and low interest in reading. Overall, the existence of specialized interest and the connection between interest and competence development indicates that a specialized interest in one domain positively influences competence development in that particular domain. Conversely, the relatively decreased interest in the other domain might also indicate a lower commitment and thus development in that domain.

Further factors to influence competence development differently should be educational decisions. The educational choices of secondary and tertiary education can be divided into several decisions (KMK, 2019): First, after Grade 9 or Grade 10, students can choose between staying in the general educational system or entering the vocational educational system. Second, after Grade 12 (or Grade 13 in some federal states), the students who remained in the general education system choose to enter vocational education or tertiary education (i.e., university). Within each educational decision, students choose not only the track but also the field of study or career specialization. Hence, after leaving general education, students also decide on their long-term professional career by choosing a specific type of vocational training or a specific study subject at university.

After leaving school, students' different career paths could be divided into specialized and unspecialized paths. Some occupations have a higher necessity for mathematical competences, especially in STEM domains (science, technology, engineering, or mathematics). These occupations likely demand and induce higher mathematical competence development when learning job-related or occupational skills. In contrast, reading specialized careers might be found in language and cultural studies, law, and print media, where high reading- or language-related skills and competences are in higher demand, thus potentially leading to higher reading competence development for these students. Most students will likely be found either in careers where mathematical competence and reading competence are equally necessary or trying multiple vocational or university courses with both reading and mathematical demands. Overall, we expect that students being found in a specialized vocational or university education would show higher competence development in their specialized domain and relatively lower in the other domain due to their higher focus and engagement on one domain.

Hypotheses

From the theoretical arguments presented so far, we derived three hypotheses on distinct student characteristics that either affect competence development in reading and mathematics similarly or to a different degree. First, regarding gender, a comparison of cross-sectional samples (Borgonovi et al., 2018) of different ages indicated that male students are likely to show a higher competence development in both reading and mathematical competence than girls in the final years of secondary education and at the transition into their further professional paths.

Hypothesis 1: Male students show higher reading and mathematical competence development than girls towards the end of secondary education and at the transition into vocational or tertiary education.

In contrast, we argued that students' specialized interests and education, both indicating a greater focus on and engagement in one domain, should affect the two domains differently. For example, a specialization of interest in either the direction of mathematics or reading should lead to higher competence development in that domain relative to the competence development in the other domain. Similarly, vocational or higher education that can be seen as specialized in reading or mathematical skills should also imply higher learning outcomes. Students spending time in one specialized area should thus exhibit higher competence development in the specialized domain than students in the unspecialized area.

Hypothesis 2: Students with a specialized interest in one domain should show higher competence development than students with a specialized interest in the other domain.

Hypothesis 3: Students in vocational or higher education with specific requirements in one of the two domains should show a higher competence development in that domain than students in vocational or higher education with specific requirements in the other domain.

We acknowledge numerous other characteristics, such as the socioeconomic status of parents (Larson et al., 2015; Wang et al., 2017) or cognitive skills (Peng et al., 2019; Peng et al., 2020), which might also explain differences in competence development. Therefore, we will control for these factors in our analyses to improve the robustness of the focal findings.

Materials and methods

Sample

This study used data from the German National Educational Panel Study (NEPS; Blossfeld et al., 2011). The NEPS aimed to collect "longitudinal data on educational processes and individual competence development across the entire life span from early childhood to late adulthood" (Blossfeld et al., 2011, p. 1-2). Participants at different points of their educational trajectories and participants of different age groups were followed longitudinally, with competence tests administered to them at consistent intervals. The students were sampled in a multi-stage stratified cluster design (Steinhauer et al., 2015) using schools and classes for clustering students.

We used a sub-sample of the NEPS ('Starting Cohort 4') that started with students in Grade 9 of the German secondary education and followed them throughout their transition to tertiary education and the labor market. Only students initially tested in reading and mathematics in Grade 9 were included in the analyses. Therefore, the study sample consisted of 15,012 students. These students were, on average, fifteen years old (M = 15.2 years, SD = 0.6), most students (78.8%) had no migration background, roughly half of the students were female (49.8%), and about one-third (36.3%) of students attended the highest school track in Germany (i.e., Gymnasium or Gymnasium branch of comprehensive schools).

Instruments

The information used in this study was acquired from different forms of assessment: The competence tests developed for the NEPS were initially conducted in a class context and later in an individual setting at home to obtain competence measures in reading, mathematics, and reasoning abilities. Additionally, questionnaires were answered by the students and their parents and used for information about the students' background, gender, interest, and educational trajectory.

Reading competence was measured at three time points. The assessment was paper-based in Grade 9 and 12 but computer-based at the last measurement point. The test duration was 28 minutes at each of the measurement points. Tests in Grades 9, 12, and three years after Grade 12 included 31, 28, and 23 or 27 items, respectively, with the final test differing depending on prior reading competence levels (Haberkorn et al., 2012; Gnambs et al., 2017; Rohm et al., 2019). The development of the individual tests was based on a framework that represents the concept of reading competence over the entire life span as coherently as possible. Items with three different comprehension requirements (finding information in text, drawing text-related conclusions, and reflecting and assessing) were distributed among texts with five different text functions (commenting, information, literary, instruction, and advertising; Gehrer et al., 2013). Using the items of each wave, competences were modeled using item response theory (Pohl & Carstensen, 2012) and linked across waves using independent linking studies (Fischer et al., 2016). Proficiency scores were estimated as weighted likelihood estimates (WLE; Warm, 1986), exhibiting marginal reliabilities of .81, .80, and .77, respectively. The WLEs were z-standardized according to the mean and standard deviation in Grade 9.

Mathematical competence was also measured at three time points in Grades 9, 12, and three years after Grade 12. As for reading, the assessment of mathematical competences was paper-based at the first and second measurement points and computer-based at the third measurement point. Test duration was 28 minutes each. Students were administered 22, 21, and 21 items, respectively (Durchhardt & Gerdes, 2013; Fischer et al., 2017; Gnambs, 2020). According to the NEPS framework for mathematical competence

(Neumann et al., 2013), the items covered four different content areas (quantity, change and relationship, space and shape, and data and chance), requiring the use of six different cognitive components (mathematical communication, mathematical argumentation, modeling, using representational forms, mathematical problem solving, and technical abilities and skills). Using the items of each wave, competences were modeled using item response theory (Pohl & Carstensen, 2012) and linked across waves using anchor items in multiple waves (Fischer et al., 2016). The WLEs exhibited marginal reliabilities of .81, .77, and .75. Again, the WLEs were standardized according to the mean and standard deviation in Grade 9.

Specialized interest was based on two interest scales in German and adapted from Baumert and colleagues (1997). Students were asked how interested they were in four different areas of both mathematics and German language on response scales from 1 “does not apply at all” to 4 “does completely apply”. Reliabilities of these scales were at .83 (German) and .85 (Mathematics). The scale scores were *z*-standardized to allow the computation of a difference score. A higher value in this final score indicated a higher interest in mathematics than in German language arts, while a lower value indicated specialized German language interest, and values around zero indicated a similar interest in both domains.

Indicators of *specialized education* were generated using students-reported episodes of schooling, training, or studying. In a first step, these episodes were coded as either mathematically specialized, reading specialized, or not specialized according to either domain. Mathematically specialized episodes included vocational training for jobs that are defined as STEM (science, technology, engineering, or mathematics) by the Federal Employment Agency of Germany (2019), as well as university programs in mathematics, natural sciences, and engineering (Federal Statistical Office of Germany, 2020). Training for jobs in law, print media, archives, and libraries was coded as reading-specialized in addition to language and cultural studies at university. The overall educational trajectory was considered specialized if students spent at least six months in specialized education of one domain without spending six or more months in the other domain. Students that did not spend enough time in specialized education or spent time in education in both domains were coded as generalized. From this information, we created two dummy-coded indicators (with reading specialized education as a reference category) that indicated mathematically specialized or generalized education.

Control variables included the students' reasoning ability, socio-economic background, migration background, and initial school type. The test on reasoning abilities included in the dataset is a sum -score of twelve matrices items (Cronbach's alpha of .66) that required students to identify a figural element that logically completed a stimulus set (Lang et al., 2014). For socio-economic background, the highest occupational prestige of the parents was taken using the International Socio-Economic Index (ISEI) of Occupational Status (Ganzeboom, 2010). Migration background was dichotomized into students who had migrated themselves or had one or both parents migrate into Germany (coded 1) and students with a different or no migration background (coded 0). Finally, the type of school in Grade 9 was similarly dichotomized to differentiate students in schools leading to university entrance qualification (Gymnasium or the Gymnasium branch in comprehensive schools; coded 1) from all other school types (coded 0).

Analysis plan

To identify the development of students, we used latent change score (LCS) analyses (Klopack, Wickrama, 2020). Change scores were estimated as the difference between the competences of two consecutive waves, resulting in two change scores per domain. Change scores were then used to identify the overall linear growth while recognizing the non-linearity of growth through a proportional growth factor β. A positive slope and a negative β (expected in this study) imply that competence development slowed down over time. Mplus (version 8.2) was used for model estimation using a robust maximum likelihood estimator (Muthén & Muthén, 1998-2017). To judge the model fit, the root mean square error of approximation (RMSEA < .05), the standardized root mean square residual (SRMR < .05), and the comparative fit index (CFI > .95) were used. The latent slope factors were regressed on the hypothesized predictors (i.e., gender, specialized interest, and specialized education) and all control variables (i.e., reasoning ability, socio-economic background, migration background, and initial school type). A 99% significance was used as an inference criterion.

Due to the transitional nature of the education system at this stage, many students dropped out of the study. Additionally, in Grade 12, students who had left or changed school did not receive all competence tests but were only administered randomly selected competence tests (Fuß et al., 2019), resulting in missing values by design. Therefore, we had to account for student dropout, item non-response, and missing by design. Using a multiple imputation approach (Rubin, 1987), this was done with 30 imputations derived from predictive mean matching in the Stata-package ICE (version 1.4.1; Royston & White, 2011). All available competence values, predictors, and control variables introduced previously were used in the imputation model.

Results

Descriptive Results

To provide an overview of the sample, variables, and imputations, Table 1 includes the distributions and correlation of the predictors and the scores in the competence tests. First, reading and mathematics showed a higher mean change between Grade 9 and Grade 12 than in the three years after Grade 12. Additionally, reading competence showed a less pronounced increase than mathematical competence on average. The variance of reading competence decreased distinctively over time. Furthermore, there were positive and slightly increasing correlations between gender and mathematical competence, whereas the correlation between gender and reading competence was initially negative and diminished over time. These correlations indicated expected gender differences in Grade 9 and a disappearing gender gap in reading competence over time. Specialization of interest in mathematics was negatively correlated to reading and positively correlated to mathematics competences. Finally, students in generalized education had lower competence in both domains than reading specialized students, while mathematics specialized students had higher mathematics competences and similar reading competences compared to reading specialized students.

The goodness-of-fit of RMSEA (0.047), SRMR (0.021), and CFI (0.993) showed that the LCS model fitted the data satisfactorily. The intercepts in both domains were set to zero, with variances of one due to mean competence being *z*-standardized in Grade 9. The constant development over three years was estimated as 0.23 (SE = 0.005, $p < .001$) in reading with a variance of .14 (SE = 0.010, $p < .001$) and 0.57 (SE = 0.007, $p < .001$) in mathematics with a variance of .26 (SE = 0.013, $p < .001$). The proportional growth factor β was estimated to be -0.64 (SE = 0.027, p < .001) in mathematics and -0.62 (SE = 0.038, p

< .001) in reading, meaning that students with higher competence levels showed lower development in comparison to students with lower initial competence levels.

Regression analyses for latent growth parameters

Included in Table 2 are the results of linear regressions of the latent growth parameters (intercept and slope) in mathematics and reading. Concerning the initial levels in Grade 9, boys had a higher mathematical competence and a lower reading competence than girls in Grade 9, as expected based on previous cross-sectional results. Additionally, specializations of interest and education were relevant: Students with highly specialized interest or education showed also higher competence levels in the respective domain in Grade 9. The control variables were associated with both intercepts. Students with higher reasoning abilities and a higher socio-economic background had higher competences in both domains. Moreover, students without a migration background and students attending the highest school track showed higher competences in Grade 9.

Regarding the slopes, the results were as follows: Male students had a slightly higher average development in reading and a distinctively average development in mathematics than girls. Specialization of interest in mathematics had a significant negative impact on reading development and a significant positive impact on mathematical development. The findings also showed that students who spent at least six months in mathematics specialized education exhibited a higher mathematical competence development and a lower reading competence development than students who spent at least six months in reading specialized education.

Students in generalized education developed slightly slower in both domains than students in reading specialized education. The other control variables affected reading and mathematical competence development in the same direction. Reasoning abilities, socio-economic background, and school type were positively related to the average slope of students' competences, with the largest effect sizes for school type. Moreover, migration background was negatively correlated to the expected competence growth in mathematics and reading.

Discussion

The main aim of this article was to investigate competence development in reading and mathematics in upper secondary education in Germany by adding predictors to explain development in both domains. As outlined in the introduction, upper secondary education is especially interesting for competence development since students are faced with different educational options offering pathways to focus on one of the two domains. Furthermore, understanding how student characteristics affect development in reading and mathematics can help us understand which students might develop faster in one domain than in the other and which students are likely to develop slower in both domains or faster in both domains. Therefore, this paper focused on one educational decision and two student characteristics.

Overall, the development of reading competence was slowing down until the end of upper secondary education, while descriptive statistics show the variance of reading competences decreasing over time. These effects lead to a convergence of students' reading competences that top students reach as early as the beginning of upper secondary education while the rest close in on these competence levels in the following years. Nevertheless, at the age of 21, considerable inter-individual differences in reading competences persisted. Similarly, there is a decrease in competence development in mathematics after Grade 12 (when most students have left general upper secondary education). However, in mathematics competences, the standard deviation of the distribution stayed relatively constant, implying that there is no competence plateau at the top competence level.

Concerning gender-specific competence development in reading and mathematical competences, previous results from Borgonovi et al. (2018) were used to argue that boys were expected to develop faster in both domains at this age. Hypothesis 1 was confirmed with the findings in the present study as well. Boys showed a higher average development in mathematics and reading, yet to a lesser degree in reading than in mathematics. This result fit the overall findings of higher competences in reading for girls and higher competences in mathematics for boys (e.g., OECD, 2016) and supported the results from Borgonovi et al. (2018) of a closing gap. Borgonovi and colleagues explain the increasing gaps in numeracy with the under-representation of women in STEM education and STEM jobs. Meanwhile, they note that “literacy is a more transversal skills [*sic*] that everybody is called to master in order to succeed in education and in the labor market, irrespective of the chosen field of study or occupation” (Borgonovi et al. 2018, p. 17). This would explain why male students, initially at a disadvantage, had a higher need to catch up in reading competences.

Regarding interest, we proposed that students’ interest and, specifically, whether a student has an interest specialized in one domain positively affects competence development in that domain. Previous research showed that interest and competence in the same domain are highly correlated (e.g., Denissen et al., 2007). Furthermore, the present study confirmed that students with specialized interests in one domain also exhibited a higher competence development in that domain and a lower competence development in the other domain (Hypothesis 2).

Educational paths chosen after Grade 9 were expected to impact the further development of reading and mathematical competences. Educational decisions for a specialized occupation or further education were hypothesized to increase competence development in the relevant domain. This hypothesis was confirmed, as students in a specialized educational track were improving faster in the specialized domain than students who obtained specialized education in the other direction.

With these results, it is essential to acknowledge the distribution of specialized education among vocational and tertiary education tracks. Courses from the field of STEM education could be encountered frequently both in university tracks and vocational training courses. Meanwhile, due to the higher need for reading competences in academic careers, about 12 % of students in *Gymnasium* (or equivalent tracks of comprehensive schools) continue in occupations or study programs with a relevant degree of reading specialized education. In contrast, only 3 % of the other students continue their education within a reading specialized education field. These ratios were much more similar for mathematical education (28% of students in Gymnasium, 33% of other tracks).

When interpreting the present study's findings, mediating effects between the predictor variables should be considered. For example, students' gender is relevant for developing students' interests, with girls being, on average, more interested in language topics and boys being more interested in mathematics (e.g., Evans et al., 2002; Ehrtmann et al., 2019). Furthermore, both students' gender and interest are likely to affect further educational decisions. For gender this has been reported often with research on gender gaps in the entrance into vocational and tertiary courses in the STEM area (e.g., Ertl et al., 2019; Jacob et al., 2020; Federal Ministry of Education and Research (BMBF), 2015; Quaiser-Pohl, 2012). Moreover, students' interests can also impact the course selection (e.g., Holmegaard et al., 2014). Consequently, an indirect effect of gender on educational decisions through specialized interest is plausible to assume. However, the indirect effects of gender and interest were not analyzed in the current model and should be investigated in future research.

Limitations

This study provides important findings on relevant predictors of students' competence development in upper secondary education in Germany. Using the advantages of the large longitudinal sample of the NEPS, the present study considered data from two competence domains over six years. However, besides the benefits of longitudinal data, several limitations have to be mentioned. One potential limitation of this study can be found in the test procedure of the NEPS competence tests, as competence values towards the top and bottom end of the distribution are harder to estimate based on a short test. With less than 30 items per wave and domain, precisely differentiating at the tails of the normally distributed WLEs was difficult. This might have led to under- or overestimated competences and thus incorrectly estimated competence development for these students.

Another difficulty of the dataset was the high number of missing values. With roughly 60% of values missing in some competence tests due to missing by design and student drop-out, dealing with missing data is especially important. However, previous research showed that appropriate analyses models allow for studying competence trajectories even with high missingness (Zinn & Gnambs, 2018). As such, the imputation model was crucial for the robustness of the results. While we tried to include all relevant variables for this question in the imputation model (all competences, predictors, and controls also used in the LCSM and regressions), it is always possible that we overlooked some important factors that could distinctively change the imputation and thus the estimation.

Conclusion and Outlook

Overall, the results of this paper showed that students who specialize their interest and educational trajectories in either mathematics or reading also showed higher competence development in the respective domain. Meanwhile, gender effects showed that male students could build on their existing competence advantage in mathematics while closing the competence gap in reading competences. These results fit our initial assumptions and the current research in this area. Furthermore, the results help explain the overall trend of the sample towards a higher mathematical competence development. Finally, they also hinted at which students might be more likely to specialize in mathematical competences to a higher degree: male students, students with a specialized interest in mathematics, and students in mathematically specialized education. Students with a specialized interest in the German language and reading specialized education might be less likely to specialize in mathematics.

More research into the use of competence specialization is still necessary to explain individual differences in specialization and the overall trend of higher mathematical competence development. Finally, a complete look at secondary education from beginning to end or even a complete look at the entirety of formal education would be fascinating to see which factors influence students most strongly in which educational periods.

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Table 1: Summary and correlation of the competences and predictors

		M	*SD*	Number of imputed Values	Correlation Reading G9	Reading G12	Reading G12+3	Mathematics G9	Mathematics G12	Mathematics G12+3	Interest	Gender	Unspec. educ.
Reading	Grade 9	0.00	1.00	1,115									
	Grade 12	0.22	0.65	9,258	.65*								
	Grade 12 + 3 years	0.32	0.59	8,199	.58*	.65*							
Mathematics	Grade 9	0.00	1.00	489	.54*	.56*	.55*						
	Grade 12	0.57	0.84	9,328	.44*	.50*	.51*	.70*					
	Grade 12 + 3 years	0.78	0.98	8,165	.47*	.52*	.58*	.68*	.68*				
	Specialization of interest	0.00	1.00	1,646	-.22*	-.20*	-.14*	.09*	.16*	.13*			
	Gender[1]	0.50	/	14	-.13*	-.11*	.01	.16*	.23*	.23*	.34*		
Education	Generalized education[2]	0.63	/	5,269	-.03*	-.05*	-.08*	-.17*	-.22*	-.21*	-.17*	-.29*	
	Mathematics specialized[2]	0.31	/	5,269	-.05*	-.03*	.01	.14*	.21*	.20*	.28*	.38*	.-87*

Note: Means of dichotomous variables can be read as proportions of total populations.. * $p < .01$; [1]Coding: 0: girls; 1: boys. [2]Reference category is reading specialized education.

Table 2. Regressions of Growth Parameters

Independent variables	Dependent variables			
	Intercept in…		Slope in…	
	Reading	Mathematics	Reading	Mathematics
Gender[1]	-.15* (.02)	.25* (.02)	.04* (.01)	.22* (.02)
Specialization of interest	-.15* (.01)	.10* (.01)	-.05* (.01)	.07* (.01)
Mathematical education[2]	-.14* (.03)	.07 (.04)	-.05* (.02)	.14* (.02)
Generalized education[2]	-.17* (.03)	-.09* (.03)	-.09* (.02)	-.02 (.02)
Reasoning ability	.30* (.01)	.26* (.01)	.10* (.01)	.17* (.01)
Highest ISEI	.08* (.01)	.09* (.01)	.07* (.01)	.07* (.01)
School type	.62* (.02)	.87* (.03)	.26* (.02)	.34* (.02)
Migration background	-.30* (.02)	-.20* (.02)	-.11* (.02)	-.16* (.02)

Note. Standardized effects. Standard errors in brackets. [1]Coding: 0: girls; 1: boys. [2]Reference category for mathematical and generalized education is reading specialized education. * $p < .01$