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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	<u>89</u>				
3	55,721	.89	.093	5,021	<u>90</u>	<u>90</u>			
4	55,729	.85	.099	4,889	<u>119</u>	<u>103</u>	<u>89</u>		
5	55,742	.84	.093	4,794	<u>158</u>	<u>144</u>	<u>101</u>	<u>4</u>	
6	55,759	<u>.67</u>	.339	3,965	849	<u>203</u>	<u>125</u>	<u>55</u>	<u>4</u>

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

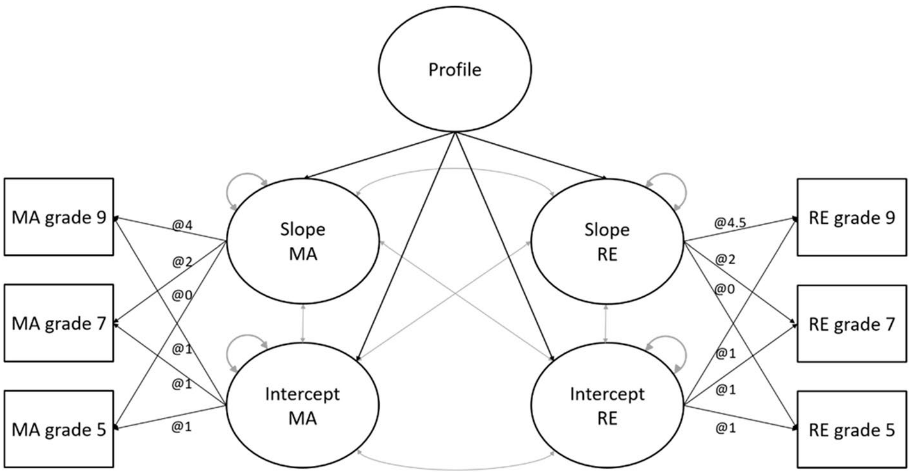

Fig. 1 Dual-process latent growth model for competence development in mathematics (MA) and reading (RE). Note. Constrained parameters are indicated with "@"

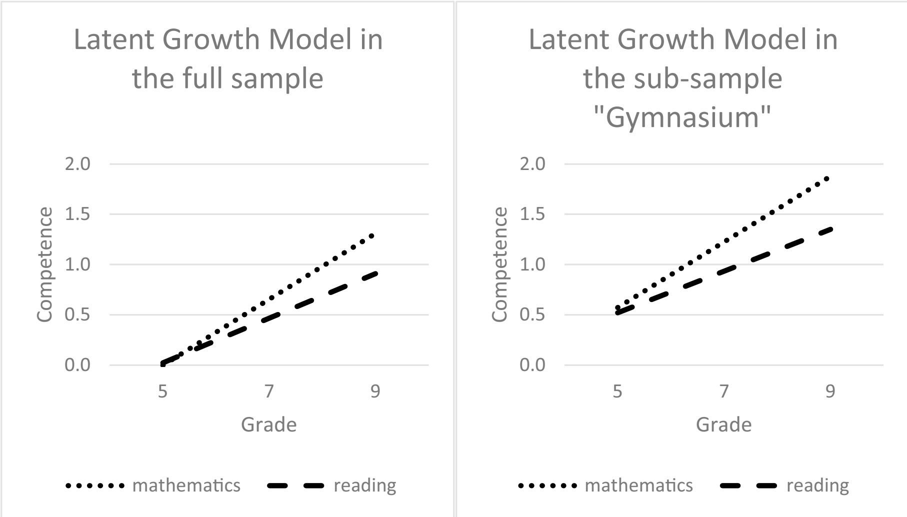

Fig. 2 Growth trajectories in the full sample (left) and the sub-sample "Gymnasium" (right)

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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:

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