Self-Regulated and Externally Regulated Learning in Adolescence: Developmental Trajectories and Relations with Teacher Behavior, Parent Behavior, and Academic Achievement

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Abstract

Both self-regulation and external regulation are key to understanding adolescents' learning and positive development at school. However, evidence on the joint development of self-regulated learning and externally related learning during adolescence is lacking. In addition, the current knowledge on interrelations between the development of adolescents' self-regulated learning, externally related learning, behaviors of teachers and parents in terms of autonomy support and achievement pressure, and academic achievement is very limited. The present multi-level longitudinal analysis focusing on the domain of mathematics (N = 1,542 German adolescents; annual assessments from grade 5 to 9; mean age at grade 5 = 11.79 years, SD = 0.71, 51.75 % female) addressed these gaps. Results from multi-level latent basic growth curve models showed that self- and externally regulated learning decreased over the five years at both the individual student and the class level. Changes in self- and externally regulated learning were linked: classes with higher levels of self-regulated learning at grade 5 showed a stronger decrease in externally regulated learning over time. Initial levels of and changes in student-reported teacher and parental autonomy support and achievement pressure were associated with self- and externally regulated learning at the individual student level; student-reported teacher autonomy support and self-regulated learning were also linked at the class level. Self-regulated learning related positively to standardized achievement test scores but not to adolescents' grades. This study adds to the scarce evidence base on different regulatory forms of adolescents' learning and can inform future research on adolescents' positive development and educational practice.

Keywords: self-regulated learning, external regulation, academic achievement, autonomy, adolescence

Public Significance Statement

This study indicated that adolescents became less self-regulated in their mathematics learning over time; however, their externally regulated learning declined as well. If teachers and parents supported their autonomy, adolescents reported higher levels of self-regulated learning, whereas adolescents who experienced that their teachers and parents pushed them to perform better at school and had unrealistic academic expectations (i.e., achievement pressure) exhibited higher levels of externally regulated learning. Teachers and parents should refrain from exerting achievement pressure and increase their provision of autonomy support for adolescents' mathematics learning as a means to promote self-regulated learning.

Self-Regulated and Externally Regulated Learning in Adolescence: Developmental Trajectories and Relations with Teacher Behavior, Parent Behavior, and Academic Achievement

The ability to self-regulate one's learning is a key skill in our rapidly changing society and a prerequisite for successful life-long learning, well-being, and personal growth (e.g., OECD, 2019; Council of the European Union, 2019; Stoeger et al., 2014). Self-regulated learning (SRL) refers to individuals' capacity to take an active role in navigating their learning experiences. SRL skills embrace a set of strategies such as planning, monitoring, and evaluating one's work, setting goals for learning, and raising and maintaining one's motivation (e.g., Dent & Koenka, 2016; Goetz et al., 2013; Panadero, 2017; Zimmerman, 2000). Adolescence is a critical period for the development of SRL (Dent & Koenka, 2016; McClelland et al., 2018). In addition to adolescents' engagement in SRL, however, adolescents' learning can also be externally regulated. Externally regulated learning (ERL) occurs when adolescents' learning heavily depends on the guidance and control of others, such as teachers (Stoeger et al., 2014; Vermunt & Donche, 2017).

Several longitudinal studies have documented declines in adolescents' engagement in SRL (e.g., Helle et al., 2013; Wang & Eccles, 2012a; Wang & Pomerantz, 2009; Ziegler & Openakker, 2018). By contrast, there is a lack of research on changes in ERL and on links between the development of these two forms of regulating learning in adolescence. In order to achieve a more comprehensive understanding of the regulation of learning during the school years and contribute to developmental theorizing, it is necessary to take both SRL and ERL into account. Hence, longitudinal studies with repeated assessments over multiple years charting developmental trajectories of both SRL and ERL in adolescence are required. In addition, whereas teacher and parent autonomy support have been found to be related to adolescents' SRL (e.g., Flunger et al., 2019; Schuitema et al., 2016), other relevant behaviors, such as teachers' and parents' achievement pressure, have received less attention. Concerning adolescents' ERL, there is a dearth of knowledge on relations to teacher and parent behaviors. This severely limits current understandings of the role of teachers and parents as important socializers for adolescents' SRL and ERL. Lastly, even though a substantial amount of research on relations between adolescents' SRL and academic achievement exists, many previous studies have been cross-sectional (see e.g., in Dent & Koenka, 2016). No study has yet addressed relations between secondary school students' ERL and academic achievement, and research on achievement and ERL in university students has been inconsistent (e.g., Fryer et al., 2016; Vermunt, 2005). Hence, research adopting a developmental lens to the study of early to middle adolescents' SRL, ERL, and academic achievement by shedding light on their longitudinal associations is warranted.

As such, the present study aimed to investigate interrelations between the development of adolescents' SRL, ERL, behaviors of teachers and parents (autonomy support and achievement

pressure), and academic achievement in secondary school. We investigated these relations in the context of mathematics as an especially important school subject (e.g., OECD, 2014; Peixoto et al., 2017). Hence, all constructs referred to mathematics and mathematics learning.

SRL and ERL in Adolescence

With regard to different ways in which individuals' learning can be regulated, internal versus external control of learning has been identified as a main distinguishing dimension (e.g., Vermunt & Vermetten, 2004). When engaging in internally regulated learning (i.e., SRL) students perform regulatory activities themselves, and are thus metacognitively, motivationally, and behaviorally active in their own learning (Zimmerman, 1986; Zimmerman, 2000). In contrast to this pattern, students can let their learning process be regulated by external sources. Students who are externally regulated in their learning rely on the guidance and control of others, such as teachers and parents (e.g., Stoeger et al., 2014; Vermunt & Vermetten, 2004). Hence, externally regulated students need others (e.g., the teacher) to decide for them when, how, and how long to learn and to provide information on their learning progress. Whereas SRL has been studied in samples of school-aged and university students, most research on ERL has been carried out in higher education settings (e.g., Vermunt & Donche, 2017). However, from a developmental perspective, younger students require more structure and guidance by parents and teachers than older students (see also e.g., Bernier et al., 2010). Even though very young (elementary) school students should depend most on ERL, ERL likely continues to be relevant in adolescence as well. For instance, adolescents are in the early stages of fully developing meta-cognitive learning strategies and learning-related skills, and thus still need external guidance (e.g., Thomas et al., 2019). Moreover, (early) adolescence coincides with the transition from elementary school to the more challenging context of secondary school, which marks a dramatic change in the school environment and the nature of academic tasks. These changes in the learning environment pose demands on adolescents' SRL, underlining the relevance of SRL in secondary school (e.g., Dent & Koenka, 2016; Jindal-Snape et al., 2020). At the same time, when students navigate the challenging transition to secondary school and the first years in secondary school, they have been found to still strongly rely on teachers and parents to inform their approaches to learning (e.g., Gniewosz et al. 2012; Thomas et al., 2019). This suggests that ERL is significant in this period as well. Overall, only accounting for one regulatory form (primarily SRL in previous research) has likely led to an incomplete understanding of how learning in adolescence is regulated. Accordingly, research investigating the concurrent development of both SRL and ERL during adolescence is needed to gain a more differentiated perspective on adolescents' learning.

Developmental Trajectories of SRL and ERL in Adolescence

Average developmental trajectories of SRL and ERL in adolescence can be understood from different theoretical perspectives. One perspective refers to what adolescents are able to do, and is strongly informed by research on age-dependent normative changes in self-regulatory capacities.

Specifically, adolescence has been portrayed as a turning point in the development of self-regulation (McClelland et al., 2018). During adolescence, competencies needed for advanced self-regulation emerge and grow, with substantial improvements in meta-cognitive monitoring, reflection, and executive function skills (e.g., Dent & Koenka, 2016; Diamond, 2013; McClelland et al., 2018). From this perspective, SRL should gradually increase during adolescence, whereas ERL should decrease. However, some caution is warranted as related studies assessed adolescents' self-regulation more broadly and not SRL specifically (Dinsmore et al., 2008). SRL focuses on the context of academic learning and can be regarded as a contextualized application of self-regulation (Wolters, 2005). Studies on the development of self-regulation have often used experimental materials and procedures that are devoid of any educational context (e.g., Effeney et al., 2013), raising the possibility that results may not generalize to SRL in specific academic domains (here: mathematics learning).

A second, more context-specific perspective focuses on adolescents' perceptions of what they actually chose to do. An example is stage-environment fit theory and respective research documenting declines in adolescents' (adaptive) motivation and learning behavior (e.g., Eccles & Roeser, 2009). Stage-environment fit theory suggests that a mismatch between adolescents' growing desire for autonomy and control and their perceptions of opportunities in their social environment may lead to academic disengagement, including decreases in SRL (e.g., Eccles & Roeser, 2009; Scherrer & Preckel, 2019; Wang & Pomerantz, 2009). Hence, even though adolescents could take advantage of their growing self-regulatory capacities, they may deliberately choose not to apply them in the academic context, particularly in mathematics as a domain that repels many students during adolescence (e.g., Frenzel et al., 2010). Increased striving for independence combined with the general downward trend in academic engagement in adolescence may also conflict with the strong reliance on teachers and parents that is implied in ERL (e.g., Mastrotheodoros et al., 2019), possibly leading to decreases in ERL over time as well. Therefore, a declining trajectory for both SRL and ERL over the adolescent years seems plausible. A number of longitudinal studies have reported decreases in adolescents' reports of adopting SRL (e.g., Helle et al., 2013; Schuitema et al., 2016; van der Veen & Peetsma, 2009; Wang & Eccles, 2012a; Wang & Pomerantz, 2009; Ziegler & Openakker, 2018). Yet conversely, other studies indicated no changes (e.g., Pintrich, Roeser, & De Groot, 1994; Schuitema et al., 2016, for the use of meta-cognitive learning strategies). Importantly, none of these studies has considered ERL, and most of them covered relatively short periods of time, from several months to two school years. Thus, research on both SRL and ERL that follows secondary school students longitudinally over an extended period of time is warranted.

Interrelations between SRL and ERL

In addition to research on the average development of SRL and ERL in adolescence, it is important to investigate links between these two regulatory forms of adolescents' learning. As SRL

and ERL are characterized by distinct foci on internal versus external dimensions of learning, scoring high on SRL may go along with lower levels on ERL. On the other hand, given that SRL and ERL are both drivers for learning, they may coexist, which would entail a positive relation between these two forms of regulation (Donche & Van Petegem, 2009). These seemingly contrasting predictions can be integrated by considering the developmental stage of the studied population. First, in childhood and early adolescence, levels of SRL and ERL may be more closely and positively connected as different regulatory processes may be less differentiated (for similar findings with regard to motivation, see Bong, 2009). As children grow older, and during adolescence when students are in secondary school, regulatory processes likely become more differentiated; hence, scoring high on SRL may forecast decreases in ERL. There is a dearth of research on these issues in adolescence, and findings from research with university students have been mixed. For example, studies have reported significant positive associations (Fryer et al., 2016; Vermetten et al., 2001), no statistically significant relations (Loyens et al., 2008), as well as small negative, albeit non-significant correlations (Heikkilä & Lonka, 2006) between university students' SRL and ERL.

Associations with Teacher and Parent Behavior

What factors set the scene for adolescents' engagement in SRL and ERL? Adolescents' development occurs in different contexts (e.g., at school and at home). Theoretical frameworks such as ecological systems theory and transactional models describe ways in which developmental contexts and relationships with others in these contexts influence and are influenced by adolescents' development of self- regulation (Bronfenbrenner, 1986; Sameroff, 2009; see also Farley & Kim-Spoon, 2014). Following these theories, SRL and ERL in adolescence evolve through interaction with different socialization agents, including parents and teachers (e.g., Pino-Pasternak & Whitebread, 2010; Thomas et al., 2020).

Concerning specific teacher and parent behaviors, student-centered behaviors that grant students responsibility for their own learning (such as teachers' and parents' autonomy support) are conceptually close to SRL, whereas controlling behavior characterized by external pressures likely increases the use of ERL (e.g., Núñez & León, 2015). More specifically, it is plausible to assume that autonomy support from teachers and parents is critical to shape students' SRL. Autonomy support has received significant attention in research on SRL, with several studies pointing towards positive associations between autonomy support provided by teachers or parents and students' SRL (e.g., Flunger et al., 2019; Jang et al., 2010; Schuitema et al., 2016). On the other hand, it seems likely that autonomy support should be negatively related to ERL, which, by definition, depends on the guidance and control by others (e.g., Vermunt & Vermetten, 2004).

A promising candidate for school- and home-based influences tapping into a more controlling dimension of teacher and parent behavior is teachers and parents' achievement pressure (also referred to as socio-academic pressure, Wang & Eccles, 2012b; Raufelder et al., 2015).

Achievement pressure can be defined as the extent to which teachers or parents push a student to work more intensely (behavioral aspect) or have unrealistically high expectations that exceed the child's actual capacity and thus put the child under emotional pressure (emotional aspect; Murayama et al., 2016; Wang & Eccles, 2012b; Raufelder et al., 2015; Kulakow et al., 2021). Achievement pressure by teachers or parents generally shows an unfavorable pattern of relations to student outcomes, such as negative associations with engagement or academic achievement (e.g., Raufelder et al., 2015) and positive associations with stress and test anxiety (Kulakow et al., 2021). Achievement pressure could give rise to elevated levels of ERL as students may feel compelled to rely on those who exert pressure to guide their learning. For the same reasons, achievement pressure seems likely to undermine SRL (e.g., Lorenz & Wild, 2007).

With regard to developmental trajectories of teacher and parent behaviors, aligned with stage-environment-fit theory, adolescents' reports suggest that autonomy support for their learning by both teachers and parents declines over time (see e.g., Schuitema et al., 2016). Stage-environment-fit theory stresses that adolescents may experience that secondary school teachers do not provide them with the opportunity to make decisions to the extent they desire, increasingly causing conflicts with adolescents' growing need for autonomy. Similarly, parental autonomy provision may not be perceived as sufficient, implying that adolescents' perceptions of parental autonomy also decline (Eccles & Roeser, 2009; Wang & Pomerantz, 2009). By contrast, parents' own perceptions of their autonomy support may remain stable or even increase. Theories on parenting and previous research using parent reports indicate that parents believe that they grant adolescents more autonomy as they grow older (see e.g., Wray-Lake et al., 2010).

Moreover, compared with elementary school, a stronger performance-oriented climate prevails in secondary school (see research on classroom goal structures, e.g., Maehr & Zushno, 2009), which likely manifests in higher levels of achievement pressure exerted by teachers and parents in secondary school (e.g., Song et al., 2015). However, this finding before and after the secondary school transition may not generalize to the development of achievement pressure over the subsequent secondary school years. For instance, achievement pressure by teachers and parents may further increase during adolescence as the end of compulsory schooling is approaching, and academic tasks get increasingly more complex over the secondary school years. It also seems conceivable that achievement pressure exhibits a stable trajectory as teachers and parents constantly push adolescents to perform better, particularly in the context of mathematics, which is typically among the subjects that students find most difficult and therefore tend to struggle with (e.g., Blackwell et al., 2007; Peixoto et al., 2017).

Associations with Academic Achievement

SRL exhibits positive associations with educational achievement in different age groups, as documented in several meta-analyses based on correlational and intervention studies (e.g., Dent &

Koenka, 2016; Dignath & Büttner, 2008). For example, the meta-analysis of Dent and Koenka (2015) has shown that students' self-reported meta-cognitive skills as a core component of SRL were positively correlated with their academic achievement. Contrasting the authors' assumption that correlations should be stronger for standardized achievement measures than for grades because grades reflect a range of factors beyond learning (such as class participation), moderator analyses did not reveal significant differences between the associations with grades versus standardized test scores (Dent & Koenka, 2016). In their meta-analysis on intervention studies in the domain of SRL, Dignath and Büttner (2008) furthermore found that such interventions were effective in secondary school in that they positively influenced academic achievement.

Studies on relations between ERL and academic achievement have produced mixed findings. Some studies yielded zero relations or even positive links between ERL and academic achievement at university (e.g., Fryer et al., 2016), whereas others revealed negative associations (e.g., Vermunt, 2005). ERL has been found to go hand in hand with learning strategies detrimental to academic performance (surface learning approaches) and negative emotions (Ferla et al., 2008; Pekrun et al., 2002, 2011) which may underlie negative effects of ERL on achievement. However, all previous findings have been obtained with samples of university students, and higher education settings differ in many regards from secondary school contexts. Hence, there is a need to test the relation between ERL and academic performance in early periods of adolescence as well.

A Multi-Level Perspective on Interrelations between Changes in SRL, ERL, Teacher and Parent Behavior, and Achievement

Even though SRL and ERL are primarily features of individual students, students also belong to higher-level units like schools or classes. In Germany, where the present study was conducted, secondary school students spend a considerable amount of time with their peers in class, and students within the same class have the same teachers. Hence, the classroom represents the broader context in which individuals' learning occurs, and different classes constitute qualitatively distinct learning environments (e.g., Lüdtke et al., 2009). While it is not assumed that SRL and ERL show distinct developmental trajectories at the individual versus class level, relations between changes in SRL and ERL and other focal constructs could differ between the two levels. In particular, in German secondary schools, students within a class share the same teachers, and teachers' behaviors are often directed to the whole class. For relations to characteristics specific to the classroom or the teacher, the classroom level therefore represents a critical level of analysis (e.g., Morin et al., 2014). At the same time, there is evidence to suggest that teacher behavior also matters at the individual student level, albeit in different ways (e.g., Lazarides & Watt, 2015; Parrisius et al., 2020; Wentzel et al., 2017). This could be related to the fact that a group of students is differentially motivated and engaged by a teacher's behaviors and reacts differently to teacher behavior than an individual student. On the other hand, associations with parent variables mapping individual

students' experiences with their parents should be primarily located at the individual student level. Expanding the focus from the individual self- or externally regulated student to adopt a multi-level perspective on interrelations between SRL, ERL, and further constructs could thus yield illuminating insights. Methodologically, the clustering of students in classes and the fact that students within the same class are more similar than students between classrooms as they belong to the same learning environment requires a methodological approach such as multi-level modeling that can appropriately account for hierarchical data structures (e.g., Snijders & Bosker, 2011).

The Present Study

Both SRL and ERL are key to understanding students' learning at school. However, there is a lack of longitudinal research exploring adolescents' developmental trajectories in SRL and ERL. In addition, no longitudinal study has scrutinized joint associations between adolescents' SRL and ERL on the one hand, and teacher behaviour, parent behavior, and academic achievement on the other hand. This study aimed to shed light on how adolescents' SRL and ERL unfold over five years, on the role of teachers' and parents' autonomy support and achievement pressure for these trajectories, and on links of SRL and ERL with academic achievement (standardized achievement test scores, school grades).

The study was conducted in the context of mathematics. Mathematics is one of the most important school subjects, and poor mathematics skills have detrimental consequences for students' life beyond graduation (e.g., limiting access to better-paying and more rewarding jobs, OECD, 2014; Peixoto et al., 2017). SRL, ERL, and teacher and parent behaviors were assessed with student reports. However, student data were triangulated with parent data by also considering parent reports of autonomy support. We used multi-level latent basis growth modeling (e.g., McArdle & Epstein, 1987) to investigate the research questions, and estimated all relations of interest at both the individual student and the class level.

Research Question 1: How do SRL and ERL change over time? Aligned with existing shorter-term longitudinal studies and stage-environment fit theory, we hypothesize that SRL decreases during adolescence (e.g., Eccles & Roeser, 2009; Wang & Pomerantz, 2009). We furthermore cautiously propose that ERL may decrease as well. In adolescence the academic domain is often devalued, while at the same time, adolescents increasingly strive for independence. Theoretically, both developmental trends likely conflict with adolescents' commitment to ERL. Regarding relations between initial levels of and changes in SRL and ERL, due to the lack of relevant research in adolescence and mixed findings in studies of university students, no hypotheses are specified, and exploratory analyses are conducted.

Given that further aims of the study centered on linking initial levels of and changes in SRL and ERL to initial levels of and changes in teacher and parent behaviors and academic achievement (see Research Questions 2 and 3), developmental trajectories of all other variables were investigated

too. In accordance with stage-environment-fit theory (e.g., Eccles & Roeser, 2009), student-perceived autonomy support by both teachers and parents is likely to decrease over time. In contrast, parents' perceptions of their autonomy provision may remain rather stable or even increase, in line with theories on parenting and previous research on autonomy support using parent reports (see e.g., Wray-Lake et al., 2010). We make no assumptions regarding changes in teachers and parents' achievement pressure due to different and contrasting plausible developmental trajectories (e.g., increasing versus stable). Following prior research, it is expected to detect growth in achievement test performance over the five years (e.g., Rescorla & Rosenthal, 2004). On the other hand, school grades reflect multiple further aspects in addition to actual performance, such as class participation and engagement, and grades are teacher-assigned. School grades thus presumably either remain relatively stable (reflecting the grading-on-a-curve phenomenon, e.g., Brookhart et al., 2016; Kulick & Wright, 2008) or decrease (reflecting stage-environment-fit theory and prior findings, see e.g., Wang & Pomerantz, 2009).

Research Question 2: How are initial levels of and changes in SRL and ERL associated with teacher and parent behavior? We hypothesized that higher initial levels of parents and teachers' autonomy support in grade 5 should be positively linked[1] to initial levels of SRL and changes (in terms of increases or weaker decreases) in SRL and negatively linked to initial levels of ERL and changes (in terms of decreases or weaker increases) in ERL. Moreover, we propose that changes in parents' and teachers' autonomy support should be positively linked to changes in SRL and negatively linked to changes in ERL. Stronger effects will emerge for student- than for parent-reported autonomy support: From a socio-cognitive perspective, students' subjective interpretations of the context should matter more for their learning (e.g., Lüdtke et al., 2009). By contrast, higher initial levels of teachers' and parents' achievement pressure should be negatively associated with initial levels of and changes in SRL, and positively associated with initial levels of ERL and changes in ERL. Furthermore, we hypothesize that changes in parents' and teachers' achievement pressure should be negatively linked to changes in SRL and positively linked to changes in ERL. Relations to parent variables should be mainly located on the individual student level, whereas relations to teacher variables should surface at both the individual student and the class level.

Research Question 3: How are initial levels of and changes in SRL and ERL associated with mathematics achievement? We hypothesize that higher initial levels of SRL should be positively linked to initial levels of and changes in academic achievement. The opposite pattern should emerge

[1] Please note that the exact configurations of changes in SRL and ERL and other variables are not known a priori; hence, depending on these configurations, "positively linked" could indicate that higher initial levels of parents' and teacher autonomy support are associated with stronger increases in SRL (if self-regulated learning tends to increase over time) or with weaker decreases in SRL (if self-regulated learning tends to decrease over time). The same applies to relations between changes in SRL or ERL and changes in other variables.

for initial levels of ERL in that higher levels of ERL at grade 5 should be negatively linked to initial levels of achievement and changes in academic achievement. Lastly, we presume that changes in SRL should be positively linked to changes in academic achievement, and that respective changes in ERL should be negatively linked to changes in academic achievement.

Method

Participants and Procedure

We used data from the longitudinal study of the *Project for the Analysis of Learning and Achievement in Mathematics* (PALMA, Pekrun et al., 2006, 2007, 2017; Marsh et al., 2018, Murayama et al., 2013, 2016) conducted in the German federal state of Bavaria. The sample used in the current study included 1,542 students from 114 classes and 43 schools, with on average 13.53 students per class (*SD* = 9.80). In the German secondary school system, students attend all or at least most lessons together as a classroom. In addition to having the same peers, students within a class also share the same teachers. Hence, what students experience during their school day reflects to a large part their experiences within the classroom as most immediate context (see also e.g., Schachner et al., 2021). Data analyzed in this study was collected over five years with each measurement approximately one year apart, with students beginning the study in grade 5 and ending the study in grade 9. The sample consisted of students who did not change class and did not repeat a grade as our multilevel modeling approach required a consistent assignment to second-level units (i.e., classes). In addition, we excluded classes for which only data from one student was available, and students who did not respond to any of the items assessing SRL and ERL.

At the first measurement point, the students were on average 11.79 years old (*SD* = 0.71), 51.75% identified as females, and 91.32 % of the students who reported their country of origin were native-born students. In Germany, at the end of primary school students are allocated to different tracks based on prior achievement. In our sample, a total of 29.83% of the students attended the highest track preparing students for university (Gymnasium), 28.34 % the intermediate track (Realschule), and 41.80% the lower track (Hauptschule). Most German states, including Bavaria, track students in the threefold school system consisting of Gymnasium, Realschule, and Hauptschule. Hauptschule is to a large part vocationally oriented and represents the school track with the lowest academic demands. The curriculum of Realschule, the intermediate track, focuses on general education, but also lays the foundation for future vocational careers. As compared to Hauptschule, Realschule offers better opportunities for acquiring higher educational qualifications. Lastly, Gymnasium is the academically most demanding track, and passing the final examination of Gymnasium entitles students to study at university (e.g., Frenzel et al., 2010). All measures were administered towards the end of each school year (May or June) by trained external test administrators in the students' classrooms. Parent questionnaires were answered individually. Parental permission was needed for students to participate. The studies of the PALMA project

received Institutional Review Board approval from the Bavarian State Ministry for Education, Science, and the Arts (reference III/5-S4200/ 4–6/68 908).

Missing Data

This study's missing data pattern reflect a common issue when conducting longitudinal studies with multiple measurement points in naturalistic classroom settings. There were 214 adolescents (13.88%) participating in one, 514 adolescents (33.33%) in two, 162 adolescents (10.51%) in three, 342 adolescents (22.18%) in four, and 310 adolescents (20.10%) in five waves of measurement. To investigate attrition mechanisms, a series of Welch's tests with Bonferroni-Holm correction was conducted to test mean differences between the five groups. Results showed no statistically significant differences between the five groups in any of the variables, with effect sizes ranging between $\eta^2 = .000$ and .072. In addition, there was no reason to assume that the absence of students at one wave of data collection might be systematically related to the investigated variables. Full information maximum likelihood estimation (Enders, 2010) was used to handle missing data.

Measures

SRL and ERL, teacher and parent autonomy support, and achievement pressure were measured using student questionnaires. Parent autonomy support was additionally assessed via parent ratings. Two achievement indicators were used, namely standardized achievement test scores and students' school grades in mathematics. All questionnaire items relied on a five-point response scale, ranging from "not at all true" to "absolutely true". We report ω reliability coefficients for all multiple-item measures and Spearman-Brown coefficients for the two scales with two items. The Spearman-Brown coefficient is a more appropriate reliability statistic for two-item scales than Cronbach's Alpha or the Pearson correlation (Eisinga et al., 2013). We furthermore report the results from multilevel confirmatory factor analyses (ML-CFAs, Hox et al., 2018) set up to test the adequacy of the measurement models of all multiple-item scales. The items of all scales can be found in Online Supplement A1.

SRL and ERL

SRL and ERL were assessed with six and five items, respectively, based on Goetz (1998). The items have been used and refined in several cross-sectional and longitudinal studies (see e.g., Pekrun et al., 2002, 2011). The items reflect different phases described in cyclical models of SRL (for an overview of models, see Panadero, 2017). Specifically, the items for SRL refer to goal setting and planning strategies, strategies students employ during learning, and students' monitoring and evaluations of their learning (sample item: "When I learn mathematics, I set myself goals and try to achieve them"). The items capturing ERL focus on regulation directed by others (sample item: "How long I spend on mathematics largely depends on my teacher"). Coefficient ω reliabilities for the SRL scale were .67, 71, .68, .66, and .69 for waves 1-5, respectively. For ERL, ω coefficients were .68, .59, .69, .68, and .67 for waves 1-5, respectively. Both SRL and ERL are complex and

multi-dimensional constructs combining multiple different components and phases, and particularly ERL strategies have a history of exhibiting low reliability coefficients. Still, the reliability of the ERL scale, even for the measurement point with the lowest score, is generally consistent with prior studies (Edelbring, 2012; Fryer et al., 2016; Heikkilä & Lonka, 2006). Moreover, the results from ML-CFAs revealed an excellent level of fit to the data for the scales assessing SRL and ERL for all five waves, providing support for their psychometric quality (for SRL: CFI ranging between .998 and 1.000, and RMSEA ranging between 0.000 and 0.039 for the five waves; for ERL: CFI ranging between .990 and 1.000 and RMSEA ranging between 0.000 and 0.027 for the five waves, see Table S1 in the Online Supplement for details).

Teachers' Autonomy Support

The items of the scale assessing students' perceptions of their teacher's autonomy support were adapted from Wild et al. (2001; five items, sample item: "My mathematics teacher lets us try to solve tasks ourselves"). Coefficient ω reliabilities were 71, .77, .70, .72, and .76 for wave 1-5, respectively. The results from ML-CFAs indicated a good model fit for all waves (CFI ranging between .964 and .998, and RMSEA ranging between 0.016 and 0.061 for the five waves, see Table S1).

Parents' Autonomy Support – Student Perspective

Two items based on Wild et al. (2001) were used to capture students' perceptions of their parents' autonomy support (sample item: "My parents encourage me to try and find the correct solution myself before helping me with mathematics homework"). Spearman-Brown coefficients were .61, .77, .68, .72, and .78 for waves 1-5, respectively.

Parents' Autonomy Support – Parents' Perspective

Two items parallel to those assessing student-perceived autonomy-support based on Wild et al. (2001) were used (sample item: "We encourage our son/daughter to try finding the correct solution themself before helping with mathematics homework"). Spearman-Brown coefficients were .61, .63, .63, .80, and .76 for waves 1-5, respectively.

Teachers' Achievement Pressure

The scale mapping students' perceptions of their teacher's achievement pressure were based on Wild et al. (2001), Pekrun (1983), and Jacob (1996). Five items were employed (sample item: "My mathematics teacher expects me to perform better than I am capable of"). Coefficient ω reliabilities were .70, .74, .65, .66, and .69 for waves 1-5, respectively. The results from ML-CFAs showed excellent measurement properties of the scales for all waves (CFI ranging between .975 and 1.000, RMSEA ranging between 0.000 and 0.046 for the five waves, see Table S1).

Parents' Achievement Pressure

A six-items scale was used to map parents' achievement pressure. The items were based on Wild et al. (2001), Pekrun (1983), and Jacob (1996). A sample item of the scale is "Even if I try very

hard, my parents are rarely completely satisfied with me." Coefficient ω reliabilities were .75, .76, .73, .76, and .76 for wave 1-5, respectively. The results from ML-CFAs indicated that the measurement models fit the data well (CFI ranging between .959 and .998, RMSEA ranging between 0.013 and 0.055 for the five waves, see Table S1).

Grades

Grades in mathematics on students' last school report (end of term grades) were used, which are in the German school system typically based on scores for written exams combined with scores for course-specific oral exams. In Germany, school grades range from 1 (excellent) to 6 (not acceptable). Grades were inverted prior to the analyses, so that higher values reflected higher achievement.

Standardized Achievement Test Scores

The Regensburg Mathematical Achievement Test (vom Hofe et al., 2002; vom Hofe et al., 2005) was used to measure students' mathematics competence. This test assessed students' modelling competencies and algorithmic competencies in arithmetic, algebra, and geometry (vom Hofe al., 2005). The test was constructed using multimatrix sampling relying on a balanced incomplete block design (see vom Hofe et al., 2002). For each wave, two different test versions were prepared containing approximately 60–90 items each, and students completed one of these two test booklets. The tests included anchor items allowing for the linkage of the two different test forms as well as the different waves. Achievement scores were scaled using one-parameter logistic item-response theory (Rasch scaling; Wu et al., 2007; see Murayama et al., 2013).

Analytic Approach

We estimated multilevel latent basis growth models (McArdle & Epstein, 1987; Meredith & Tisak, 1990) with two analytic levels (Level 1: student, Level 2: class). The latent basis model is a flexible growth model for modelling nonlinear change patterns, where the nonlinear change is derived in a data-driven manner. That is, factor loadings at the individual student and class level for the first wave are constrained to 0 and the factor loadings for the last wave are constrained to 1, while all intervening factor loadings are freely estimated. As a result, the mean of the slope factor is interpreted as the total amount of change across all waves of measurement, while the factor loadings correspond to the proportion of total change that has occurred up to and including that wave (McNeish, 2020).

In the first step, we estimated univariate growth models for each variable separately to investigate the change at the student and class levels. In the second step, a bivariate growth model for SRL and ERL was set up to examine correlations between intercept (i.e., initial levels at grade 5 in SRL or ERL) and latent slope parameters (i.e., changes in SRL or ERL). In the third step, bivariate growth models for SRL and autonomy, achievement pressure, and achievement were estimated to investigate correlations between intercept and latent slope parameters of the growth

model for SRL with intercept and latent slope parameters of the growth model for autonomy, achievement pressure, and achievement. In the fourth step, bivariate growth models for ERL and autonomy, achievement pressure, and achievement were estimated. Please note that the reported estimates are correlation coefficients and can thus be directly interpreted as effect sizes, with values of .10., .20, and .30 reflecting relatively small, typical, and relatively large effects, see Gignac et al., 2016, for effect size guidelines). Models were estimated using the Bayesian Markov Chain Monte Carlo (MCMC) method. Bayesian estimation was chosen due to model complexity: When estimating complex models, frequentist estimation methods like maximum likelihood estimation oftentimes encounter convergence problems, whereas Bayesian analysis can handle even highly complex models efficiently. Weakly informative priors were specified for all parameter of substantial interest (i.e., factor loadings and the latent mean of the intercept and slope parameters). Non-informative priors according to the program's default settings were specified for all other parameters. Specification of the prior distributions for the factor loadings and the latent mean of the intercept and slope parameters are shown in Table S2 in the Online Supplement. In addition, in Online Supplement A2 we provide a detailed text-based explanation of the chosen priors. As recommended by Hox et al. (2012), convergence was assessed using the Gelman-Rubin criterion with a stricter cutoff value of 0.01 rather than the default setting of 0.05. Eight chains were requested for the Gibbs sampler and a minimum number of 10,000 iterations were specified. All trace plots were manually inspected to check for convergence. Model fit of the growth models were evaluated using the posterior predictive *p*-value (PPP) and the 95% confidence interval for the difference between the observed and the replicated χ^2 values. A PPP value close to .50 and a χ^2 difference of 0 falling close to the middle of the confidence interval imply good fit (Muthén & Asparouhov, 2012).

Transparency and Openness

We describe the sample and procedure and report all data exclusions in detail. Data were analysed using Mplus 8.6 (Muthén & Muthén, 1998-2017). The analysis consists of a secondary data analysis of the PALMA longitudinal study which was not preregistered. The data set is currently not publicly available due to data privacy/ethical restrictions.

Results

Descriptive statistics, manifest bivariate correlation coefficients at both the individual student and the class level, and intraclass correlation (ICC) coefficients are shown in Table S3 in the Online Supplement. Whereas school grades and achievement test scores were highly stable over time, the stability of other constructs (SRL, ERL, parent and teacher behaviors) was on average lower than in previous longitudinal studies (e.g., Helle et al., 2013; Fryer et al., 2016; Schuitema et al., 2016; Song et al., 2015, Wang & Eccles, 2012a, Wray-Lake et al., 2010; Ziegler & Oppendaker, 2018). However, differences between our study and these existing studies need to be considered

(specifically, shorter time periods between measurement points in many previous studies). The highest ICC coefficients were observed for standardized achievement test scores. ICC coefficients for SRL and ERL and grades were lower, but within the range commonly observed for student characteristics such as motivation and engagement. Values for variables assessing teacher and parent behavior were generally higher for adolescents' perceptions of their teachers and lower for adolescents' perceptions of their parents, albeit the latter were comparable to those for SRL, ERL, and grades. The lowest values were obtained for parent-rated parent autonomy support. Even though recent evidence indicates that a multi-level modelling approach is appropriate even in the case of low ICC values (Bliese et al., 2017) and even though we included all variables at both levels, we thus emphasize that any relations to parent-rated parental autonomy support will likely only be located at the individual student level.

Developmental Trajectories Over Time

Results of the multilevel latent basis growth models are shown in Table S4, including factor loadings for each grade, standard deviations of all intercepts and slopes at both levels, and ICCs of all intercepts and slopes. According to the posterior predictive *p*-value and the 95% confidence interval for the difference between the observed and the replicated χ^2 values value, all models showed an acceptable model fit.

On average, SRL decreased over time (Est. = -0.41, 95% CI [-0.51, -0.30]). Similarly, on average, ERL decreased over time (Est. = -0.33, 95% CI [-0.43, -0.22]). Figure 1 displays the developmental trajectories of SRL and ERL at the student and class levels over the five-year period. Decreasing trajectories were found for all variables of autonomy support. Specifically, on average, student-perceived teacher's autonomy support decreased over time (Est. = -0.38, 95% CI [-0.50, -0.26]). Parents' autonomy support as perceived by students decreased as well, (Est. = -0.90, 95% CI [-1.05, -0.77]). Moreover, on average, parents' autonomy support as assessed via parent ratings decreased over time (Est. = -0.60, 95% CI [-0.72, -0.49]). Figure 2 provides an overview of the developmental trajectories of autonomy support on the individual student and the class level. Students' ratings of teachers' achievement pressure did not change over time on average (Est. = -0.03, 95% CI [-0.10, 0.07], whereas student-reported parental achievement pressure declined over time on average (Est. = -0.35, 95% CI [-0.45, -0.24]). Figure 3 shows the developmental trajectories for achievement pressure. Math grades did not change over time on average (Est. = -0.08, 95% CI [-0.21, 0.04]). On the other hand, standardized achievement test scores increased over time (Est. = 142.26, 95% CI [829.32, 848.24]) (see Figure 4 for the developmental trajectories of both achievement indicators).

Associations between Initial Levels of and Changes in SRL and ERL Over Time

Results of the multilevel bivariate latent basis growth model are displayed in Table 1. According to the posterior predictive *p*-value and the 95% confidence interval for the difference between the observed and the replicated χ^2 values, the model showed an acceptable model fit.

At the student level, the intercept and slope of the growth model for SRL were negatively related (Est. = -.49, 95% CI [-.66, -.19]), indicating that adolescents with higher SRL at grade 5 had a stronger decrease in SRL across time. At the class level, intercept and slope for SRL were also negatively related (Est. = -.76, 95% CI [-.94, -.24]). Moreover, at the class level the intercept for SRL was positively related with the intercept for ERL (Est. = .69, 95% CI [.08, .95]); thus, higher levels of SRL at grade 5 were associated with higher levels of ERL at grade 5. In addition, the intercept for SRL was negatively related to the slope for ERL (Est. = -.67, 95% CI [-.94, -.01]) at the class level, indicating that higher levels of SRL at grade 5 were linked to stronger decrease in ERL. Lastly, the intercept and the slope for ERL were negatively related (Est. = -.84, 95% CI [-.97, -.36]) at the student level, i.e., the higher students' ERL at grade 5, the stronger the decrease in ERL.

Associations Between Initial Levels of and Changes in SRL, Autonomy Support, Achievement Pressure, and Achievement Over Time

Results of the multilevel bivariate latent basis growth model are shown in Table 2. According to the posterior predictive *p*-value and the 95% confidence interval for the difference between the observed and the replicated χ^2 value, the model had an acceptable model fit.

At the student level, the intercept for SRL was correlated with the intercepts for student-perceived teacher autonomy support (Est. = .45, 95% CI [.22, .63]), student-perceived parental autonomy support (Est. = .71, 95% CI [.48, .88]), student-perceived parental achievement pressure (Est. = .23, 95% CI [.01, .45]), and standardized achievement test scores (Est. = .23, 95% CI [.08, .40]). Accordingly, higher levels of SRL at grade 5 were associated with higher levels of student-reported teacher autonomy support, student-reported parental autonomy support, student-reported parental achievement pressure, and standardized achievement test scores. Furthermore, the slope of the growth model for SRL was correlated with the slope for student-reported teacher autonomy support (Est. = .56, 95% CI [.20, .84]) and the intercept (Est. = -.36, 95% CI [-.62, -.03]) and slope (Est = .48, 95% CI [.11, .76]) of parental autonomy support as rated by students. Hence, a weaker decrease in student-rated teacher autonomy support was related to a weaker decrease in SRL. Moreover, lower values in student-rated parental autonomy support at grade 5 were related to a weaker decrease in SRL. In addition, a weaker decrease in student-rated parental autonomy support was correlated with a weaker decrease in SRL.

At the class level, the intercept for SRL was correlated with the intercept for student-perceived teacher autonomy support (Est. = .56, 95% CI [.28, .95]), that is, the higher students' ratings of teachers' autonomy support at grade 5, the higher students' SRL at grade 5. The slopes for SRL and student-perceived teacher autonomy support were also positively related (Est. = .81, 95%

CI [.33, .97]). Hence, a weaker decrease in student-perceived teacher autonomy support was related to a weaker decrease in SRL.

Associations Between Initial Levels of and Changes in ERL, Autonomy Support, Achievement Pressure, and Achievement Across Time

Results of the multilevel bivariate latent basis growth model can be consulted in Table 3. According to the posterior predictive *p*-value and the 95% confidence interval for the difference between the observed and the replicated χ^2 values value, the model fit was acceptable. At the student level, the intercept for ERL was correlated with the intercepts for student-perceived teacher achievement pressure (Est. = .40 95% CI [.14, .65]) and student-perceived parental achievement pressure (Est. = .47, 95% CI [.24, .67]); that is, the higher students' ratings of teacher achievement pressure and parental achievement pressure at grade 5, the higher ERL at grade 5. At the class level, correlations between intercepts and slopes of the growth models were all statistically non-significant. It should be noted that the estimates in Table 1 and 2 are correlation coefficients and can thus be directly interpreted as effect sizes. However, we also report the amount of shared variance for each relation (i.e., the amount of variation of two variables that overlaps) in the Online Supplement to provide further information (see Tables S5 and S6).

Discussion

The current study examined how adolescents' engagement in SRL and ERL in mathematics developed over five years in secondary school. We furthermore investigated how SRL and ERL relate to each other, to salient influences from school and home, and to indicators of academic achievement. As such, our work is at the forefront of building a more comprehensive evidence base of SRL and ERL in adolescence.

Developmental Trajectories

It was hypothesized that both SRL and ERL display a downward trend during adolescence. The results revealed that SRL significantly decreased over the five-year period at both the student and class levels. This expands upon findings from previous studies focusing on shorter periods (e.g., Helle et al., 2013; Schuitema et al., 2016; van der Veen & Peetsma, 2009; Wang & Eccles, 2012) by showing that SRL continues to decline over adolescents' secondary school career up to grade 9. The findings are aligned with stage-environment fit theory (e.g., Eccles & Roeser, 2009; Wang & Pomerantz, 2009) predicting a decrease in (adaptive) motivational and learning-related characteristics during adolescence, due to a mismatch between adolescents' wish for more autonomy and control and the constraints of academic environments.

A major novel contribution of this work lies in investigating developmental trajectories of adolescents' ERL. The development of ERL mirrored that of SRL with significant drops over time at both levels. Adolescents often devalue the academic domain, while at the same time, they strive for independence (e.g., Frenzel et al., 2010; Wang & Pomerantz, 2009), and both of these

developmental trends could conflict with adolescents' commitment to ERL. Overall, the simultaneous decrease in SRL and ERL adds to theorizing on the development of adolescents' regulation of their learning: Instead of shifting from one to the other form (i.e., decreases in one and increases in the other) or stable trajectories, both individual students and entire classroom environments exhibited a declining trend of SRL as well as ERL. More generally, our study underscores the importance of moving beyond the predominant focus of research on SRL in this age group (e.g., Song & Vermunt, 2021), as solely looking at internal regulatory processes neglects that individuals also rely on external sources to guide their learning. However, it should also be acknowledged that the present study's findings on declining SRL and ERL may, to some extent, be bound to the specific context (i.e., learning in mathematics) as a subject that students tend to find most difficult and oftentimes dislike (e.g., Blackwell et al., 2007; Frenzel et al., 2010; Peixoto et al., 2017). Both SRL and ERL demand commitment on the adolescents' side: Whereas SRL is complex and depletes cognitive resources (e.g., Seufert, 2018), ERL requires adolescents to interact with and follow the feedback and guidance of authority figures (e.g., Vermunt & Donche, 2017). Adolescents may simply not be willing (or increasingly less willing) to invest such efforts into a subject they do not like.

In accordance with stage-environment-fit theory (e.g., Eccles & Roeser, 2009), student-perceived autonomy support by both teachers and parents was hypothesized to decrease over time. By contrast, based on theories on parenting and previous research on autonomy support using parent reports (see e.g., Wray-Lake et al., 2010), we had assumed that parents' perceptions of their autonomy provision may remain stable or even increase. In the current study, decreasing trajectories were found for all aspects of autonomy support: teacher autonomy support, student-rated parental autonomy support, and parent-rated parental autonomy support, at the student and the class levels. Hence, supporting our hypotheses, adolescents perceived that both teachers and parents as major social interaction partners granted them less autonomy in mathematics learning over time. Although parents tended to report on average higher levels of autonomy support than students, their self-perceived provision of autonomy support also dropped, which contradicted our hypothesis. A tentative explanation for this finding could be that with the onset of early adolescence and after the transition to secondary school, parents had started granting their children substantial autonomy with regard to their learning. However, faced with increasing academic disengagement during adolescence (e.g., Wang & Pomerantz, 2009), they reduced the provision of autonomy. As parental autonomy support is domain-specific (e.g., Smetana et al., 2004) and as mathematics represents a learning domain that students become particularly disengaged with, the declining trajectories may be tied to the context of the current study.

We had refrained from specifying hypotheses regarding the development of student-reported achievement pressure due to different theoretically plausible trajectories and the absence of a

consistent empirical evidence base. Adding to the current knowledge on changes in achievement pressure in adolescence, the results indicated that adolescents' perceptions of parental achievement pressure declined at the individual student and class level. Parents' school-related behaviors, such as achievement pressure, require parents to take on an active role in their child's learning. Over the course of adolescence, parents may feel that responsibilities are shifting, and that it is the school's and, in particular, the teacher's duty to push students to do better in school. This could especially hold for mathematics as a subject that parents may have struggled with themselves. Alternatively, it may be that parents adapt their expectations for their children's mathematics performance over time, prompting them to reduce their exerted achievement pressure. Teachers' achievement pressure, on the other hand, remained relatively stable over time at both levels. Supporting students in the acquisition of subject matter knowledge and the development of competencies represent major aims of teachers' professional work. At the same time, teachers themselves are under pressure to cover all prescribed contents of the curriculum, which may evoke perceptions of constant achievement pressure by students.

For the development of school grades, we had hypothesized that they may remain either stable (reflecting the "grading on a curve" phenomenon, e.g., Brookhart et al., 2016; Kulick & Wright, 2008) or decrease (aligned with stage-environment-fit theory and declines in academic engagement in adolescence, e.g., Eccles & Roeser, 2009). Standardized achievement tests scores were presumed to increase over time. It was shown that school grades did not significantly change over time, which may point towards teachers' tendency to "grade on a curve" (e.g., Brookhart et al., 2016; Kulick & Wright, 2008). In accordance with the goal of formal schooling, a growth in students' mathematics competencies as measured via standardized achievement test scores was detected at both levels (see also e.g., Rescorla & Rosenthal, 2004).

Relations Between Initial Levels of and Changes in SRL and ERL

Considering the lack of relevant research in adolescence and mixed findings in studies of university students, we did not outline specific hypotheses regarding relations between initial levels of and changes in SRL and ERL. The respective findings from the current study can be summarized along four lines. First, higher levels of SRL at grade 5 forecasted stronger decreases in SRL at the student and class levels. For ERL the same pattern was obtained at the student level. Statistically, higher base rates of SRL and ERL make larger decreases possible. Theoretically, in adolescence the salience of peer relations increases substantially (e.g., Brown, 2009; Sentse et al., 2017). In order to fit in and adapt to peer group norms, which in adolescence oftentimes include devaluing the academic domain, particularly adolescents with initially higher levels of SRL and ERL may increasingly refrain from using these forms of regulation.

Second, SRL and ERL assessed at grade 5 were positively related at the class level: In classes in which high levels of one regulatory form were present, adolescents tended to engage in the

other form as well. One possible explanation is that at a younger age, it may be difficult to distinguish between different regulatory forms. Similar findings have been obtained for motivational constructs, such as achievement goals (Bong, 2009). It may also be the case that in order to successfully navigate the secondary school transition, a "double regulation" of mathematics learning, and thus, the co-occurrence of SRL and ERL within classes is seen as advantageous.

Third, no significant associations between changes in SRL and ERL at both levels emerged. As compared to the positive concurrent class-level association between SRL and ERL at grade 5, the regulation of mathematics learning seems to become increasingly differentiated over time, both in individual students and entire class environments. This may indicate that the two regulatory forms can be conceived of as independent developmental processes in adolescence.

Fourth, higher levels of SRL at grade 5 were associated with a stronger decrease in ERL at the class level. It may be that in classes in which students had better developed regulatory competencies (i.e., higher initial levels of SRL), adolescents feel less need to rely on ERL. This finding further reinforces the importance of supporting SRL skills already at primary school prior to the transition to secondary school (e.g., Dignath et al., 2008). Overall, in light of the lack of research on relations between SRL and ERL in early and middle adolescence, the present findings make an important contribution to the current body of knowledge.

Relations Between SRL, ERL and Teacher and Parent Behavior

It was hypothesized that higher initial levels of parents and teachers' autonomy support (as rated by adolescents and parents) in grade 5 should be positively linked to initial levels of SRL and changes and negatively linked to initial levels of ERL and changes in ERL. Changes in adolescents' perceptions of parents' and teachers' autonomy support should furthermore be positively associated with changes in SRL and negatively associated with changes in ERL. The opposite pattern of results (positive relations to ERL and negative relations to SRL) was assumed for adolescent-rated achievement pressure. Among the two variables capturing teacher and parent behavior, autonomy support proved to be more relevant for adolescents' SRL than achievement pressure. As can be expected based on the literature (e.g., Flunger et al., 2019; Jang et al., 2010; Schuitema et al., 2016) adolescents' perceptions of their teachers' and parents' autonomy support at grade 5 were significantly associated with higher levels of SRL at the student level. Moreover, weaker decreases in both adolescent-perceived parental and teacher autonomy support were related to weaker decreases in SRL, potentially indicating that autonomy support can buffer against negative trajectories of SRL. At the class level, higher adolescent-rated teacher autonomy support at grade 5 was linked to higher SRL at grade 5, and a weaker decrease in adolescent-rated teacher autonomy support was found to relate to a weaker decrease in SRL.

However, surprisingly, lower values in student-rated parental autonomy support at grade 5 were associated with a weaker decrease in SRL. One potential explanation relates to the notion that

SRL rarely develops spontaneously; instead, students need to acquire respective competencies, or in other words, need to learn how to learn (e.g., Dignath et al., 2008; Stoeger et al., 2014; Thomas et al., 2020). It could be that some parents use the transition period to directly instruct SRL strategies and other adaptive approaches to mathematics learning (e.g., Thomas et al., 2021), which may come at the cost of lower autonomy provision at grade 5. Hence, at grade 5 higher student-perceived parental autonomy support and higher SRL go hand in hand; nonetheless, adolescents' perceptions of their parents' efforts to directly promote adolescents' SRL that temporarily results in lower autonomy support may pay off in the longer term by mitigating some of the subsequent reduction in SRL. This interpretation remains speculative and needs to be tested in future work.

No significant relations to parents' reports of their autonomy-enhancing behavior were obtained in our study. Aligned with socio-cognitive perspectives, this underlines that students' perceptions of parents' autonomy support and not those of parents themselves are important for students' SRL (i.e., what matters are the messages that the students perceive, see e.g., Lüdtke et al., 2009). Another explanation for the lack of significant results for parent-reported autonomy support could relate to social desirability, as some parents may report engaging in positive parenting practices to a higher extent than they actually do. It can furthermore not be ruled out that adolescent and parent reports tap into different dimensions of autonomy support (see also e.g., Mastrotheodoros et al., 2019). Adolescents often desire more autonomy at earlier ages than their parents are willing to grant, and consequently, parents and adolescents tend to differ in their beliefs regarding how autonomy should be supported (Daddis & Smetana, 2005; McCurdy et al., 2020).

In the current study, the concurrent relations between adolescents' and their parents' agreement on parental autonomy support ranged from small to, at best, moderate levels of agreement, indicating that their perceptions diverged to a substantial degree (see Table S3). It has recently been criticized that it is difficult to understand how much adolescents' perceptions align with those of their parents given that scholars largely rely on youth reports of parental autonomy support and rarely include both sources of information in the same study (McCurdy et al., 2020). This study's findings on the partial convergence between adolescents' and parents' reports thus adds a piece of evidence to the discussion on youth-parent agreement on autonomy provision.

Moreover, the results revealed a positive concurrent association between higher levels of student-reported parental achievement pressure at grade 5 and higher levels of SRL at the student level. It may be that those parents who were perceived to push their children to do better (higher achievement pressure) in the critical first year following the transition were also particularly concerned with their children's learning (e.g., van Rens et al, 2018), which could be reflected in their children's higher initial levels of SRL. On the other hand, given the cross-sectional nature of this association, it is equally plausible that parents of adolescents with more adaptive learner characteristics (i.e., more skilled self-regulated learners) exerted more pressure as a means to

supposedly help them to realize their academic potential. The lack of longitudinal relations suggests that for adolescents' development as self-regulated learners, adolescent-rated parental achievement pressure may be less relevant and other factors such as autonomy support carry more weight.

Concerning ERL, we found that higher levels of adolescents' perceptions of teacher achievement pressure and parental achievement pressure at grade 5 were positively related to ERL at the student level. Previous research has linked achievement pressure to stress, and lower engagement and achievement (e.g., Kulakow et al., 2021; Raufelder et al., 2015). The present study extends the current knowledge base on linkages of adolescent-rated achievement pressure by demonstrating that adolescents' perceptions of both parents' and teachers' achievement pressure went along with ERL. The lack of longitudinal relations, however, may indicate that over time student-rated achievement pressure does not translate into ERL. Furthermore, ERL did not show any significant relations with autonomy support. Hence, other home- and school-based factors, such as achievement pressure and further variables (e.g., perceptions of responsibility for one's learning) may matter more for ERL and its development.

Relations Between SRL, ERL and Academic Achievement

A large body of research has examined relations between SRL and academic achievement. However, most studies relied on cross-sectional designs (e.g., Dent & Koenka, 2016), and existing longitudinal studies tend to focus on one achievement indicator (e.g., Schuitema et al., 2016). The present research was guided by the hypotheses that that higher initial levels of SRL should be positively linked to initial levels of and changes in academic achievement, and that changes in SRL should be positively linked to changes in academic achievement. The results yielded a significant positive correlation between grade 5 SRL and standardized achievement test scores at the student level. The correlation with grades was also positive and only slightly smaller than that for standardized achievement test scores but failed to reach statistical significance. This finding is partly in line with the results of the correlation-based meta-analysis by Dent and Koenka (2015) revealing relations between SRL and standardized achievement test scores as well as school grades of comparable size. The relations between the change parameters were positive as well but did not reach statistical significance. Still, this pattern of findings underpins the need for longitudinal research on SRL and achievement: Educational and developmental psychologists are often concerned with how effects unfold over time and extrapolating from the large and rather promising looking cross-sectional body of research on the SRL-achievement link to relations between changes in SRL and achievement may be misleading.

Higher levels of ERL at grade 5 were presumed to negatively relate to initial levels of achievement and changes in academic achievement. In addition, changes in ERL should be negatively linked to changes in academic achievement. In our study, ERL did not exhibit significant relations with either achievement indictor. This adds to the body of research on ERL and academic

achievement in higher education (e.g., Fryer et al., 2016; Heikkilä & Lonka, 2006; Loyens et al., 2008) by pointing out that ERL, standardized achievement test scores, and school grades do not share significant associations in early and middle adolescence—at least not in our study. However, we caution that it may also be that ERL is not directly but rather indirectly related to academic achievement, for example mediated via negative emotions or less adaptive concrete learning approaches, such as surface learning strategies (Pekrun et al., 2002). We thus encourage studies following up on our work testing longitudinal mediation processes.

Limitations and Directions for Future Work

The current research has a number of strengths, including the use of five-year longitudinal data, different indicators of adolescents' academic achievement, and different data sources for self-reports, and the consideration of both SRL and ERL. However, several limitations also need to be acknowledged, and can be used to derive directions for future research. First, the study focused on one subject, namely mathematics. Although we believe that the basic processes underlying associations between SRL and ERL and the variables investigated in our study should apply to different subjects, it has also been stressed that academic domains differ with respect to the nature of instructional tasks and the structure of their subject matter, which influences how students regulate their learning (e.g., Alexander et al., 2011; Dent & Koenka, 2016). Hence, replications and extensions of our work examining a variety of school subjects are required (e.g., Dent & Koenka, 2016).

Second, the present work was conducted in Germany, leaving it open whether similar findings could be obtained in other countries and cultural contexts (e.g., Wang & Pomerantz, 2009). Research with members from other cultures characterized by different approaches to teaching, learning, and parenting, as well as self-representations (e.g., independent versus interdependent self-construal, Markus & Kitayama, 1991; Cross et al., 2011) should follow up on our work.

Third, we relied on self-reported SRL and ERL. Self-report tools have been shown to provide valuable insight into students' awareness about themselves as learners and about their use of learning strategies (Butler et al., 2011; Vandevelde et al., 2013). Nonetheless, future research could triangulate self-reports with further assessments methods, such as digital traces of students' learning while they work on online tasks (e.g., van Halem et al., 2020).

Fourth, we focused on academic achievement as a crucial educational outcome. Future research could expand on this by examining associations between SRL and ERL, and school-related well-being, engagement, motivation, and social belonging (e.g., Bardach et al., 2022; Lazarides et al., 2021), as well as long-term outcomes (e.g., study program choices and adjustment at university, e.g., Jansen et al., 2021). Fifth, our study was based on a secondary data analysis and we did not perform post-hoc power analyses in line with recommendations from the methodological literature (e.g., Dziak et al., 2020). Still, we endorse the importance of prospectively considering statistical

power when deciding on sample sizes for planned future studies on SRL and ERL and respective data collections. Effect size estimates obtained in our study can profitably feed into power calculations for such future studies. Finally, it has been proposed that approaches to learning should change most when the context changes (Fryer et al., 2016; Vermunt & Donche, 2017). Accordingly, more pronounced changes may take place in the first months after the transition to secondary school. Although the annual assessments fit the goal of the study to map long-term development of SRL and ERL from grade 5 until grade 9, more fine-grained daily or weekly assessments of SRL and ERL over a shorter period of time after the transition could produce complementary further insights. Such designs would furthermore lend themselves well to disentangling time-consistent and fluctuating proportions of students' SRL and ERL at different levels of analysis and to test how they are shaped by specific teacher and parent behavior and momentary changes in these behaviors (e.g., Parrisius et al., 2021).

Practical Implications

For educational practitioners interested in students' positive school-related development, our study highlights the need to counteract declines in adaptive learning approaches during adolescence (Eccles & Roeser, 2009). A further core finding with potential implications for practice concerns the links between adolescents' reports of teachers' and parents' autonomy support and SRL, as, for example, more advantageous autonomy support trajectories were found related to more advantageous developmental trajectories of SRL over time. Increasing adolescents' SRL is an important educational goal, and our study underscores the importance of autonomy provision from different sources (teachers, parents) in this regard (e.g., Núñez, & León, 2015; Pino-Pasternak & Whitebread, 2010). By contrast, teachers and parents should be careful not to push adolescents too hard to perform better at school and communicate unrealistic high expectations, given that adolescents who experienced higher levels of achievement pressure were more likely to let their learning be externally regulated. Overall, even though students' SRL and ERL showed a similar developmental trend over time, our study points towards specific types of parent and teacher behavior that were differentially related to the two regulatory forms and that could therefore be targeted in interventions and professional development programs.

Conclusions

Students' learning can be regulated in different ways and thus, different forms of regulation need to be taken into account in order to achieve a more complete understanding. The present five-year longitudinal study is the first to show that both adolescents' SRL and their ERL decline over the secondary school years. The findings furthermore uncover an intricate pattern of relations between SRL and ERL, link parent and teacher behavior to SRL (mainly in terms of relations with adolescent-rated autonomy support) as well as ERL (solely related to adolescent-rated achievement pressure), and explore how SRL and ERL are associated with achievement indicators. Taken

together, our study generates important insights into the development of SRL and ERL in adolescence, and serves as a springboard for future research on the regulation of adolescents' learning, and its potential sources and implications.

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Figure 1

Trajectory Plot with Estimated Trajectories at the Student and Class Levels for Self-Regulated Learning and Externally Regulated Learning

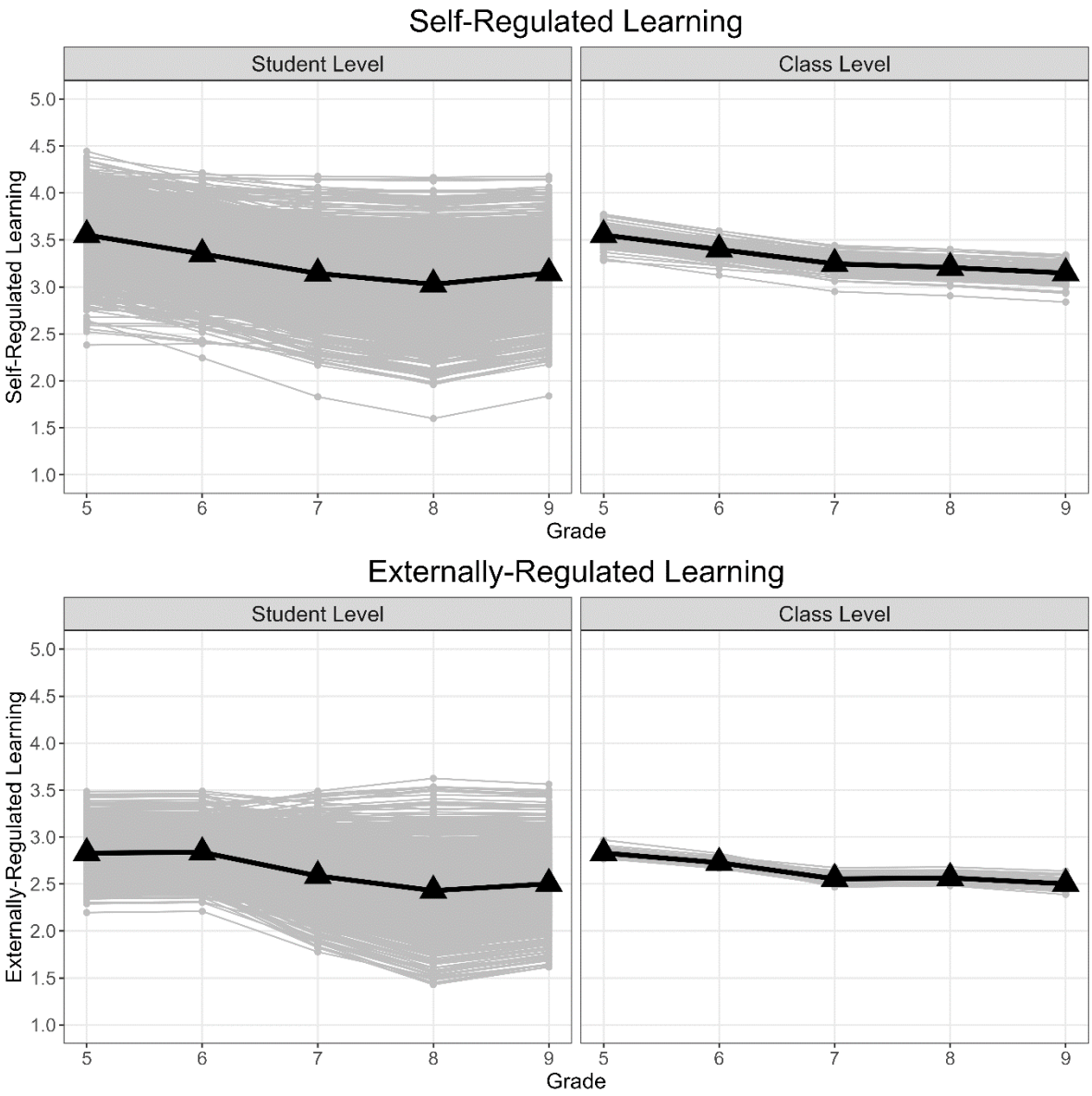

Figure 2

Trajectory Plot with Estimated Trajectories at the Student and Class Level for Autonomy Support

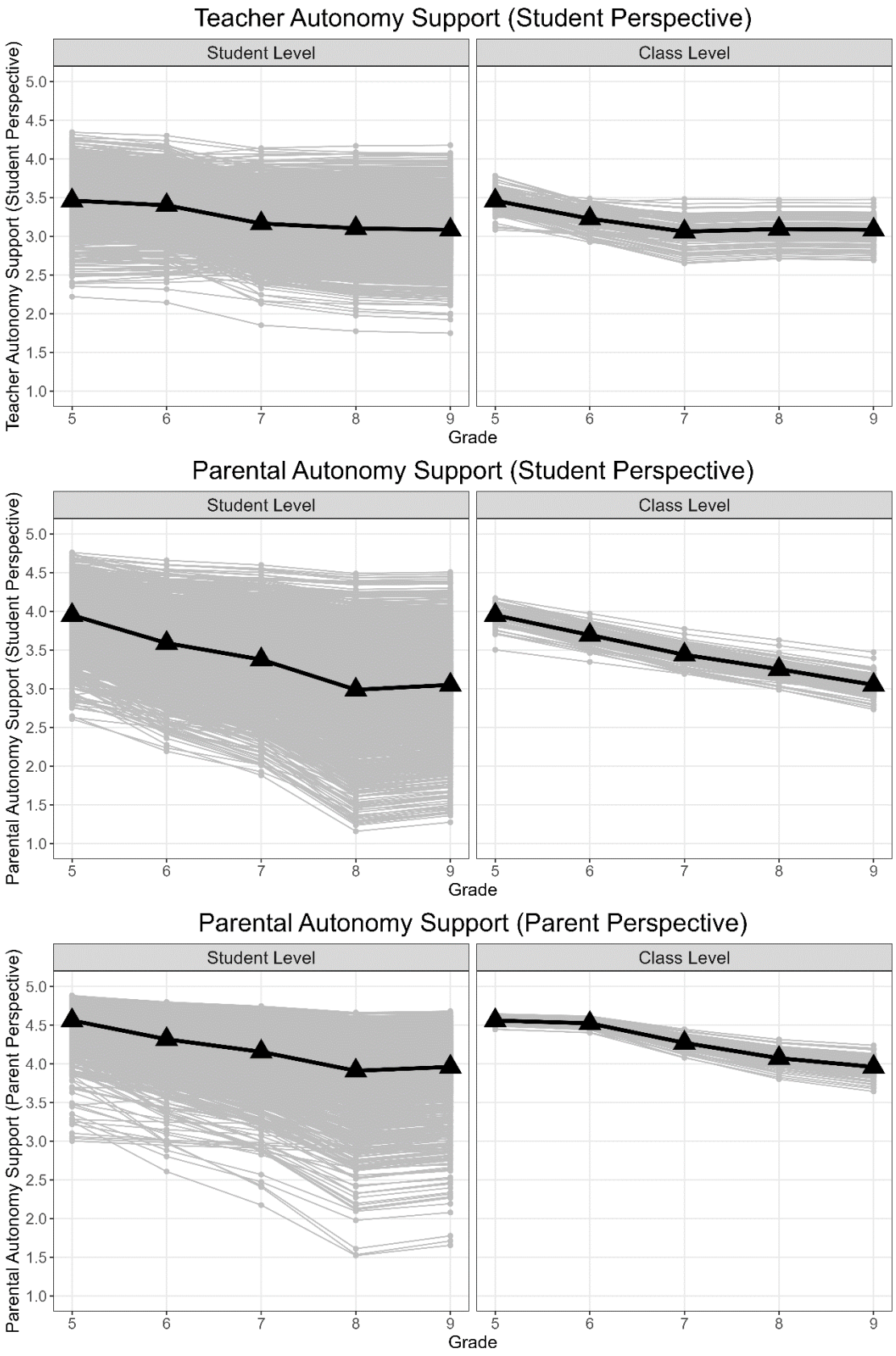

Figure 3

Trajectory Plot with Estimated Trajectories at the Student and Class Level for Achievement Pressure

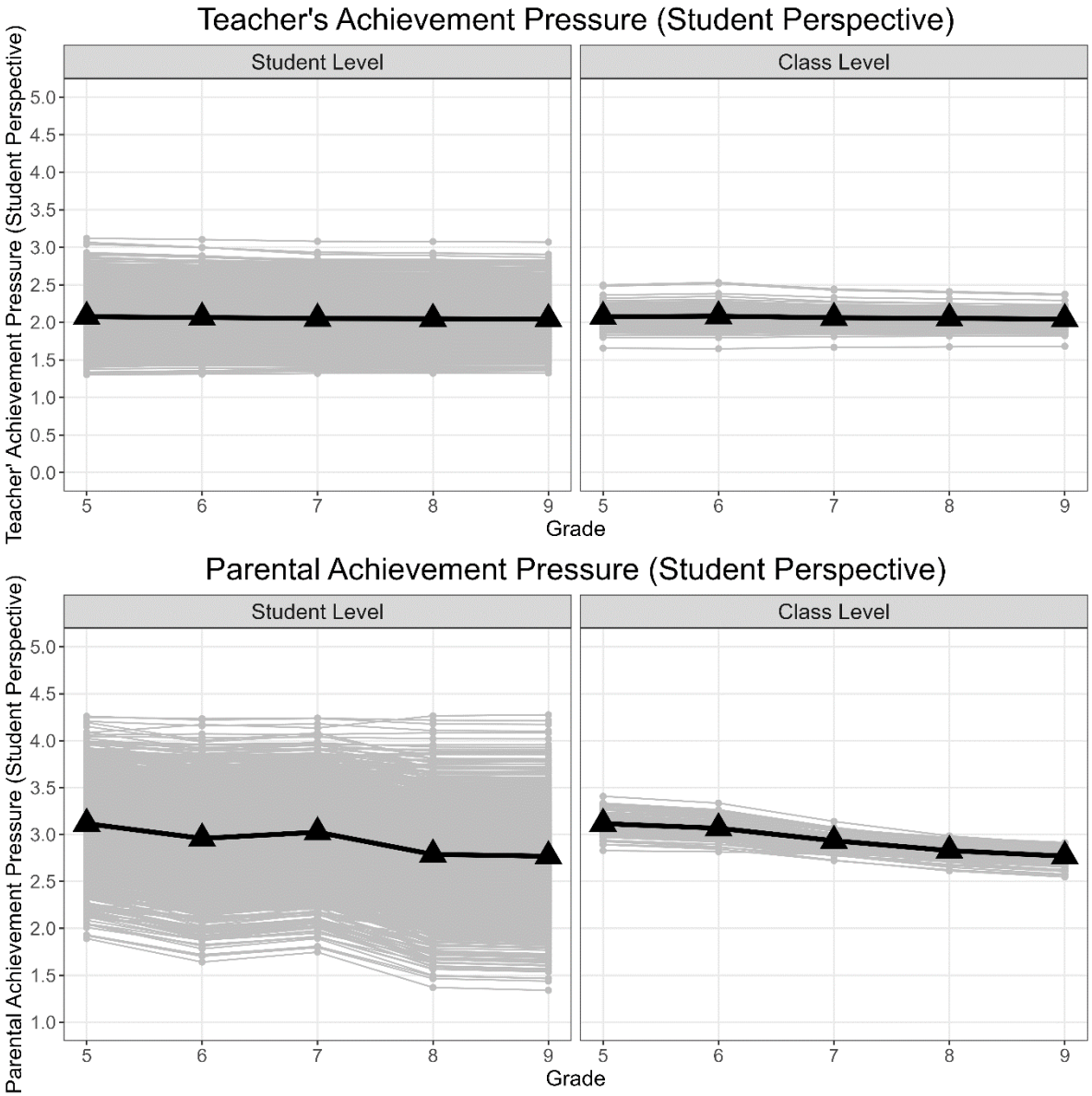

Figure 4

Trajectory Plot with Estimated Trajectories at the Student and Class Level for Achievement

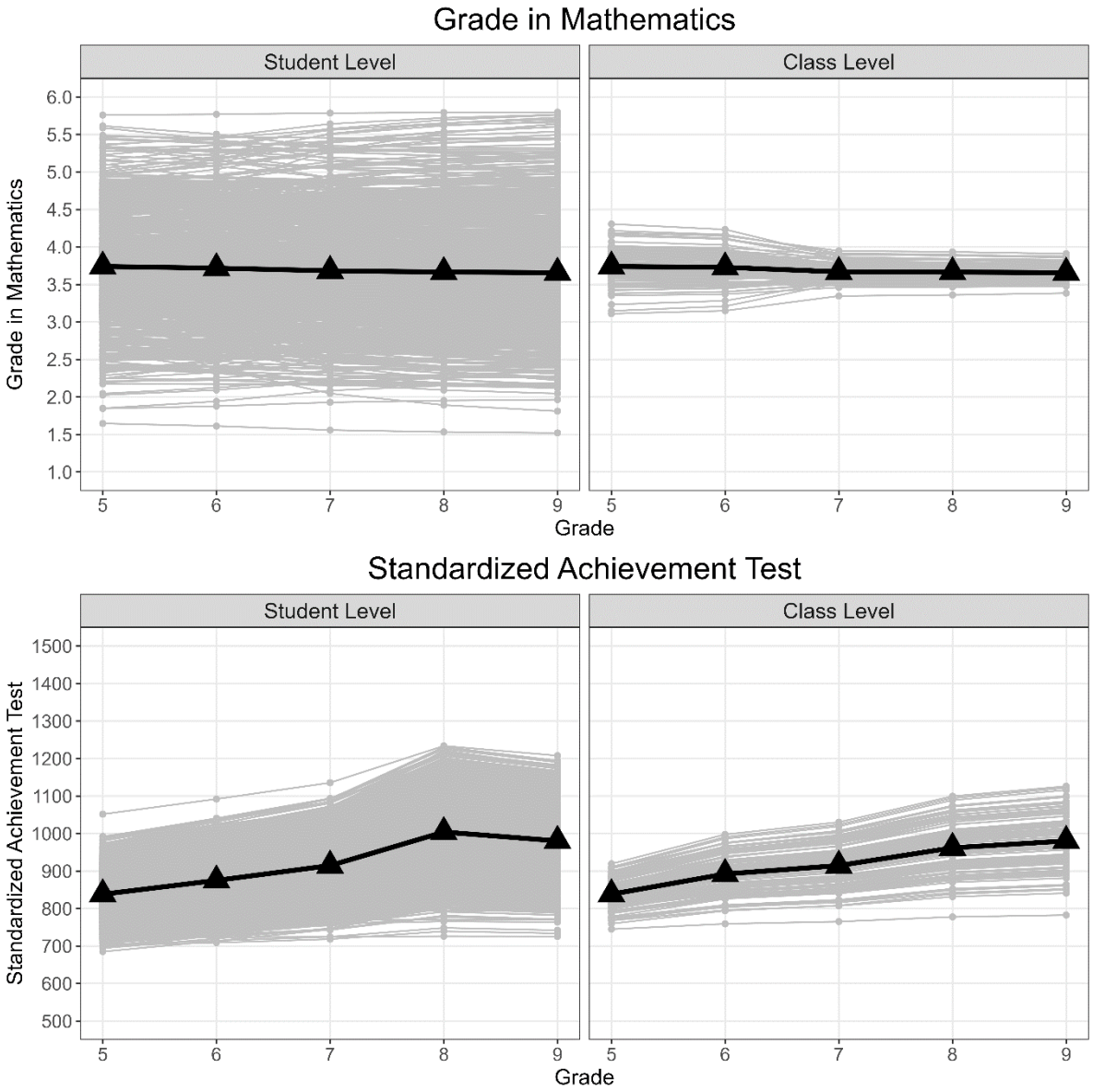

Table 1

Multilevel Latent Basis Growth Model: Latent Correlations Between the Parameters of Self-Regulated and Externally Regulated Learning

	1.	2.	3.	4.
Self-regulated learning				
1. Intercept		**-.76**	**.69**	**-.67**
2. Slope	**-.49**		-.59	.64
Externally regulated learning				
3. Intercept	.13	.29		**-.84**
4. Slope	.21	-.28	-.22	
Model Fit				
PPP		.460		
95 % CI		[-44.43, 47.32]		

Note. 1,542 students from 114 classes. Correlation coefficients at the student level in the lower triangle and correlation coefficients at the class level in the upper triangle. PPP = Posterior predictive *p*-value. 95 % CI = 95% confidence interval for the difference between the observed and the replicated χ^2 values. Statistically significant results at $\alpha = .05$ are shown boldface.

Table 2

Multilevel Bivariate Latent Basis Growth Models: Latent Correlations Between Self-Regulated Learning and Externally Regulated Learning and Autonomy Support, Achievement Pressure, and Achievement

	Teachers' autonomy support		Parents' autonomy support (student perspective)		Parents' autonomy support (parent perspective)		Teachers' achievement pressure		Parents' achievement pressure		Achievement			
											Grades		Standardized test scores	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Self-regulated learning														
Student Level														
Intercept	**.45**	-.24	**.71**	-.25	.03	-.02	.10	.23	**.23**	.28	.19	-.06	**.23**	-.14
Slope	-.18	**.56**	**-.36**	**.48**	.00	.02	-.17	.03	-.18	-.11	.07	.25	-.02	.26
Class Level														
Intercept	**.72**	-.48	.58	-.34	.30	-.18	.00	-.13	.17	-.21	.43	-.49	.36	.42
Slope	-.52	**.81**	-.14	.53	.00	.39	-.21	.01	-.40	.14	-.05	.30	-.05	-.06
Model Fit														
PPP	.370		.507		.532		.479		.532		.325		.442	
95 % CI	[-37.74, 54.05]		[-45.82, 45.04]		[-46.84, 42.79]		[-43.33, 46.49]		[-46.05, 42.41]		[-36.00, 57.18]		[-42.56, 49.27]	
Externally regulated learning														
Student Level														
Intercept	.25	-.08	-.02	.26	.02	-.03	**.40**	-.26	**.47**	-.17	.06	-.08	.10	-.01
Slope	-.22	.37	.08	-.13	-.06	.15	.03	.24	-.20	.28	.10	.06	.02	.03
Class Level														
Intercept	.50	-.41	.29	-.54	-.21	-.07	.48	-.40	.45	-.25	-.14	-.01	.10	-.06
Slope	-.29	.55	-.49	.68	.55	.06	-.09	.21	-.45	.54	-.03	.23	-.22	-.22

Model Fit							
PPP	.345	.507	.463	.450	.527	.427	.419
95% CI	[-37.94, 56.41]	[-44.56, 46.59]	[-43.38, 47.52]	[-42.10, 47.52]	[-48.29, 43.44]	[-41.41, 49.65]	[-42.56, 50.12]

Note. 1,542 students from 114 classes. PPP = Posterior predictive p-value; 95% CI = % confidence interval for the difference between the observed and the replicated χ^2 values. Statistically significant results at $\alpha = .05$ are shown in boldface.