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ARTICLE

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Does motivation lead to academic success, or conversely? Reciprocal relations between autonomous and controlled motivation, and mathematics achievement

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Abstract

Background: While it's clear that autonomous motivation significantly boosts academic success, there are conflicting findings regarding the opposite relation. Besides, the reciprocal relations among controlled motivation and achievement present mixed results. Adequately distinguishing between variations among individuals and within individuals results key to acknowledge such relations.

Aim: This longitudinal study examines the reciprocal relations between controlled and autonomous forms of motivation and academic achievement using the RI-CLPM methodology.

Sample: Participants were 1042 high school students (M = 16 years, 52% male adolescents) from 16 different high schools in urban and rural areas.

Methods: A random intercept cross-lagged panel model (RI-CLPM) was tested to estimate whether students' autonomous and controlled motivation predicted achievement and/or vice versa. Independent models were estimated for the two types of motivation.

Results: Overall, the RI-CLPM results indicated a unidirectional relationship between autonomous motivation and achievement. As for controlled motivation, the results of RI-CLPM models showed no reciprocal relationship between this type of motivation and achievement.

Conclusions: These results underline the importance of taking within- and between-person processes into account when analysing reciprocal relations and provide crucial insights for enhancing student motivation and achievement in diverse educational contexts.

KEYWORDS
academic achievement, cross-lagged panel model, longitudinal study, mathematics, motivation, reciprocal relationships

INTRODUCTION

Does student motivation predict academic achievement and/or does academic achievement predict motivation? Disentangling the relations between motivation and achievement has been a core concern among researchers for a long time (Kriegbaum et al., 2018; Morgan & Fuchs, 2007; Mouratidis et al., 2021; Seaton et al., 2014; Skaalvik & Valås, 1999). Whereas there is no doubt about the predictive power of autonomous motivation on academic achievement—this is performing activities for their own sake, with volition and choice, because of the inherent value or enjoyment the activity brings— (Cerasoli et al., 2014; Hattie, 2009; Roth, 2019; Šakan et al., 2023; Taylor et al., 2014) studies have long suggested the possible existence of bidirectional relations between motivational constructs and student achievement (Jang et al., 2024). Nonetheless, this remains unclear given that such studies have primarily used methods that do not allow the establishment of 'Granger-causal' effects among these two[1] variables, this is, not conducted reciprocal effects over time using longitudinal designs (Granger, 1969). Besides, both few studies that have done so, have led to mixed results (Alamer & Alrabai, 2023; Liu et al., 2023) and explored only autonomous motivation. Altogether there is still a need to properly disentangle the relation among achievement and investigate how changes in one variable leads to subsequent changes in another variable (the cause-and-effect relation), while accounting for confounding factors of change or baseline levels of such variables. Recognizing the mutual influence between these two constructs is significant, given that, as Voight et al. (2024) stress, educational policies could strategically aim to enhance both motivational environments and students' academic competencies concurrently.

Following the self-determination theory (SDT), the present study aims to analyse the reciprocal relations between two kinds of motivations (i.e. autonomous and controlled) and academic achievement of secondary school students, using the random intercept CLPM (RI-CLPM). This cross-lagged panel recognizes that baseline levels in dynamic constructs may reflect stable characteristics of the person (trait factors) and that these stable traits need to be accounted for to obtain reliable evidence on reciprocal relations (Hamaker et al., 2015; Núñez-Regueiro et al., 2022). It therefore acknowledges that we all have unique starting points in life, a vision more attuned to real-world complexities such as individual differences. Moreover, the present study focuses on both autonomous and controlled motivation contrastingly to previous studies that have solely relied on autonomous forms of motivation (Nuñez-Regueiro, 2024). This is crucial as it enables researchers to capture the complexity of motivational processes while recognizing their unique contributions to student outcomes. Moreover, the present study emphasizes mathematics achievement among middle and high school students, as success in this subject during these critical stages has a profound impact on their ability to navigate challenges in today's information-driven society (Seaton et al., 2014). Mathematics also plays a pivotal role in shaping future career opportunities and social success (Lim & Chapman, 2012; Valiente et al., 2014). Supporting students in

[1]Throughout the study, for brevity, we use the notion of 'causality' (and related notions of 'cause' and 'effect') to mean 'Granger-causality'. Although Granger causality might be seen as providing weaker forms of causal inference than experimental or quasi-experimental causality, it is the strongest available paradigm to conceptualize mutual influences based on observational data (Hamaker et al., 2015; Nuñez-Regueiro et al., 2022). We acknowledge, however, that Granger causality (i.e. of one variable predicting longitudinal changes in another variable, while accounting for counfounding factors), cannot establish, per se, ontological causality (i.e., of one variable being the unique or main factor of change in another variable).

this area is therefore essential, particularly at a developmental stage when many students experience a decline in interest in mathematics (Lazarides et al., 2019).

Autonomous and controlled motivation as causes and effects of achievement

SDT examines students' motivational approaches by analysing the quantity and quality of students' motivation (Roth, 2019). Whereas the quantity of motivation refers to the intensity or the amount of motivation a student has towards completing a task, the quality refers to the type of motivation experienced by a student which can be either autonomous or controlled. Hence, a student might be motivated in an autonomous manner (high quality of motivation) but still lack sufficient intensity or persistence (low quantity) to achieve academic success, and vice versa. This distinction is important as both the quality and quantity of motivation contribute in different ways to academic achievement, and understanding their interaction can provide deeper insights into how motivation influences learning and performance.

As mentioned, autonomous motivation describes when students pursue activities based on their own free will; it represents motivation whose locus of causality is internal. When motivated in such a manner students engage in an activity due to the value attributed to such activity or by the pleasure and enjoyment of the activity itself. Students consciously consider the activity to be important and meaningful for their own (Ryan & Deci, 2020). In contrast, controlled motivation has an external locus of causality characterized by carrying out activities to increase self-esteem or to avoid feeling guilty (internal pressure); or to obtain rewards or avoid punishments (external pressure). In this case, the student's behaviour is not regulated by the self (Ryan & Deci, 2017).

Within schools, autonomously motivated behaviour relates to positive student functioning, whereas negative functioning is associated with controlled motivation across age groups and cultures (Ryan & Deci, 2000). Specifically, the scientific literature has shown that autonomous motivation predicts positive outcomes such as concentration, persistence, time management, deep learning, and achievement (Everaert et al., 2017; Vollmeyer & Rheinberg, 2000). Accordingly, students who are motivated in a self-determined manner invest more time and effort in activities that line up with their values and their interests, achieving higher grades (Ryan et al., 2022), thus resulting in a motivation of high quality. In contrast, controlled motivation has been related to negative outcomes such as maladaptive coping strategies, test anxiety, superficial learning, dropping out of school and low achievement (Ryan & Deci, 2020; Vansteenkiste et al., 2010), and thus, understood as a motivation of low quality.

Whereas the positive influence of autonomous motivation on academic achievement is undeniable (Richardson et al., 2012; Soenens & Vansteenkiste, 2005), there is some mixed evidence towards the effect controlled motivation can have on students. Whereas controlled motivation has been linked to lower achievement (Botnaru et al., 2021; Manganelli et al., 2019), it has also been found to positively predict grades (Liu & Hou, 2018). In this sense, being motivated in a controlled manner does not necessarily imply a negative impact on students' performance, but rather a lower effect. Being motivated in a controlled manner can lead to achievement, specifically when tasks do not involve creativity (i.e. open-ended tasks such as writing) and instead are rudimentary (i.e. closed-ended tasks such as multiple choice; Cerasoli et al., 2014; Hubley et al., 2024). At the same time, recent evidence highlights a positive effect of controlled motivation if it coincides with high levels of autonomous motivation (Nuñez-Regueiro, 2024; Mouratidis et al., 2021). Thus, speaking of both quality and quantity, and demonstrating the importance of adjusting the effect of autonomous motivation, in order to understand the net impact of controlled motivation on achievement (Nuñez-Regueiro et al., 2024).

Still, whether grades have a positive or negative effect on motivation remains unclear. For instance, achieving high grades provides feedback on quality of task performance, which can potentially satisfy students' sense of competence and, thus, foster motivation in two ways (Pulfrey et al., 2013). First, grades may enhance autonomous motivation because they may represent something students value. Additionally, such feedback from mastering the content (i.e. grades) might pose a challenge for students to maintain this sense of competence. Moreover, gradually mastering learning materials allows students to discover new insights within the subject, thereby stimulating curiosity and interest in the content itself, ultimately fostering autonomous motivation (Ryan & Deci, 2017). Secondly, grades can also enhance students' controlled motivation as they can represent a reward in themselves. Moreover, it can also translate in gaining approval from others or/and from the self (Lee & Ju, 2021; Ryan & Deci, 2020).

Moreover, when examined in longitudinal studies, the inverse relation where grades predict motivations shows mixed results for autonomous motivation, as some studies highlight a positive effect (Alamer & Alrabai, 2023; Liu et al., 2023; Skaalvik & Valås, 1999) while others show a non-significant relation and a negative effect of grades on controlled motivation (Taylor et al., 2014). Among the many possible explanations for such inconsistency, some may point out methodological factors, including the kind of model used for longitudinal data analysis. For instance, using a CLPM design, Skaalvik and Valås (1999) showed that mathematics and verbal motivation were prospectively affected by achievement in secondary school students, but the reciprocal relation was not evident; results that are in line with other studies (Gottfried et al., 2013; Skaalvik & Rankin, 1995). Additionally, Taylor et al. (2014) found the common relation where autonomous motivation had a positive effect on achievement, while controlled motivation had a negative effect. However, when exploring the reverse relation (grades to motivation) authors found that high achievement predicted a decrease in future controlled motivation, meaning that when students succeeded, they were less likely to be motivated by external pressures or rewards later. However, their achievement was not related to changes in autonomous motivation. Altogether, results suggested that controlled motivation had a reciprocal relation with achievement, meaning that controlled motivation and achievement influenced each other in a back-and-forth manner. These findings suggest a causal sequence different from the traditional perspective of SDT, which typically posits a flow from motivation to achievement. Instead, Taylor et al.'s findings suggest that achievement can influence motivation in a reverse direction—a flow from achievement to motivation.

Studies examining reciprocal effects between other motivational constructs (i.e. academic self-concept) and achievement (Ehm et al., 2019, Nuñez-Regueiro et al., 2022) have also questioned findings established via the CLPM. As detailed hereafter, the CLPM confounds dynamics associated with within-person processes of change (of interest to the researcher) with stable traits of motivation or achievement—so-called 'between-person processes of change'—thus undermining the identification of reciprocal effects. Using the RI-CLPM enables separating the two sources of variance in processes of change (Hamaker et al., 2015), which can lead to contrastingly different—but more reliable results—from the CLPM (Ehm et al., 2019; Nuñez-Regueiro et al., 2022). Regarding SDT, to the best of our knowledge, only two studies have assessed the reciprocal relations of motivation and achievement while using the RI-CLPM (Alamer & Alrabai, 2023; Liu et al., 2023) and their results were also mixed. For instance, Alamer and Alrabai (2023) found in a sample of university students learning a second language a positive reciprocal relation but only in a successive manner across time waves, so that autonomous motivation predicted achievement from T1 to T2 (but not from T2 to T3), whereas achievement predicted autonomous motivation from T2 to T3 (but not from T1 to T2). By contrast, Liu et al. (2023), in a sample of high school students, using RI-CLPM found a unidirectional effect of overall achievement across subjects on proxy measures of autonomous motivation (i.e. value of education) Importantly, both RI-CLPM studies did not take into account the effect of controlled motivation, despite evidence pointing out to its role on achievement (Skaalvik & Valås, 1999; Taylor et al., 2014). Overall, considering previous studies, the relations between motivation and achievement remains complex (Liu et al., 2023) and with important gaps to address such as the direction of causality and the possible effect of different motivation constructs (Vu et al., 2022) such as controlled versus autonomous motivation on achievement. Altogether, properly understanding how these different forms of motivation relate to achievement remains a challenge, specifically in a subject that plays an important role in students. Mathematics is widely regarded as a challenging subject (Hannover & Kessels, 2004), often evokes negative emotions (Di Leo et al., 2019; Sakaki et al., 2024) and appears to be particularly effective at inducing boredom in students with lower achievement levels (Schwartze et al., 2024). Altogether, understanding students' motivation in mathematics can provide insights into how to address such negative emotions and how to foster greater engagement and persistence, especially among those with lower achievement levels.

Accounting for stable individual differences

Unlike the classic CLPM, the RI-CLPM separates within- and between-person processes of change by adding random intercepts, which represent baseline levels in motivation and achievement estimated across the entire observation period (e.g. from T1 to T3; see Figure 1). These intercepts are 'random' in that they are specific to each individual, meaning that each student has their own estimated baseline level of achievement and motivation. This modelling of student-specific baseline levels formally represents stable interindividual differences in change, referred to as trait factors. The variance remaining in the model can then be interpreted as momentary within-person changes in the dynamic constructs, known as state factors, which are modelled using autoregressive and cross-lagged effects. As Hamaker et al. (2015) demonstrated, the parameter estimates within the standard model (i.e. CLPM) may confound processes of change between and within individuals. Consequently, studies (Ehm et al., 2019; Liu et al., 2023; Nuñez-Regueiro et al., 2022) have shown that such models may provide inaccurate estimates of reciprocal effects between motivation and achievement when stable individual differences are present. By allowing for the capture of individual heterogeneity in longitudinal data, the RI-CLPM is considered the most suitable model for the nature of our data and the objectives we aim to address.

The present study

This study is the first to explore reciprocal relations between controlled and autonomous forms of motivation and achievement while using the methodology of RI-CLPM. Specifically, by relying on RI-CLPM, this study's aims were twofold: (1) examine the reciprocal relations among autonomous motivation and academic achievement and (2) examine the reciprocal relations among controlled motivation and academic achievement. According to SDT metanalyses and cross-national analyses (Nuñez-Regueiro, 2024; Ryan & Deci, 2020; Taylor et al., 2014), autonomous and controlled motivations were expected to have positive (H1) and negative (H2) cross-lagged effects on achievement. The reverse effects have received less attention and resulted in inconsistent findings, some underlining the positive (Alamer & Alrabai, 2023; Liu et al., 2023; Skaalvik & Valås, 1999) or non-significant effect of achievement on autonomous motivation and its negative effect on controlled motivation (Taylor et al., 2014).

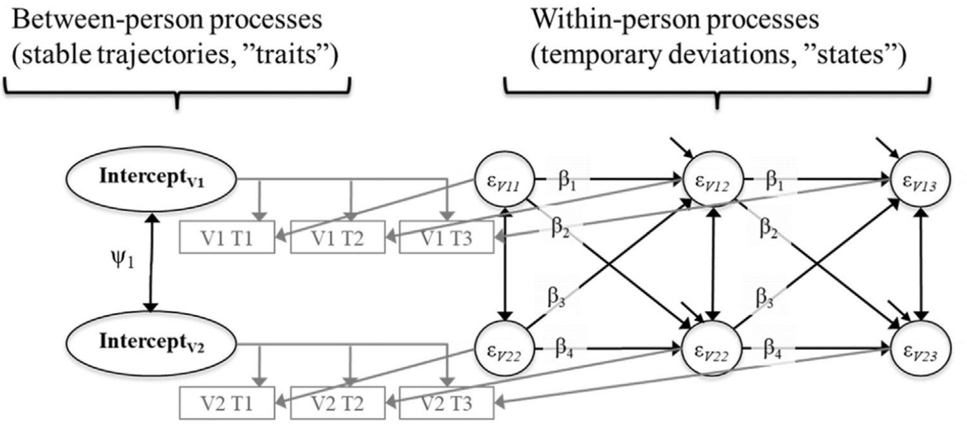

FIGURE 1 Illustration of random-intercept cross-lagged models.

Overall, it was expected that achievement would have positive cross-lagged effects on autonomous motivation (H3), and negative cross-lagged effects on controlled motivation (H4).

METHOD

Participants

Participants consisted of a total of 1048 students from 58 classes between grades 9 and 12, with 1042 of them taking part in at least one measurement wave and being included in the analyses (mean age = 16.36; *SD* = 1.27; 51.6% male adolescents). Participants were from 16 different secondary schools located in urban and rural areas of Gran Canaria, Spain. Most of the students came from middle-class families, and there were no discernible ethnic differences among the sampled schools. Given that motivational processes change depending on the subject area (Arens et al., 2019; Guay & Bureau, 2018), to reduce potential bias, the survey questions were specifically designed for a single subject, mathematics. This ensured that all participants in the study were studying the same subject and received an equal amount of instruction time each week from the same teacher.

Procedure

Participants were provided with an explanation of the study's objectives and were assured that their involvement was entirely voluntary and would be kept confidential. To protect their anonymity and privacy, only minimal personal information, such as date of birth, gender, and class, was collected. This approach allowed us to connect data gathered over multiple trimesters while upholding the participants' confidentiality. Data collection occurred during a regular classroom session, facilitated by a member of the research team. At the conclusion of each school trimester, students assessed their motivation and teachers reported on their grades for the trimester. The first wave of data collection (T1; $n = 749$) took place during the month of November, the second wave (T2; $n = 712$) during the month of February and the third wave (T3; $n = 571$) during the month of May with 467 students answering the three time points. The study adhered to the ethical principles outlined in the Declaration of Helsinki and was granted approval by the University Human Research Ethics Committee.

Measures

Autonomous and controlled motivation

To assess students' motivation, we used the Spanish version of the Academic Motivation Scale (Núñez Alonso et al., 2005). According to the assumptions of the SDT, autonomous motivation was measured based on the items of the intrinsic and identified subscales (e.g. '*Because I experience pleasure and satisfaction while learning new things*'), whereas controlled motivation was based on the items of the introjected and external subscales (e.g. '*To have a better salary in the future*'). Each subscale was composed of four items preceded by the question 'Why do you study?'. Sum scores displayed a good internal consistency ($\alpha =$ [.84, .91]).

Academic achievement

To measure academic achievement, we relied on school grades. These were obtained from the official records of their respective schools. In the Spanish education system, these grades are assigned by teachers, who use government-mandated rubrics. These grades range from 1 to 10, with 10 representing the highest achievable grade (León et al., 2017).

Covariates

Background covariates were accounted for in the modelling strategy. Covariates included age, gender (0 = 'female', 1 = 'male'), vocational track (0 = 'academic', 1 = 'vocational') and high school level (0 = 'middle school', 1 = 'high school').

Analytic strategy

Reciprocal, lagged effects between students' motivation to learn and their achievement were tested through a RI-CLPM in Mplus 8.3 (Muthén & Muthén, 2023). Missing data (T1 = [4%, 25%], T2 = [11%, 27%], and T3 = [13%, 40%]) was handled with the full information maximum likelihood approach, allowing for the recovery of information from the entire sample even when data is not missed at random (Little et al., 2014). Data clustering was accounted for using a single-level specification that corrected estimates for cluster-level variance. This correction method by Muthen and Satorra (1995) uses the sandwich (ML) estimator with clustering correction (i.e. type = 'complex' analysis on Mplus) and leads to a much simpler model that provides equivalent results to multilevel specification in the RI-CLPM).

Measurement invariance analyses

In a first step, to investigate the long-term impacts of motivation and achievement using a latent cross-lagged panel analysis, following recommendations (Nuñez-Regueiro et al., 2021; Mulder & Hamaker, 2021) we initially conducted tests to ensure that the measurements remained consistent across different time points. In this study's context, measurement invariance signifies the extent to which motivation and achievement assessments reflect the same underlying concepts over time. Hence, initial psychometric analyses were conducted to ensure that changes in measurements across different waves accurately reflected the evolution of latent processes related to motivation and achievement (referred to as alpha change), rather than changes in measurement models (i.e. beta changes). As so, several models were computed, where the measurement models across different time points were restricted to share identical indicators (configural), the same factor loadings (metric), the same indicator intercepts (scalar), and the same indicator variances (unique). Lack of invariance was determined for models that displayed satisfactory fit. Following guidelines established by simulation studies (Cheung & Rensvold 2002; Hu & Bentler, 1999) and employed in applications of RI-CLPM (Nuñez-Regueiro et al., 2022; Li & Wang, 2022; Pekrun et al., 2023), the goodness-of-fit was considered satisfactory and excellent when comparative fit index (CFI) values exceeded .90 and .95, respectively, and when the root-mean-square error of approximation (RMSEA) values exceeded 0.08 and 0.06, respectively. Similarly, parametric constraints were retained between nested models when the change in goodness-of-fit was greater than or equal to −0.01 for CFI (i.e. $\Delta CFI \geq -0.01$), and less than or equal to −0.015 (i.e. $\Delta CFI \leq -0.015$). According to these criteria, it was confirmed that metric invariance was upheld, meaning that the factor loadings remained consistent across different time points.

Analyses of reciprocal relations

In a second step, we proceeded with the main analyses in which a series of random intercept cross-lagged panel models were tested to estimate whether students' motivation predicted achievement and vice versa. Separate models were estimated for autonomous and controlled types of motivation, and robustness checks were made by including both kinds of motivation and achievement into a single trivariate model (Data S1). Aligning with recommendations and practice in the field (Marsh et al., 2023; Pekrun et al., 2023), the ΔCFI criterion was used to test differences between nested models instead of the chi-squared difference test, which is overly sensitive in large samples such as our and tends to produce inflated Type I errors (i.e. incorrectly rejecting well-specified models). Additionally, we tested whether autoregressive and cross-lagged effects could be constrained to be invariant over time, by observing that such constraints resulted in trivial decrements in model fit (i.e. $\Delta CFI \geq -0.01$). All effects were found to be time-invariant (see Table S2, SM). Additionally, to account for potential factors that could confound the results, we included covariates. Hence, two final models were obtained and compared: RI-CLPM (Model 1), and RI-CLPM with covariates (Model 2).

RESULTS

Descriptive statistics

Descriptive statistics for students' motivation and achievement are displayed in Table 1.

Intraclass correlation coefficients demonstrated that scores varied as a function of the class, with this class variability ranging from 15% to 24% for achievement and 2%–7% for motivation. Given the moderate correlation observed between autonomous and controlled motivation (as expected from the simplex model of the autonomy continuum; Ryan & Deci, 2017), a trivariate model that integrated the two types of motivation into a single model was tested as a robustness check of the covariance between both variables (see Data S1). Relations among both variables resulted non-significant.

Longitudinal invariance of measurement models

Psychometric analyses demonstrated that the measurement model for both autonomous and controlled motivation exhibited a satisfactory to excellent fit with the data, as indicated by comparative fit index

TABLE 1 Means, standard deviations and correlations among variables.

	Mean	*SD*	ICC	1	2	3	4	5	6	7	8
1. Achievement (T1)	5.72	2.38	.23	–							
2. Achievement (T2)	5.66	2.51	.24	.83*	–						
3. Achievement (T3)	6.11	2.44	.15	.79*	.82*	–					
4. Autonomous motivation (T1)	5.45	1.18	.04	.15*	.17*	.16*	–				
5. Autonomous motivation (T2)	5.32	1.31	.02	.14*	.17*	.20*	.61*	–			
6. Autonomous motivation (T3)	5.31	1.32	.06	.10*	.15*	.18*	.57*	.64*	–		
7. Controlled motivation (T1)	5.15	1.29	.07	−.03	−.02	−.01	.64*	.42*	.41*	–	
8. Controlled motivation (T2)	5.01	1.37	.05	−.06	−.03	.01	.43*	.69*	.48*	.61*	–
9. Controlled motivation (T3)	5.00	1.38	.06	−.09*	−.04	−.01	.39*	.46*	.69*	.58*	.69*

Note: $N = 1088$.

*$p < .05$.

(CFI) values ranging from 0.936 to 0.947 and root mean square error of approximation (RMSEA) values between 0.051 and 0.053. Importantly, the model's fit was not significantly compromised when cumulative constraints were applied to factor loadings, item intercepts, and item variances across different time points ($\Delta CFI \geq -0.01$; see Table S1 in SM). Based on these findings, it was inferred that scores reflecting motivational constructs remained sufficiently consistent across waves, supporting their reliable use in modelling processes of change.

RI-CLPM results

Table 2 displays the fit indices for the two models tested; results showed that all models displayed a satisfactory to excellent fit of the data. Overall, for both autonomous and controlled motivation models the fit to the data was also better when covariates were included.

Autonomous motivation

Results for the cross-lagged model tested are displayed in Table 3. For the RI-CLPM, autoregressive effects were large and significant at 5%. Changes within students' motivation and their achievement were inherently driven by previous states and remained connected to them, even when we considered stable individual differences by including trait factors. Including covariates did not change findings on reciprocal relations. Regarding cross-lagged effects, RI-CLPM results showed a cross-lagged effect of autonomous motivation to achievement from T1 to T2 (β_2 = .116, p = .002) and from T2 to T3 (β_2 = .140, p = .002). The same findings could be observed when including covariates (Model 2) with a slight decrease in the parameters (.116–.113 for T1–T2 and .140–.137 from T2 to T3). Therefore, RI-CLPM gathered evidence towards a unidirectional causal relation between autonomous motivation on achievement. In other words, the RI-CLPM indicated that increases in students' autonomous motivation in a given trimester contributed to increases in achievement in the next trimester, whereas increases in achievement did not systematically conduce to increases in autonomous motivation. Finally, random intercepts for students' autonomous motivation and achievement correlated positively ($\psi_{\text{Model 1}}$ = .180, p = .000; $\psi_{\text{Model 2}}$ = .163, p = .002), indicating that higher levels of motivation were systematically related to higher levels of achievement throughout the year (See Figure 2).

Controlled motivation

For controlled models (Table 4), all autoregressive effects resulted significantly at 1% for both controlled motivation and achievement. Regarding cross-lagged effects, results showed no reciprocal

TABLE 2 Fit indices of models of reciprocal relations between student motivation and achievement.

	Df	χ^2	*p*	CFI	TLI	RMSEA	SRMR
Autonomous Motivation-Achievement							
Model 1: RI-CLPM	9	111.4	.000	.964	.939	.100	.037
Model 2: RI-CLPM with covariates	30	139.4	.000	.965	.955	.054	.031
Controlled Motivation-Achievement							
Model 1: RI-CLPM	8	116.1	.000	.962	.929	.109	.039
Model 2: RI-CLPM with covariates	28	139.9	.000	.965	.952	.056	.030

Abbreviations: CFI, comparative fit index; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual; TLI, Tucker–Lewis's index.

TABLE 3 Results for the cross-lagged models tested: autonomous motivation and achievement.

	Model 1: RI-CLPM		Model 2: RI-CLPM with covariates	
Autoregressive	V1	V2	V1	V2
T1–T2	.233**	.246**	.231**	.248**
T2–T3	.293**	.297**	.291**	.303**
Cross-lagged	V1 = >V2	V2 =>V1	V1 = >V2	V2 = >V1
T1–T2	.116**	.100	.113**	.094
T2–T3	.140**	.125	.137**	.119
Trait Factors	V1	V2	V1	V2
Intercept	6.092***	2.789***	6.181***	6.255***
Psi_{within}	.180***		.163**	
Covariates			V1	V2
Age			.000	−.277***
Male			−.177†	.000
Vocational			.000	.723**
High school			.000	.000

Note: $N = 1042$ students, 58 classes. Standardized coefficients are reported.

Abbreviations: V1, autonomous motivation; V2, achievement.

†$p < .10$.

*$p < .05$.

**$p < .01$.

***$p < .001$.

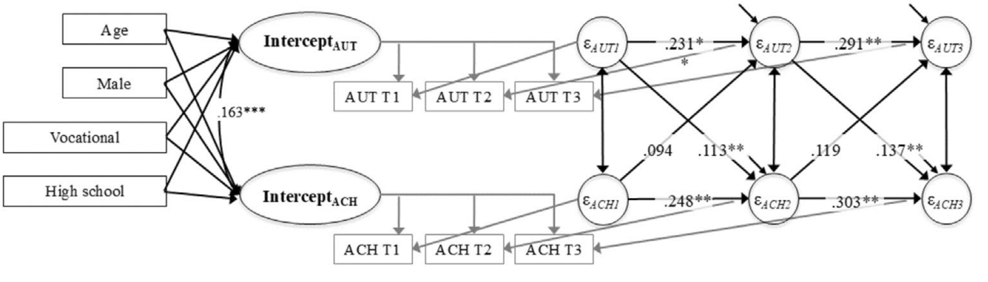

FIGURE 2 Model 2 results for autonomous motivation and achievement.

effects among controlled motivation and achievement in the RI-CLPM. Hence, being motivated in a controlled manner on an occasion did not relate to changes in achievement on a subsequent occasion, neither positively nor negatively. Conversely, changes in achievement did not contribute to changes in students' controlled motivation. Finally, trait factors between students' controlled motivation and their achievement levels correlated weakly and negatively ($\psi_{\text{Model 1}} = -.126$, $p = .054$; $\psi_{\text{Model 2}} = -.123$, $p = .060$; See Figure 3).

Robustness checks

The above results were robust to the inclusion of student background covariates but also to the joint inclusion of autonomous motivation, controlled motivation, and achievement using trivariate model specifications (see Data S1).

TABLE 4 Results for the cross-lagged models tested: Controlled Motivation and Achievement.

	Model 1: RI-CLPM		Model 2: RI-CLPM with covariates	
Autoregressive	V1	V2	V1	V2
T1–T2	.313***	.255**	.313***	.257**
T2–T3	.383***	.312**	.385***	.318**
Cross-lagged	V1 = >V2	V2 = >V1	V1 = >V2	V2 = >V1
T1–T2	.105†	.054	.105†	.050
T2–T3	.119†	.072	.120†	.067
Trait Factors	V1	V2	V1	V2
Intercept	5.471***	2.792***	5.635***	6.347***
Psi_{within}	−.126†		−.123†	
Covariates			V1	V2
Age			−.285***	.000
Male			.000	−.192*
Vocational			.763**	.000
High school			.000	−.245*

Note: $N = 1042$ students, 58 classes. Standardized coefficients are reported.
Abbreviations: V1, Controlled motivation; V2, achievement.
†$p < .10$.
*$p < .05$.
**$p < .01$.
***$p < .001$.

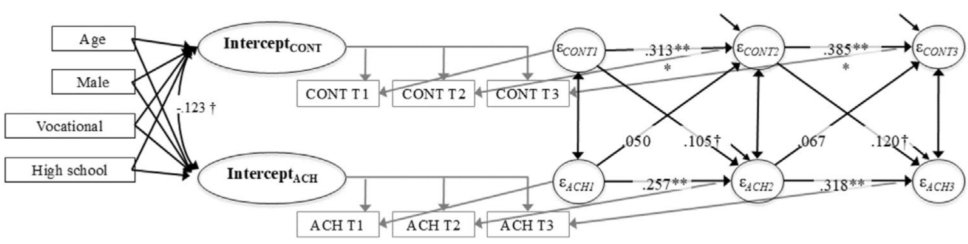

FIGURE 3 Model 2 results for controlled motivation and achievement.

DISCUSSION

The present longitudinal study aimed to examine the reciprocal relations between both autonomous and controlled motivation, and achievement using alternative methodological approaches, namely the RI-CLPM. The RI-CLPM separates within-person (state-like) fluctuations from between-person (trait-like) differences. When examining motivation, a 'trait' effect would capture the consistent level of motivation that a student exhibits across time, relative to other students. This reflects how inherently motivated a student is in comparison to peers. Similarly, in the context of academic achievement, a trait effect would represent an individual's stable academic performance over time, accounting for their inherent abilities or long-term effort levels. Conversely, 'state' refers to the fluctuations or changes that occur within an individual over time, reflecting more situational, temporary influences. In the relation between motivation and achievement, a state effect would capture how a student's motivation level changes from one measurement point to the next and how these changes correlate with concurrent changes in academic performance. Overall, findings from the RI-CLPM indicated a unidirectional relation going from autonomous to achievement (validation of H1, invalidation of H3). Regarding controlled motivation, results from CLPM and RI-CLPM showed no reciprocal relations among this type of motivation and achievement (invalidation of H2 and H4). The present findings shed light on the causal ordering of motivation and achievement, thanks to the refinement of the methodology used to analyse reciprocal relations. Altogether, when we account for stable, between-person differences (trait effects), autonomous motivation predominantly influences academic achievement, rather than the other way around, suggesting that RI-CLPM models are most suitable when assessing individual processes of change, this is, how individual characteristics such as one's motivation predict individual behaviour such as academic achievement (state effects).

Furthermore, findings indicate a one-way association between autonomous motivation and achievement, aligning with the principles of the SDT (Ryan & Deci, 2017) and consistent with previous studies (Liu & Hou, 2018; Mouratidis et al., 2021). Accordingly, a student who is autonomously motivated will engage in activities for the pleasure and value of the activity itself, eventually leading to increased achievement levels. On the contrary, experiencing poor or high achievement does not seem to influence levels of autonomous motivation, at least over a school year. This finding can be explained by the fact that when the locus of control is internal, autonomous motivated students can be more inclined to invest self-driven efforts, explaining their higher academic achievement (Taylor et al., 2014). Behaviour would be self-determined and volitional, independent of external factors, such as achievement. This finding presents an interesting and potentially thought-provoking departure from previous RI-CLPM findings (Alamer & Alrabai, 2023; Liu et al., 2023). These departures may stem from differences in variables employed, periods and context of studies. For example, Liu et al. (2023) employed indicators of the value of education as measures of motivation as opposed to self-determination constructs of motivation employed in the present study. In the case of Alamer and Alrabai (2023), reasons for divergence could be due to differences among the intervals between measurements, yielding similar results as the present study when time intervals were comparable (e.g. a full semester from T1 to T2, compared to a full trimester in this study), but different results when time interval differed (e.g. 3 weeks from T2 to T3 in their study). Finally, such authors conducted their research at the university level. While both high school and university students may experience autonomous motivation, the nature and sources of this motivation can differ between the two groups leading to different motivational dynamics. Hence, divergence among results can also be due to the different situational scenarios.

Findings also suggested that changes in controlled motivation do not lead to changes in achievement (state effects), invalidating hypotheses 2 and 4. Similarly, changes in state achievement did not lead to changes in state controlled motivation, suggesting that controlled motivation and achievement are not related, contrary to past studies highlighting their mutual positive or negative relations (Liu & Hou, 2018; Taylor et al., 2014). These results contradict previous findings highlighting the negative prospective effects of controlled motivation on achievement, but they somehow align with the uncertainty surrounding these reciprocal effects of achievement on controlled motivation, which was positive, negative, or non-significant depending on the sample or indicator of controlled motivation being used (Taylor et al., 2014). Another explanation is the possible presence of nonlinear-interactive effects between autonomous and controlled motivation on achievement, which were not modeled in this study but could reveal an impact of controlled motivation uunder varying degrees of autonomous motivation (Nuñez-Regueiro, 2024). Similarly, we did not investigate whether the reciprocal effects of controlled motivation and achievement were contemporaneous (within occasions) rather than lagged (between occasions) (Marsh et al., 2024). Finally, the fact that controlled motivation and achievement were not related in terms of reciprocal effects but were negatively—albeit weakly—related in terms of baseline levels (i.e. random intercepts), may indicate that their mutual relations were stabilized prior to the observational period (e.g. during elementary school or middle school), and did not evolve at present (during high school). Future studies could therefore investigate whether these relations are more apparent using complementary techniques for interactive-nonlinear relationships (e.g., cubic response surface analysis; Nú ñez-Regueiro & Juhel

2022; 2024) or contemporaneous effects (Muthén & Asparouhov, 2024), or among younger students experiencing more malleable motivational processes.

Limitations and future directions

This study presents some limitations. First, the sample represented students at the secondary level, but these might differ among primary or university levels. They were also circumscribed to a subject: mathematics learning. As relations among motivational processes and achievement may differ as a function of disciplinary subjects or age groups (e.g. Arens et al., 2019; Skaalvik & Valås, 1999), complementary research using more diversified samples and subjects is needed. Mathematics is often perceived as challenging (Hannover & Kessels, 2004), is likely to provoke boredom (Pekrun et al., 2010) and its performance is the lowest among all OECD countries in PISA examinations (OECD, 2023). In this sense, the 'opposite effect' from achievement to autonomous motivation might be found in subjects less challenging where students might display higher achievement rates and positive emotions allowing them to feel competent. This situational scenario might explain why such an effect was not found. In different contexts, expectations may vary, thus, findings cannot be generalized to other subject domains. Second, the present study relied on a three-wave data approach, but if were interested to further control for unstable differences among growth trajectories of students' future research should rely on at last another wave of data to estimate random curve cross-lagged panel models (Curran et al., 2014; Nuñez-Regueiro et al., 2022). Besides, it could be that the chosen time points do not allow for significant changes to occur. Future research could test the hypothesized relations with larger time points or at specific scenarios such as those when students' transition from primary to secondary or when they are about to choose their major. A lack of substantial change among the selected time points could explain the absence of cross-lagged effects. Third, although the RI-CLPM enables approximating causal influences in processes of change, such processes are limited to the student level and do not inform on causalities at the class level. Finally, given the novelty of the present findings and that the lack of prior research has focused on different time points, from 17 weeks (Alamer & Alrabai, 2023) to up to years (Liu et al., 2023), comparisons to prior research in the scope of RI-CLPM are limited. Further research is needed to reassess the idea that controlled motivation is unrelated to achievement, or that changes in achievement levels do not conduce to changes in autonomous motivation.

Implications for practice

Mathematics holds a crucial position among the subjects taught in secondary school (Tan et al., 2012). Some researchers have even noted a link between mathematics performance and growth in Gross Domestic Product (OECD, 2010). Thus, fostering students to succeed in such a domain seems to be a primary goal, specifically in a developmental stage where students face a lack of interest towards the subject of mathematics (Lazarides et al., 2019). From a practical point of view, the present findings can have implications for various actors in the educational or research community. For mathematic teachers, findings can be useful as they can help teachers focus on those approaches that have been proven to foster autonomous motivation. As opposed to what it has been proven before, the present findings show that controlled motivation might not be as negative for students' grades as it has been thought (Taylor et al., 2014; Vansteenkiste et al., 2010). Furthermore, although research has shown that controlled motivation might be beneficial, this mostly occurs when it co-exists with autonomous motivation (2024; Mouratidis et al., 2021). Thus, instead of pressuring students through rewards or punishments, what seems more reasonable is for teachers to rely on messages that highlight the value and joy that learning interesting things brings, as these have proven effective (Santana-Monagas & Núñez, 2022). Similarly, parents can also cultivate such environments by relying on such messages, which if combined with further autonomy-supportive practices, such as providing rationales for demands or linking their mathematical learning to life goals (Ahmadi et al., 2023), change is most likely to occur.

CONCLUSION

In conclusion, this longitudinal study utilized RI-CLPM models to investigate the reciprocal relations between autonomous and controlled motivation and academic achievement. The comparison between the two models revealed important insights. RI-CLPM demonstrated a unidirectional positive effect of autonomous motivation on achievement, aligning with the principles of SDT. Hence, by distinguishing between 'trait' and 'state' effects, the RI-CLPM model provides insights into the nature of the motivation-achievement relation, highlighting the importance of accounting for these different levels of analysis in educational research. These results challenge previous findings and emphasize the importance of considering within- and between-person processes when analysing reciprocal relations, using the RI-CLPM. They also highlight the predictive causal relation between autonomous motivation and achievement. Based on previous findings (2024Mouratidis et al., 2021; Taylor et al., 2014) and the current ones, a clear conclusion can be drawn regarding the distinct impact of autonomous forms of motivation on student achievement. Exerting one's potential for the sake of one's interest and pleasure, or to attain what is valuable for one's self-realization, seems to be the key to success.

AUTHOR CONTRIBUTIONS

Elisa Santana-Monagas: Conceptualization; writing – original draft; visualization; writing – review and editing; investigation. **Fernando Núñez-Regueiro:** Writing – review and editing; methodology; formal analysis; data curation; conceptualization. **Juan L. Núñez:** Writing – original draft; supervision; conceptualization; writing – review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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