

## Measuring self-regulated learning in physics courses: A structural equation modeling of learning autonomy and motivational-metacognitive components

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### Abstract

The purpose of this study was to examine the structural relationship between learning autonomy (LA) and the motivational (self-efficacy [SE], intrinsic value [IV], and test anxiety [TA]) and cognitive-metacognitive (cognitive strategy use and self-regulation [SR]) components of self-regulated learning in physics courses. The study group consisted of 291 undergraduate students taking a physics course at a university in Kazakhstan. Data were collected via online administration of MSLQ and LAQ. After testing the measurement model and then following the two-step process of structural equation modeling, we examined the structural model. According to confirmatory factor analysis, both scales demonstrated acceptable validity in the current study. LA was modeled as second-order latent variable that comprises four factors: self-awareness, difficulty management, planning, and action. Due to poor fit of the initial structural model, theoretically justified modifications were carried out and as a result, the final model demonstrated acceptable overall fit to the data. The results have shown that LA significantly and positively predicts SE ( $\beta = .64$ ), IV ( $\beta = .60$ ), cognitive strategies ( $\beta = .72$ ), and SR ( $\beta = .73$ ); and although the link between LA and TA is relatively weak ( $\beta = .23$ ), it is still positive and significant. These findings suggest that instructional methods promoting student autonomy in physics education can help develop motivational beliefs and self-regulatory skills of students. Physics educators and curriculum designers are highly recommended to create learner autonomy supportive environments where students will be able to take part in planning, making decisions and assessing their performance.

**Keywords:** learning autonomy, self-regulated learning, physics education, motivation, structural equation modeling

## INTRODUCTION

Physics education is commonly known as one of the most challenging subjects within the curriculum due to the abstract mathematical modeling, construction of concepts and theories, and the theoretical analysis of ordinary occurrences (Abtokhi et al., 2021; Irsalina et al., 2025). Under traditional approaches of teaching where physics classes are still prevalent, learners are usually pushed into formulaic problem-solving and are therefore encouraged to learn superficially (Alpaslan et al., 2016). In the era of information and digitization, the focus of science education in both high school and tertiary institutions has evolved from the simple

communication of scientific facts to teaching learners “how to learn” and helping them take ownership of their own learning process (McDowell, 2019). In this regard, self-regulated learning (SRL) has emerged as a fundamental concept in science education, representing the mechanism by which students regulate their cognitive, motivational, and behavioral activities to accomplish certain academic goals (Zimmerman, 2000). In the science, technology, engineering, and mathematics (STEM) areas, this is especially important since a learner’s capability to overcome conceptual barriers and succeed academically largely depends on their ability to control the process of learning (Paz-Baruch, 2025). It has been proven that students

### Contribution to the literature

- This study contributes to the literature by conceptualizing learning autonomy as a second-order construct encompassing self-awareness, difficulty management, planning, and action, and by empirically validating this structure in the context of physics education.
- It extends previous research by examining learning autonomy and motivational and cognitive-metacognitive components of self-regulated learning within a single structural equation model, providing evidence on their interconnected roles in physics learning.
- The findings provide empirical evidence that learning autonomy is positively associated with self-efficacy, intrinsic value, cognitive strategy use, and self-regulation, while also showing a weaker but significant relationship with test anxiety, thereby offering implications for designing autonomy-supportive physics learning environments.

experience problems in physics courses due to test anxiety (TA), effort regulation, and low metacognition (Irsalina et al., 2025; Yumusak et al., 2007). The inability of students to monitor, evaluate, and regulate their cognition results in an absence of significant learning in physics, thus making one of the reasons for academic attrition, which prevents learners from pursuing STEM education (McDowell, 2019; Maldonado & Stewart, 2023).

While the development of self-regulation (SR) skills has been viewed as important for academic achievement in previous studies, there is still uncertainty regarding which particular affective and metacognitive skills determine the development of such skills and their correlation with learning autonomy (LA) (Rovan et al., 2024). Although classical theories consider the motivational beliefs of students as a point where the SR cycle begins, they fail to discuss, in a structural approach, the role of autonomy as a catalyst for these processes and the involvement of metacognitive strategies in such interactions (Ilishkina et al., 2022). In most of the studies conducted in the field, these variables have been considered independently, or correlations between two variables have been provided (McDowell, 2019). However, the influence of a person's level of autonomy on the development of physics self-efficacy (SE) and task value and subsequent activation of metacognitive strategies, such as planning, monitoring, and evaluation, has not been explained (Rovan et al., 2024). The lack of testing these correlations through the use of a theoretical model does not provide teachers with information on how to encourage learners to become self-regulated and autonomous (Maison et al., 2019). In terms of physics education specifically, it is essential to quantitatively study the connection between students' perceptions of autonomy, their motivational beliefs (i.e., SE and task values), and their metacognitive strategies in order to test the validity of models and to design effective pedagogical interventions (Maison et al., 2019).

Alpaslan et al. (2016) applied structural equation modeling (SEM) to determine the direct and indirect impact of high school students' epistemology on their personal self-regulatory learning strategies and beliefs in

motivation, with particular emphasis on the "source and development of knowledge" dimensions contributing substantially to their SR skills. Maison et al. (2019) also explored, by means of PLS-SEM, the connection between the perceived climate of learning environment in physics classes and students' beliefs in physics and SR strategies. According to them, collaborative and inquiry-based classroom environments predict SR. In turn, Maldonado and Stewart (2023) found out that a SR intervention conducted in a university physics course led to improved examination results and study habits of high-performing students, whereas poor-performing students stayed in a continuous process of searching for SR strategies. However, the emphasis of these researches is concentrated on the assessment of impacts of either learning practices or epistemology, without focusing on LA as the primary predictor within the motivational-metacognitive framework.

While most existing research investigates either motivational beliefs (SE, intrinsic task value) or cognitive strategies (metacognitive monitoring, deep cognitive strategies), the connection between autonomy and the ability to move from motivational beliefs to cognitive strategies is ignored (Rovan et al., 2024). Although Ilishkina et al. (2022) identified the differences in motivation regulation strategies for intrinsically or extrinsically oriented students, the mediation effect of these strategies was not tested within a structural model. Geng and Su (2025), who used epistemic network analysis and discovered that in blended learning environment students use different SR strategies depending on their metacognitive knowledge and regulation levels, failed to incorporate both variables into one linear SEM model, which links them to achievement outcomes. Consequently, the lack of an SEM study in the field of physics education, where autonomy will be investigated as a preceding variable, motivational beliefs as its driving mechanisms, and metacognitive strategies as the action-oriented strategies, which will directly predict achievement is one of the key gaps. This study attempts to fill it.

## THEORETICAL FRAMEWORK

### Learning Autonomy in the Self-Regulated Learning Process

Autonomy in learning is considered the ability of a person to take responsibility for the process of his or her learning, to formulate personal learning goals and choose the learning pathways for meeting these goals (Abtokhi et al., 2021). Autonomy is one of the three basic psychological needs that have to be fulfilled to ensure psychological development, integration, and intrinsic motivation of individuals within the theoretical basis of self-determination theory (Deci & Ryan, 2000; Held & Mejeh, 2024). Fulfilling the need for autonomy in the classroom environment results in increasing students' interest in learning activities and allows seeing the process of learning as the result of personal willpower rather than external pressure (Held & Mejeh, 2024). Autonomy support is one of the critical psychological resources that enables students to persist in the process of learning in cognitively challenging and abstract disciplines like physics (Maison et al., 2019). Autonomous students are more likely to find their own learning pathways that correspond to their own cognitive schemata rather than adhere to the fully structured learning process dictated by a teacher (Neber et al., 2008).

Autonomy is at the core of the "forethought" stage preceding any action related to learning within Zimmerman's (2000) SRL cycle. The first stage involves individuals with autonomy setting realistic and achievable educational goals while taking into consideration their personal limitations and skills in the analysis of tasks (Del Mario & Tran, 2024). A student with the freedom to define his/her learning goals determines independently what kind of cognitive skills, elaboration, organization, etc., are necessary to achieve the goal (Alpaslan et al., 2016). The autonomy of an individual enables him/her not only to predict the material that he/she is going to acquire, but also to plan how he/she will deal with distracting factors and organize the studying environment. Autonomy in this case provides the foundation of strategic planning and goal setting at the first stage of the cycle, which ensures the success of subsequent performance stages (Geng & Su, 2025).

One more influence that autonomy exercises on self-regulated learners is the constant provision of motivational beliefs (Rovan et al., 2024). In the case when a learner perceives oneself as an autonomous individual and the leader of the own learning process, one will tend to attribute successes or failures not to external factors (luck, a teacher, examination difficulty, etc.), but to one's own effort and chosen strategy (Held & Mejeh, 2024). As a result, control over the learning beliefs increases and becomes stronger, and the commitment to learn physics

improves. Indeed, studies indicate that students whose needs of autonomy were fulfilled had higher intrinsic task value and SE in physics classes (Irsalina et al., 2025; Li & Singh, 2024). Autonomy, then, acts as an incubator for the formation and maintenance of motivational beliefs, helping students become active agents in their own learning.

Another aspect of LA is the capacity of the learner to be able to diagnose his or her own learning needs. With the difficulty and complexity that the study of physics involves, an autonomous learner is able to recognize on his or her own the areas where he or she requires assistance in learning and the resources needed to do so (Abtokhi et al., 2021; Maldonado & Stewart, 2023). Learners who are able to realize their weak spots, whether in the classroom setting or online environment, have a much higher probability of seeking peer interaction, guidance from teachers, or additional digital assistance (Geng & Su, 2025). Autonomous learners who can diagnose their learning requirements seem to construct more robust conceptual structures in physics and are less prone to cognitive hindrances during problem-solving (Winarti et al., 2022).

Choosing of the appropriate learning strategies by the students is one of the main milestones in the implementation of autonomous learning. Obviously, no single strategy, be it memorizing formulas or just reading the book, will help solve any physics problems (Alpaslan et al., 2016). The autonomous learner uses a range of strategies in a flexible way in order to make the image of physics problems, pick up the appropriate physics strategies, and check their mathematical calculations. Thus, the process of selection contributes to the preference of the deep strategies, such as elaboration and organization, to the surface strategies, such as rehearsal (Abtokhi et al., 2021). At the same time, the student can freely choose his/her strategy and control its effectiveness as well as switch to some other strategies once he/she sees that the chosen one does not work.

The sustainability of the learners' autonomy lies in the creation of autonomy supportive classrooms and e-learning environments (Li & Singh, 2024). Autonomy arises due to the provision of the learners with choice, taking into consideration their pace of learning and accepting their mistakes as part of the learning process (Held & Mejeh, 2024). Allowing the students to come up with their own questions and perform their own experimental designs, especially in physics laboratories and project works, brings their autonomy to its maximum point (Bilgin et al., 2015; Maison et al., 2019). Due to excessive control of the teacher and guidance for each action, the learners become passive, their autonomy is hindered, and as a consequence their SR collapse (Held & Mejeh, 2024). The comprehensive SR theory, thus, ought to treat the learners' autonomy as the main structural precursor which determines and structures all

the motivational and cognitive processes (Rovan et al., 2024).

### **Motivational Beliefs in Physics Education**

According to the social cognitive theory by Bandura (1977), the concept of SE can be described as an individual's self-perceived capability to manage, structure, and execute a set of actions required to produce a desired performance or finish an involved activity. With respect to the teaching of physics in particular, the concept of SE is associated with academic SE which represents students' beliefs regarding their capability to grasp challenging physical theories, conduct experiments in the laboratory, and resolve problems (Xie, 2026). It should be stressed that literature makes a distinction between academic SE and "SE for SRL" (Rovan et al., 2024). The first is concerned with students' belief in their capability to learn, whereas the second one represents their capability to plan, control time and manage themselves despite all distractions (Li & Singh, 2024; Rován et al., 2024).

Task value, one of the elements of motivational beliefs, refers to the extent to which students perceive physics learning as valuable, useful, and interesting (Li & Singh, 2024). In the context of expectancy-value theory, task value involves three positive elements: intrinsic value (IV) (interest and enjoyment), attainment value (desire for success), and utility value (value for future career goals) (Wigfield & Eccles, 2000). The appreciation of how physics subject matters have practical applications in the daily routine of a person and the understanding that physics lessons will be used as tools for future careers as an engineer or scientist increase the value that students give to physics lessons. High levels of task value beliefs cause students to apply deeper thinking processes in their studies of physics topics and to engage with those topics out of the classroom environment (Li & Singh, 2024; Maison et al., 2019; Neber et al., 2008).

In more contemporary reconstructions of the expectancy-value framework, "cost" viewed as the antithesis of task value has proven to be a motivational belief equally as potent in influencing students' SR choices as value is (Rovan et al., 2024). The concept of cost comprises the amount of effort needed to complete a task, the social opportunities foregone while performing it, and the psychological price the student is expected to pay, such as fear of failure or anxiety. High perception of cost, which is common in cognitively challenging subjects like physics, leads to academic procrastination and ultimately dropping out of the class by the student (Rovan et al., 2024). A strong perception of cost overrides the students' SE beliefs and the task value itself, leaving them unwilling to apply any cognitive effort. Cost assessment is a potent psychological screen that dictates directly how much

effort the student will make in the process of SR (Held & Mejeh, 2024).

With regard to the motivational component of SRL, the goal orientations of the students play an important role in their attitudes towards their academic tasks. Typically, in the literature, there is a distinction made between mastery goal orientation and performance goal orientation (Alpaslan et al., 2016; Ma & She, 2024). Mastery goal orientation implies that a student tries to become competent in physics, learn new skills, and understand the subject matter. Since these students see failure as a part of the learning process, they do not give up when facing challenges in learning physics and make the maximum use of metacognitive skills (Ma & She, 2024; Neber et al., 2008). Performance-oriented students care more about outdoing their peers and getting positive evaluations via good grades or not showing incompetence. It is evident that students who have strong performance-avoidance goals experience more anxiety during tests and exams in physics classes and utilize surface learning strategies for fear of failure (Irsalina et al., 2025; Yumusak et al., 2007).

The phenomenon of TA is one of the most disruptive negative affective factors that hinder both motivation and SR. Due to the fact that there are extensive calculations and logical thinking involved in studying physics, students are likely to experience significant TA during the process of writing tests (Irsalina et al., 2025). High TA levels make students have difficulties with building a proper logic and self-monitoring during problem-solving. Students experiencing anxiety that destroys their belief in their efficacy do not have the capacity to regulate their efforts and abandon the problem the moment they face the first difficulty (Aydin et al., 2011; Irsalina et al., 2025). Thus, it is important to understand the hindering role TA performs regarding metacognitive strategies and the ways to control it.

Theories view motivation beliefs, SE, task values, costs, and goal orientation as the "psychological engine" behind the application of metacognitive and cognitive strategies (Pintrich, 2000). Even the most autonomous learner who does not believe he/she can acquire the knowledge (SE), or perceives no value in the subject at hand, will not be able to apply any metacognitive strategies like planning, monitoring, and evaluating (Rovan et al., 2024). Motivation beliefs provide the psychological energy and direction for cognitive investment. In other words, the autonomy resulting from the learner's independence first goes through motivation beliefs before taking the form of specific metacognitive strategies (Alpaslan et al., 2016; Ilshkina et al., 2022).

## Structural Relationships Among Metacognitive Strategies, Problem-Solving, and Academic Achievement

To begin with, metacognition is defined as an individual's understanding of his own cognitive processes as well as the monitoring and regulation of these processes. In other words, metacognition is a combination of metacognitive knowledge, which involves a student's awareness of his cognitive strengths and weaknesses as well as awareness of the strategies needed for each particular physics task. Metacognitive regulation, in turn, consists of planning cognitive activities to reach a goal, actively monitoring the process, and evaluating outcomes in order to correct strategies as needed (Geng & Su, 2025; Winarti et al., 2022). In physics courses, students with strong metacognitive regulation skills approach problems almost like scientists, breaking them down into stages (Maldonado & Stewart, 2023). A student who can monitor their own cognition is able to catch a mistake mid-calculation, correct it, and update their mental models by learning from the error (Kortemeyer, 2007).

In physics education, cognitive strategies can be categorized into surface and deep strategies based on the depth at which they process information. Cognitive strategies such as rehearsal do not create any memory trace of physical concepts but are applicable in short-term formula retrieval (Alpaslan et al., 2016). Higher-order cognitive strategies such as elaboration, organization, and critical thinking enable students to link the new information with their schemas (Alpaslan et al., 2016; Paz-Baruch, 2025). Elaboration enables the students to explain physics concepts in their language and link the concepts to real-life experiences (Winarti et al., 2022). Organizational strategies expose the structure of the physics concepts through the use of concept maps, graphs, and tables. The regular application of the deep cognitive strategies enables the learners to overcome memorization and experience conceptual change as well as transferring of physics knowledge in different situations (Alpaslan et al., 2016; Maldonado & Stewart, 2023).

The final connection of this SR process which starts with LA, is supported by motivational beliefs and implemented through metacognitive and cognitive strategies, is the academic achievement (Rovan et al., 2024). Structural modeling analysis indicates that metacognitive SR and higher-level cognitive strategies are the most influential and reliable direct predictors of academic achievement in physics classes regardless of using either GPA or grade points at the end of semester (Alpaslan et al., 2016; Yumusak et al., 2007). Learners' competence in terms of regulating their own study decreases the TA and contributes to better test scores and conceptual achievements (Maldonado & Stewart, 2023; Irsalina et al., 2025). In turn, academic achievement impacts the "self-reflection" stage of the SR cycle,

contributing to the learner's future autonomy and motivational beliefs (Zimmerman, 2000).

## Research Questions and Hypotheses

In this study, the structural relationships between LA and the motivational and cognitive-metacognitive components of students' SRL in physics courses were tested through SEM. To this end, the general research question was formulated as follows: "How is LA in physics courses structurally related to students' motivational beliefs (SE, IV, TA) and cognitive-metacognitive SR strategies (cognitive strategy use [CSU] and SR)?" The following hypotheses were tested within the scope of this question.

- H1:** The self-awareness, managing difficulties, planning, and action dimensions will significantly and strongly load onto the "LA" variable.
- H2:** There is a positive, significant structural relationship between LA and SE.
- H3:** There is a positive, significant structural relationship between LA and IV.
- H4:** There is a positive, significant structural relationship between LA and TA.
- H5:** There is a positive, significant structural relationship between LA and CSU.
- H6:** There is a positive, significant structural relationship between LA and SR.

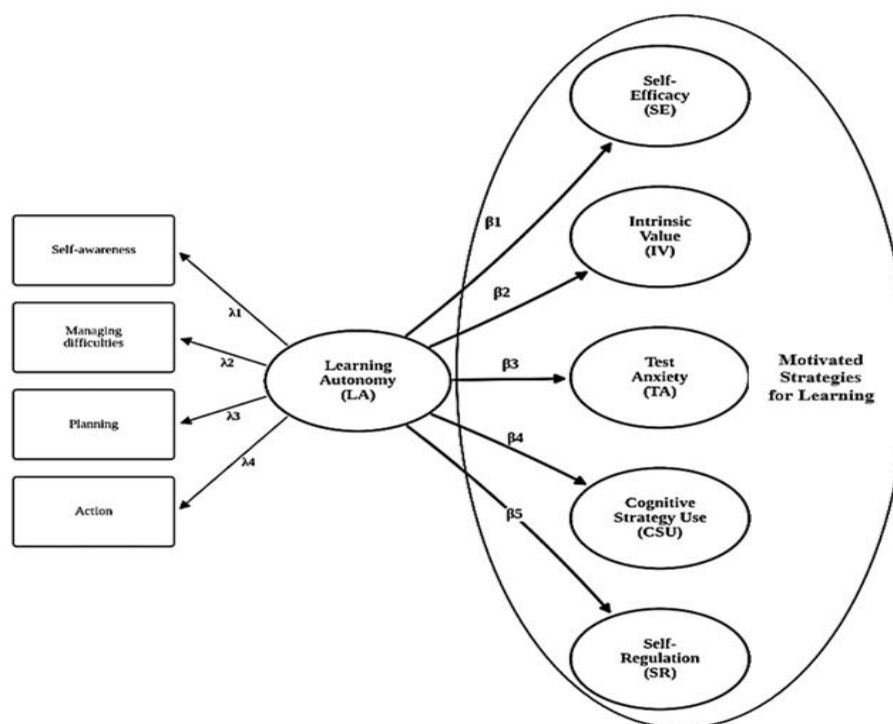
## Tested Model

The structural model tested in this study is presented in **Figure 1**. In the model, LA is positioned as a second-order latent exogenous variable, loaded by four dimensions (self-awareness, managing difficulties, planning, and action), which in turn predicts the five motivational-metacognitive components in the physics course (SE, IV, TA, CSU, and SR).

## METHOD

### Research Design

This study was designed as a cross-sectional correlational study within a quantitative research approach, aimed at examining the structural relationships between LA and the motivational and cognitive-metacognitive components of SRL in physics courses. Direct and indirect relationships among the variables were tested using SEM (Byrne, 2016; Wang et al., 2017). Specifically, a two-step modeling approach was followed, in which the measurement model was first validated through confirmatory factor analysis (CFA) and subsequently the structural model was tested, with LA specified as a second-order latent exogenous variable predicting the five motivational and cognitive-metacognitive components (Anderson & Gerbing, 1988).



**Figure 1.** Tested structural model (path diagram) (designed by the authors)

### Population and Sample

The population of the study consisted of university students taking a physics course in Kazakhstan during the 2025-2026 spring semester. The sample consisted of 291 undergraduate students selected through convenience sampling in Kazakhstan, all of whom were taking a physics course at a single university and volunteered to take part in the study. Convenience sampling is a non-probability sampling method in which the researcher forms the sample from participants who are easily accessible and willing to take part in the study (Winton & Sabol, 2022).

Of the participants, 62.9% ( $n = 183$ ) were female and 37.1% ( $n = 108$ ) were male. By year of study, students were distributed as follows: first year ( $n = 88$ , 30.2%), second year ( $n = 61$ , 21.0%), third year ( $n = 60$ , 20.6%), and fourth year ( $n = 82$ , 28.2%). Regarding attitude toward the course, 76.3% ( $n = 222$ ) reported liking physics, 21.0% ( $n = 61$ ) reported liking it somewhat, and 2.7% ( $n = 8$ ) reported not liking it.

### Data Collection Tools and Data Collection

#### Motivated strategies for learning questionnaire

Motivated strategies for learning questionnaire (MSLQ) with 44 items, which was developed by Pintrich and De Groot (1990) and modified for use in physics classes was applied in the current research. The process of modification was done through a standard back-translation procedure carried out by two bilingual language experts, after which a subject-matter expert reviewed the translated version to validate its content.

The questionnaire was administered in Russian, the primary language of instruction for the participating cohort. The translation followed a standard forward-back-translation procedure: two bilingual language experts carried out the translation and back-translation, and a subject-matter expert then reviewed the translated version for content accuracy and terminological precision in the physics context. This questionnaire is comprised of five different subscales and responses are provided on a seven-point scale (1 = not at all true of me to 7 = very true of me): SE (9 items), IV (9 items), TA (4 items), CSU (13 items) and SR (9 items).

A single-factor CFA was carried out in the current sample to evaluate the structure of the original nine-item SR subscale of the scale. It was found that the nine-item structure did not provide for acceptable model fit ( $\chi^2[27] = 499.58$ ,  $p < .001$ , CFI = .615, TLI = .487, RMSEA = .246). It was observed that three reverse-scored items (27, 37, and 38) had negative factor loadings ( $\lambda = -.33$ ,  $-.51$ , and  $-.40$ ). Considering that negatively phrased items may result in method effect unrelated to the latent variable (Dunn et al., 2012), these three items were excluded. Six-item single-factor structure revealed improved fit ( $\chi^2[9] = 51.20$ ,  $p < .001$ , CFI = .940, TLI = .900, RMSEA = .127). Factor loadings varied from .60 to .82. Thus, the SR subscale consisted of six items (6 items,  $\alpha = .85$ ).

#### Learner autonomy questionnaire

Learner autonomy questionnaire (LAQ) scale created by Bei et al. (2019) is applied for assessing the perceived degree of autonomy of students in the learning process. Two dimensions of autonomy are assessed with the help

of the instrument, which are related to the personal/psychological characteristics of the learner and to the educational program, correspondingly. "Personal autonomy (PA)" (7 items) is related to self-awareness of learners of their capabilities and limitations as well as to their independence in managing problems during the learning process. "Educational autonomy (EA)" (9 items) includes planning (setting goals, time, and steps) and action (control over the content, methods, and means of learning). This study employed the validated 16-item version of the scale ("PA" – 7 items; "EA" – 9 items). The scale is rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Translation/back-translation and expert review approaches were used for content validation.

A CFA was performed to assess the scale's originally postulated four-factor structure (self-awareness, coping with difficulties, planning, action) in the current sample. The four-factor structure was found to provide significantly better fit than a one-factor structure ( $\Delta\chi^2[5] = 107.70$ ,  $p < .001$ ), and to show adequate model fit ( $\chi^2[98] = 365.87$ ,  $p < .001$ , CFI = .913, TLI = .894, RMSEA = .097). Standardized factor loadings varied from .65 to .87, all items had significant factor loadings on their corresponding factors ( $p < .001$ ). This suggests that the four-factor measurement structure suggested by Bei et al. (2019) is also valid in the current sample.

Data were collected using an online survey (Google Forms) during February-March of the 2025-2026 spring semester. Participants volunteered to take part in the experiment, and informed consent was obtained from each participant before data collection.

## Data Analysis

The data set was examined for missing data and outliers before the analyses. No missing data were found ( $N = 291$ ). Since both scales were completed in a single sitting through self-report, a Harman's single-factor test was run beforehand to check whether common method variance could be driving the pattern of relationships. All 69 items were entered into an unrotated principal component analysis, and the first factor accounted for 38.5% of the total variance—well under the 50% mark usually taken as a warning sign (Podsakoff et al., 2003). This obviously does not eliminate method effects altogether, but it makes a single dominant factor an unlikely explanation for the correlations reported later. Internal consistency of the measures was assessed using Cronbach's alpha coefficient. The associations between the variables were established through a two-step strategy that is recommended by Anderson and Gerbing (1988), and according to which the measurement model is tested first, followed by the testing of the structural model. In order to reduce the complexity of the model and the number of indicators, the item parcels were made based on MSLQ scales containing nine or more items (SE, IV, cognitive strategies, and SR) using the

**Table 1.** Descriptive statistics and reliability coefficients for the scales

| Variable              | k  | M    | SD   | $\alpha$ |
|-----------------------|----|------|------|----------|
| PA                    | 7  | 4.12 | 0.76 | .91      |
| Self-awareness        | 3  | 4.22 | 0.79 | .87      |
| Managing difficulties | 4  | 4.04 | 0.82 | .86      |
| EA                    | 9  | 4.11 | 0.72 | .91      |
| Planning              | 4  | 4.12 | 0.78 | .83      |
| Action                | 5  | 4.10 | 0.77 | .87      |
| SE                    | 9  | 5.55 | 1.07 | .92      |
| IV                    | 9  | 5.82 | 1.00 | .91      |
| TA                    | 4  | 4.45 | 1.67 | .88      |
| CSU                   | 13 | 5.41 | 0.97 | .90      |
| SR                    | 6  | 5.40 | 1.14 | .85      |

Note. PA and EA items are scored on a 1-5 scale and the MSLQ subscales (SE, IV, TA, CSU, SR) on a 1-7 scale; K: Number of items; M: Mean; SD: Standard deviation;  $\alpha$ : Cronbach's alpha internal consistency coefficient; & N = 291

item-to-construct balance technique; three parcels were used for all scales, except SR, for which two parcels were enough (Little et al., 2002). The four-item TA scale (TA4) was subjected to analysis without creating any item parcels. The second order latent variable LA included the mean score of four dimensions (self-awareness, difficulty management, planning, and acting). In the original model of LAQ, PA, and EA were conceived as two different exogenous variables; however, since the latent correlation between the two was  $r = .79$ , which is high enough to induce multicollinearity, structural coefficients became non-stable and hard to interpret. Thus, the two were pooled into one second order variable of "LA".

Analyses were carried out in Python using the semopy package (version 2.3.11), with parameter estimation by means of maximum likelihood. Model fitness was assessed in terms of the chi-square statistic ( $\chi^2$ ) and degrees of freedom (df) along with fit indices that are less influenced by the sample size: comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). Based on the recommendations of Hu and Bentler (1999) and Kline (2016), and Byrne (2016), satisfactory values of CFI and TLI ( $> .90$ ;  $> .95$  is preferable for acceptable fit) and RMSEA and SRMR ( $< .08$ ) were considered as indications of acceptable model fit. As the fit indices for the hypothesized model were borderline, standardized residual covariances were analyzed and adjustments were made on theoretical grounds prior to model retesting (see results).

## RESULTS

### Descriptive Statistics

Descriptive statistics and internal consistency (alpha reliability) coefficients of the measurement instruments used in this study are summarized in **Table 1**. The PA

**Table 2.** Correlation coefficients among the variables

| Variable | 1     | 2     | 3     | 4     | 5     | 6     | 7 |
|----------|-------|-------|-------|-------|-------|-------|---|
| 1. PA    | -     |       |       |       |       |       |   |
| 2. EA    | .79** | -     |       |       |       |       |   |
| 3. SE    | .54** | .53** | -     |       |       |       |   |
| 4. IV    | .53** | .52** | .84** | -     |       |       |   |
| 5. ta    | .14*  | .24** | .24** | .19** | -     |       |   |
| 6. CSU   | .62** | .64** | .71** | .76** | .24** | -     |   |
| 7. SR    | .62** | .63** | .71** | .70** | .37** | .87** | - |

Note. N = 291; \*  $p < .05$ ; & \*\*  $p < .01$

and EA scales were measured on a 1-5 scale, and MSLQ scales on a 1-7 scale. Reliability coefficients for all scales ranged between .83 and .92, which exceeded the .70 criterion set by Nunnally (1978).

### Relationships Among the Variables

Pearson product-moment correlation coefficients between the LA components and the motivational-metacognitive components are presented in **Table 2**. PA and EA were strongly related to each other ( $r = .79$ ,  $p < .001$ ). Both autonomy dimensions showed moderate-to-strong relationships with SE, IV, CSU, and SR ( $r = .52-.64$ ,  $p < .001$ ), and weak relationships with TA ( $r = .14-.24$ ).

### Measurement Model

The analysis of this study was done using a two-stage SEM methodology. The measurement model validity was assessed by conducting CFA. Standardized factor loadings are shown in **Table 3**. All indicator factor loadings on corresponding latent constructs varied between .72 and .93 and were statistically significant ( $p < .001$ ), hence demonstrating convergent validity of the measurement model. Average variance extracted (AVE) values, calculated from the standardized loadings in **Table 3**, ranged from .64 to .81 across the six constructs, further supporting convergent validity. Discriminant validity was checked against the Fornell and Larcker (1981) criterion by comparing each construct's  $\sqrt{\text{AVE}}$  with its correlations with the others. This was satisfied for every pair except CSU and SR, where the correlation between the two ( $r = .87$ ) was marginally higher than  $\sqrt{\text{AVE}}$  for CSU (.86). Given that both constructs describe closely related regulatory behavior in the MSLQ, some item-level overlap is not surprising, but the two should be read as strongly related rather than fully distinct dimensions. Four constructs of LA, self-awareness, dealing with difficulties, planning and action, factor-loaded significantly onto second-order latent variable "LA" ( $\lambda = .83-.86$ ), which confirmed **H1**. A full list of indicators' (parcels) scale items is given in **Appendix A**.

### Structural Model and Model Fit

Following the confirmation of the measurement model, the entire structural model, with LA predicting

**Table 3.** Standardized factor loadings for the measurement model

| Latent variable | Indicator             | $\lambda$ | SE   | z     | p      |
|-----------------|-----------------------|-----------|------|-------|--------|
| LA              | Self-awareness        | .85       | -    | -     | -      |
|                 | Managing difficulties | .84       | .058 | 17.86 | < .001 |
|                 | Planning              | .86       | .054 | 18.42 | < .001 |
|                 | Action                | .83       | .055 | 17.28 | < .001 |
| SE              | SE parcel 1           | .93       | -    | -     | -      |
|                 | SE parcel 2           | .81       | .049 | 19.47 | < .001 |
|                 | SE parcel 3           | .88       | .041 | 23.39 | < .001 |
| IV              | IV parcel 1           | .93       | -    | -     | -      |
|                 | IV parcel 2           | .86       | .039 | 22.95 | < .001 |
|                 | IV parcel 3           | .85       | .043 | 21.97 | < .001 |
| TA              | Item 1 (TA1)          | .72       | -    | -     | -      |
|                 | Item 2 (TA2)          | .82       | .084 | 13.15 | < .001 |
|                 | Item 3 (TA3)          | .86       | .087 | 13.55 | < .001 |
|                 | Item 4 (TA4)          | .80       | .082 | 13.05 | < .001 |
| CSU             | CSU parcel 1          | .75       | -    | -     | -      |
|                 | CSU parcel 2          | .90       | .092 | 17.27 | < .001 |
|                 | CSU parcel 3          | .92       | .090 | 17.85 | < .001 |
| SR              | SR parcel 1           | .90       | -    | -     | -      |
|                 | SR parcel 2           | .90       | .044 | 23.36 | < .001 |

Note. All loadings are taken from the standardized solution (estimated standards) because the first indicator for each latent variable was fixed as the reference (marker) indicator, no SE, z, or p value was generated for it & Three item parcels, created using the item-to-construct balance technique, were used for the larger MSLQ subscales (SE, IV, CSU), and two parcels for self-regulation (Little et al., 2002)

the five motivational-metacognitive variables, was evaluated. The initial (theoretically hypothesized) model demonstrated poor fit indicators,  $\chi^2(147) = 927.19$ ,  $p < .001$ , CFI = .846, TLI = .821, RMSEA = .135 (90% CI [.127, .144]), SRMR = .084.

The examination of the standardized residual covariances revealed that

- the relationship between SE and IV is grounded in their common motivational belief system, as indicated by the theoretical literature (Pintrich & De Groot, 1990) and
- the disturbance variables for all five outcome (endogenous) variables share the additional variance not accounted for by LA.

Therefore, theoretically justified correlations were introduced between the disturbance variables of SE, IV, TA, CSU, and SR. Also, the error terms were correlated between one parcel of the CSU scale (CSU1) and the fourth item of the TA4 ( $r = -.16$ ,  $p < .001$ ). The resulting revised model provided much better fit than the initial model,  $\Delta\chi^2(11) = 523.66$ ,  $p < .001$ . The results regarding the model fit are summarized in **Table 4**.

Modification indices were inspected sequentially, and the largest individual improvements in fit came from the SE-IV and CSU-SR pairs ( $\Delta\chi^2[1] = 147.1$  and 110.0, respectively). The remaining eight covariances produced smaller individual improvements, several of which fell below the conventional significance threshold

**Table 4.** Comparison of fit indices for the initial and modified structural models

| Model                          | $\chi^2$ | df  | $\chi^2/df$ | CFI        | TLI        | RMSEA [90% CI]   | SRMR       |
|--------------------------------|----------|-----|-------------|------------|------------|------------------|------------|
| Model 1 (initial)              | 927.19   | 147 | 6.31        | .846       | .821       | .135 [.127-.144] | .084       |
| Model 2 (modified)             | 403.53   | 136 | 2.97        | .947       | .934       | .082 [.073-.092] | .051       |
| Criterion (Hu & Bentler, 1999) | -        | -   | < 3-5       | $\geq .95$ | $\geq .90$ | $\leq .08$       | $\leq .08$ |

Note. Model 2 was derived from model 1 through the addition of ten covariances for the disturbances of SE, IV, TA, CSU, and SR, and one covariance for the errors of CSU1 and TA4 ( $r = -.16$ ,  $p < .001$ ; 11 df in total);  $\chi^2(11) = 523.66$ ,  $p < .001$ ; Model 2 is significantly better than model 1 based on the nested models analysis as well as absolute fit criteria and thus was chosen as the final model; CI: Confidence interval

**Table 5.** Structural effects of LA on the motivational-metacognitive components

| Path     | B     | SE   | z     | $\beta$ | p      | R <sup>2</sup> |
|----------|-------|------|-------|---------|--------|----------------|
| LA → SE  | .991  | .090 | 10.98 | .635    | < .001 | .403           |
| LA → IV  | .911  | .088 | 10.40 | .605    | < .001 | .366           |
| LA → TA  | .484  | .138 | 3.52  | .231    | .0004  | .053           |
| LA → CSU | .729  | .064 | 11.35 | .725    | < .001 | .526           |
| LA → SR  | 1.156 | .091 | 12.76 | .731    | < .001 | .535           |

Note. B: Unstandardized path coefficient; SE: Standard error;  $\beta$ : Standardized path coefficient; R<sup>2</sup>: Proportion of variance explained in the corresponding endogenous variable; & LA: Second-order latent variable

when tested in isolation; however, retaining only the statistically largest modifications left the model short of the RMSEA  $\leq .08$  criterion (RMSEA = .096), so the full set of ten covariances was retained to achieve acceptable overall fit. This trade-off between parsimony and fit is acknowledged as a limitation of the modification process.

It should be noted that although the modified model represents a substantial improvement over the initial model, RMSEA remains marginally above the conventional .08 criterion and CFI is marginally below the preferred .95 threshold; the fit is therefore best characterized as acceptable/adequate rather than good. Path coefficient values, standard error values, z values, probability values, and R-squared values for the impact of LA on the five output variables are illustrated in **Table 5**.

All six hypotheses, **H1** to **H6**, were supported. The four dimensions of LA had high and significant loadings on the latent variable LA (**H1**). LA had positive and high predictive power for SE ( $\beta = .64$ ), IV ( $\beta = .61$ ), CSU ( $\beta = .73$ ), and SR ( $\beta = .73$ ) (**H2**, **H3**, **H5**, and **H6**). The path coefficient for LA-TA relationship was considerably low compared to others but was statistically significant and positive ( $\beta = .23$ ,  $p < .001$ ; **H4**). This model had explained 5.3% of the variance in TA, while in CSU and SR, it accounted for 52.6% and 53.5% of the variance, respectively (**Figure 2**).

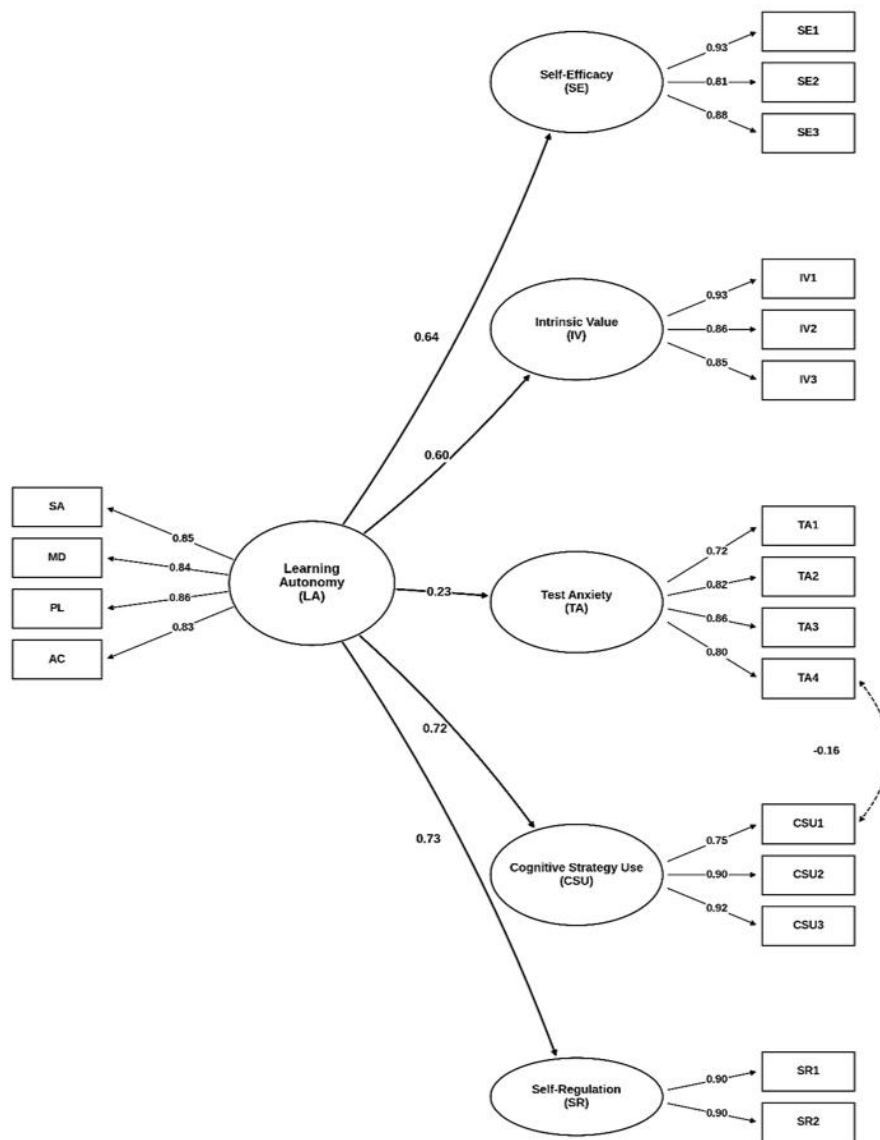
## DISCUSSION

In this research, the structural relations between LA and motivational and cognitive/metacognitive aspects of SRL in physics were examined using SEM. The first result is the complete confirmation of the is **H1**, which states that LA can be conceptualized as the second-order latent variable of four dimensions including self-awareness, managing difficulties, planning, and action. Hence, students' perception of autonomy in physics

courses goes beyond the scope of educational actions in class or awareness alone, because both educational and personal dimensions are needed for constructing this concept. Such construction of the concept coincides with the original one proposed by Bei et al. (2019) and proves that autonomy in physics is a higher-order construct which integrates students' cognitive and emotional processes. More specifically, the extremely high correlation between PA and EA latent variables indicates that learners' ability to deal with difficulties is inseparable from their planning and action during the studying process in physics.

The results demonstrating the significant positive predictive role of the autonomy support variable on students' SE beliefs and IV of the physics learning process were in line with **H2** and **H3**, correspondingly. The result implies that the greater freedom in making decisions, setting personal goals, and choosing one's own way of learning in the process of learning physics, the higher SE that is, belief in the ability to accomplish difficult tasks in the physics domain as well as students' interest in physics (IV) will become (Irsalina et al., 2025; Li & Singh, 2024). This finding correlates with Self-Determination Theory postulate about the importance of satisfying such psychological needs as autonomy, competence, and relatedness for fostering motivation (Deci & Ryan, 2000; Ryan & Deci, 2017). Other similar findings in the literature prove that the provision of autonomy support directly contributes to enhancing students' SE and IV of tasks in STEM domains and that these affective beliefs feed each other (Eccles & Wigfield, 2002; Rován et al., 2024). With increasing capability for independent action, physics topics implying abstract mathematical models become more feasible and become the driver of cognitive efforts (Maison et al., 2019).

**H4** was verified as a positive and significant structural relationship exists between LA and TA. Yet, this relationship only explains 5.3% of the variance of TA. At the first sight, this result may appear to contradict



**Figure 2.** Estimated model with modification (path diagram) (designed by the authors)

expectations since autonomy is expected to lower anxiety; yet it is quite consistent in light of high stakes and assessment-oriented context of physics teaching (Alpaslan et al., 2016). Indeed, when students become autonomous, taking complete responsibility for their learning and academic results, it creates a certain level of performance and TA because of feeling personally responsible for their results. This explanation should be regarded as one plausible interpretation rather than a definitive account, given that the model explains only 5.3% of the variance in TA; other unmeasured factors may also contribute to this relationship. Additionally, in the centralized educational system such as that of Kazakhstan, when there is exam pressure based on traditional exam system, the discrepancy between the autonomous learning strategies and outcomes, measured through exams, is likely to create some kind of cognitive anxiety among autonomous learners (Alpaslan et al., 2016; Dunn & Lo, 2015). This interpretation is supported by Maison et al. (2019) and Irsalina et al.

(2025) since in their physics SRL profiles they identified TA as a vital affective barrier limiting achievement, while autonomous learning strategies operate independently from this factor.

The observation that there was a significant and positive prediction of the use of cognitive strategies and SR by LA contributed to the acceptance of **H5** and **H6**. The fact that the model accounted for 52.6% and 53.5% of the variances in the use of cognitive strategies and SR, respectively shows that LA plays an important part in influencing strategic and deep learning in physics classes. Autonomous learners, being given control over themselves, adopt higher order cognitive strategies like elaboration, organization, and critical thinking instead of using only lower order surface strategies like rehearsal and assess their own learning processes during the process (Paz-Baruch, 2025; Winarti et al., 2022). The findings of the study support the theoretical framework set up by Muis (2007) about the role of PA in activating cognitive and metacognitive strategies. As learners play

a more independent role, they can be more efficient in coordinating higher order problem-solving steps, such as qualitative analysis of the physics problem, visualization of the problem, and integrating the physical concepts into mathematics (Abtokhi et al., 2021).

The modifications performed when the fit indices were on the borderline of acceptance of the model resulted in changes (model 2), which present the interrelations between motivational and metacognitive factors in physics learning. The increased fit of the model due to the correlations of the disturbances of SE, IV, TA, CSU, and SR indicate the presence of common variance of these endogenous variables beyond the influence of LA on its own (Pintrich & De Groot, 1990; Rován et al., 2024). It aligns well with the social-cognitive theory put forward by Pintrich and De Groot (1990): the motivational beliefs of the learners (SE and IV) and the cognitive-metacognitive activities (strategy use and SR) act as the parts of the system operating in the classroom at once. In other words, while autonomy is the key exogenous variable that stimulates these mechanisms, various environmental factors (interaction with peers, teacher's support, course structure, etc.) feed the common variance of the factors continually (Li & Singh, 2024; Maison et al., 2019). As noted above, several of the retained disturbance covariances were not individually significant, and their inclusion reflects a deliberate trade-off between model parsimony and overall fit rather than a fully data-driven respecification.

The presence of a negative correlation at the error-term level between CSU1 and TA4 in the final structural model ( $r = -.16$ ,  $p < .001$ ) shows a significant psychometric and theoretical aspect. This negative correlation indicates that students who use cognitive strategies, especially those that organize knowledge like elaboration and organization, are capable of overcoming some types of anxiety and worries during exams. Deeper processing of information through cognitive strategies decreases the cognitive load imposed on students when dealing with complex physics problems and, therefore, helps to free working memory and mitigate anxiety by not creating any cognitive blocks for students when taking exams, including the inability to remember a memorized formula (Sweller, 1988). Hence, even though LA in general has a very low positive connection with TA, the CSU stimulated by LA seems to be a protective buffer that alleviates the negative effects of TA (Winarti et al., 2022).

The dominance of females in the current sample population, coupled with the university in Kazakhstan setting, have far-reaching implications in terms of generalizability of the structural associations discovered in this study as well as issues concerning equity in STEM education. Previous research in the field of physics education (Cwik & Singh, 2021; Li & Singh, 2024) suggests that female students, who attain similar grade

results in physics classes as their male counterparts, generally perform worse in affective aspects of their studies, such as SE, interest, and physics identity and face difficulties in feeling like they belong to the discipline. However, the results of the current study demonstrate that LA is a universal factor that works as a significant predictor of more than 50% of the variance in cognitive strategies and SR among both male and female participants. Autonomous learning approaches may be beneficial for women in physics classes that are usually perceived as a domain for men to control their cognitive skills, improve SE, and stay within STEM discipline (Cwik & Singh, 2021; Li & Singh, 2024).

In spite of the structural insights provided by this study, there are several issues that need to be considered while interpreting the research findings. Firstly, the data was collected from a sample of 291 undergraduate students from one university of Kazakhstan, using the convenient sampling procedure; therefore, the obtained results cannot be generalized to other socio-cultural and national settings. Second, the use of self-reported questionnaires makes it difficult to obtain reliable information about the students' classroom behavior or SR process. Moreover, the exclusion of the three negative items from the SR subscale on the psychometric grounds, in a sense, changes the initial scale and thus becomes a limitation of this study. Additionally, while the retained disturbance covariances were grounded in theoretical rationale, not all of them reached conventional significance when tested individually; their joint retention reflects a trade-off between statistical parsimony and achieving acceptable overall model fit, and this trade-off should be considered when interpreting the modified model. Lastly, due to the cross-sectional design used, the test of possible causal relationships or reciprocal changes of the variables was impossible.

## CONCLUSION AND RECOMMENDATIONS

The structure of the connection between the LA of undergraduate students in physics and motivational and cognitive metacognitive components of their self-regulatory processes has been identified in this research. All the hypotheses put forward in the research (**H1-H6**) were supported; LA exerted strong and significant structural effects on students' SE, IV, CSU, and SR, and a weaker but still significant effect on TA.

This implies that the path to successful learning in such a complicated and challenging STEM discipline as physics with its abstract concepts and abundant use of mathematical models goes through allowing learners to make their own decisions and control their own educational processes. Independence in learning does not only directly raise the level of intrinsic motivation to study the topics related to physics and SE but is an

essential step in the process of activating higher-order thinking and metacognitive SR processes needed for developing higher-order thinking skills. The positive but relatively weak relationship between TA and LA ( $\beta = .23$ ,  $R^2 = .053$ ) appears to reflect a secondary emotional process linked to assuming responsibility for one's own learning, which can be managed through appropriate cognitive strategies

It is high time that physics educators and curriculum designers moved away from the traditional, teacher-centered approach, based on formulas, and hastened the shift towards a learner-centered environment where students become more autonomous in their learning. It requires designing curricula that would allow students to make choices concerning what to study, how to solve problems, and how to perform experiments; this should be accomplished through implementing innovative methods of instruction that would ensure cognitive autonomy of learners, including PjBL, laboratory studies using an inquiry-based approach, and mind mapping. Moreover, in order not to cause TA due to the autonomous way of learning, there should be a minimum use of written tests.

Having considered all the limitations of the present study, it would be reasonable to suggest for the future researchers to conduct more analysis on the basis of the same structural model of LA and its components in regard to SRL in larger samples selected randomly in various cultural/national settings (e.g., across various cultures/school subjects). As for the ways of coping with the weaknesses of the self-report measures, it would be reasonable to conduct a mixed methods of research with the help of semi-structured interviews, observation checklists, and think-aloud procedure while solving problems. The longitudinal design would be preferable as it would make it possible to observe the reciprocal relationships between the variables. The other factor structure or bifactor SEM could be applied in order to overcome the methodological bias of the reverse-coded items in the SR subscale.

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**AI statement:** No generative AI or AI-based tools were used in the preparation, writing, analysis, or any other stage of this manuscript.

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## APPENDIX A: COMPOSITION OF THE INDICATORS (PARCELS) USED IN THE MEASUREMENT MODEL

**Table A1** shows which original scale items make up the item parcels created using the item-to-construct balance technique described in the method section. The four dimensions of learning autonomy were not created through parceling but were based on the original subscale structure; test anxiety, given its small number of items, was modeled directly at the item level without parceling. Item numbers correspond to the original 44-item (MSLQ) and 25-item (LAQ) numbering presented in Bei et al. (2019). Item-to-construct balancing means that each parcel was formed to contain a balanced mix of the items with the highest and lowest item-total correlations. In the self-regulation subscale, the three reverse-scored items were removed before parceling.

**Table A1.** Item composition of the measurement model indicators

| Latent variable | Indicator             | Component items               | Construction method                  |
|-----------------|-----------------------|-------------------------------|--------------------------------------|
| LA              | Self-awareness        | PAS items 2, 3, 4             | Original subscale (Bei et al., 2019) |
|                 | Managing difficulties | PAS items 6, 7, 8, 9          | Original subscale (Bei et al., 2019) |
|                 | Planning              | EAS items 1, 2, 3, 7          | Original subscale (Bei et al., 2019) |
|                 | Action                | EAS items 4, 5, 6, 8, 10      | Original subscale (Bei et al., 2019) |
| SE              | SE parcel 1           | MSLQ items 6, 11, 19          | Item-to-construct balance            |
|                 | SE parcel 2           | MSLQ items 2, 9, 13           | Item-to-construct balance            |
|                 | SE parcel 3           | MSLQ items 8, 16, 18          | Item-to-construct balance            |
| IV              | IV parcel 1           | MSLQ items 10, 17, 21         | Item-to-construct balance            |
|                 | IV parcel 2           | MSLQ items 4, 14, 15          | Item-to-construct balance            |
|                 | IV parcel 3           | MSLQ items 1, 5, 7            | Item-to-construct balance            |
| TA              | TA1-TA4               | MSLQ items 3, 12, 20, 22      | Direct item (no parceling)           |
| CSU             | CSU parcel 1          | MSLQ items 26, 30, 31, 42, 44 | Item-to-construct balance            |
|                 | CSU parcel 2          | MSLQ items 24, 29, 36, 39     | Item-to-construct balance            |
|                 | CSU parcel 3          | MSLQ items 23, 28, 34, 41     | Item-to-construct balance            |
| SR              | SR parcel 1           | MSLQ items 33, 35, 43         | Item-to-construct balance            |
|                 | SR parcel 2           | MSLQ items 25, 32, 40         | Item-to-construct balance            |

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