Metacognition and epistemic cognition in physics are related to physics identity through the mediation of physics self-efficacy

Yaren Ulu [1] and Sevda Yerdelen-Damar [2]

[1] *Department of Physics and Astronomy, College of Arts & Sciences, Texas Tech University, Lubbock, 79409, Texas, USA*

[2] *Faculty of Education, Department of Mathematics and Science Education, Bogazici University, Bebek, 34342, Istanbul, Turkey*

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This study aimed (i) to investigate how epistemic cognition in physics and metacognition, together with three dimensions of physics identity framework—recognition, physics self-efficacy, and interest—predicted the overall physics identity of Turkish high school students and also (ii) to investigate gender differences in study constructs. A sample of 1197 high school students participated in the study. The collected data were analyzed using structural equation modeling. The analysis results indicated that the model fitted the data well, further motivating intervention studies to test the causal relations proposed in the model. The results showed that recognition and interest directly predicted physics identity and mediated the relation of physics self-efficacy to it. Metacognition and epistemic cognition predicted physics identity through physics self-efficacy. The study also observed significant direct and indirect relations among metacognition, epistemic cognition, self-efficacy, recognition, and interest. Furthermore, gender differences were found in the current study. While no gender difference was observed in metacognition and epistemic cognition in physics, male students scored higher than female students in physics identity, self-efficacy, recognition, and interest. However, the mediation analysis further indicated that gender differences in physics self-efficacy might explain gender differences in physics identity, recognition, and interest. The results of this study could motivate future interventions testing the effect of metacognitive and epistemic activities on both physics self-efficacy and identity, and also, the interventions testing whether practices that reduce the gender gap in physics self-efficacy will help eliminate the gender gap in physics identity, recognition, and interest.

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I. INTRODUCTION

Physics identity refers to the degree to which a person considers herself or himself a “physics person” [1]. Various research studies have shown that students’ physics identity predicts their participation in physics classes and their choice of careers related to physics [1,2]. The sophistication in identity enables learners to become active agents in science by combining their knowledge with scientific thinking methods to be purposeful and strategic learners [3]. Based on research findings demonstrating the crucial role of identity in students’ learning, engagement, and career paths, Organization for Economic Cooperation and Development (OECD) [4] added scientific identity to the Program of International Student Assessment (PISA, 2024) assessment framework as a new dimension. It is claimed that identity can be a tool to create a learning ecology; therefore, the assessment framework should involve probing students’ identities.

On the other hand, it is noteworthy that interest in physics departments has gradually decreased worldwide. For instance, fewer bachelor’s degrees in physics are given out each year in the United States compared to other scientific, technology, engineering, and mathematics subjects [5]. Furthermore, although there was a slight increase in the number of physics undergraduates in the United Kingdom, there needed to be more growth since 2010 [6]. The inadequate increase in the rate of science, technology, engineering, and mathematics (STEM) graduates was also the case in Turkey [7]. While women receive just around one-fifth of these degrees in the United States [8], the low rate of women in STEM careers persisted between 2013 and 2019 in Turkey [9]. Similarly, according to the 2018 National Centre for Universities and Business report, only 22.2% of A-level physics students in the United Kingdom were women [10]. Therefore, determining the factors leading to this low choice rate and gender difference is vital for physics education. As students’ physics identity is a predictive variable in their career choices, especially during secondary education [1], this study examined Turkish high school students' physics identity. Also, it investigated how two related constructs, metacognition and epistemic cognition in physics, predicted physics identity.

II. THEORETICAL AND EMPIRICAL BACKGROUND

A. Identity

Gee defines identity as "being recognized as a certain 'kind of person,' in a given context" [11] (p. 99). Identity does not only depend on the individual but also on the social aspects, such that it is an outcome of an individual's actions and perceptions of significant others on that person. For example, a person reaches their scientific identity as an outcome of their competence and performance in science. Also, they can reach their recognition as a science person in their community [12].

According to Carlone and Johnson [12], identity comprises three components: competence, performance, and recognition. While competence is related to one's knowledge and understanding of science and does not have to be visible to the public, performance refers to revealing scientific practices using tools or even talking. On the other hand, recognition is a social dimension which means that one's recognition of oneself and others as a science person affects identity significantly. One may not have each dimension adequately. One may have exceeding skills meeting the performance criterion, but others may not recognize that one can perform it. One may have the relevant knowledge but may not be able to perform it or vice versa. In addition, since experiences gained in schools affect skills and knowledge, they are related to performance and competence dimensions. Although performance, recognition, and competence were the critical components of science identity, interest was also considered a component; however, because the researchers were already working with practicing scientists, interest was attributed to the participants and was not included in the model [12].

Hazari *et al.* [1] developed a physics identity framework utilizing Carlone and Johnson's science identity study [12]. Physics identity refers to the degree to which a person considers himself or herself a "physics person." Hazari *et al.* [1] proposed a framework that includes performance, competency, recognition, and interest, which are the fundamental interrelated constructs affecting the formation of physics identity. For the physics identity framework, competence is believing in the ability to understand physics, and performance is believing in the ability to carry out requisite physics assignments. In addition, recognition is being recognized by others as a physics person when interest is defined as the eagerness to get more knowledge about physics and do more activities related to physics.

While Hazari *et al.* [1] mentioned performance and competence as separate constructs, in a later study, Lock *et al.* [13] examined the effect of physics and math identities on students' choice of physics careers. They found that performance and competence were not independent constructs. However, they comprise one construct, "performance or competence," which is defined as students' beliefs in their abilities to carry out necessary physics tasks like problems and experiments and understand physics content. In the literature, a term similar to performance or competence is conceptualized. *Self-efficacy* is an individual's confidence in her or his ability to carry out behaviors required to achieve particular performance goals [14]. This study uses these terms interchangeably and prefers self-efficacy over performance or competence.

The later quantitative studies examining disciplinary identity in physics, mathematics, and engineering observed significant relations among these components. They revealed that students' interest and external recognition significantly related to an overall identity construct and self-efficacy. Self-efficacy was not directly related to physics identity but was positively related to identity through the mediating relations of interest and external recognition [2,8,15–18]. For example, Dou and Cian [17] worked on expanding the STEM identity framework by looking at the relationships between STEM recognition, self-efficacy, interest, and identity, and relevant demographic and social factors, such as gender, ethnicity, home support of science, parental education, and science talk. They found that students' interests and external recognition were strongly connected to their self-efficacy beliefs, which were indirectly related to their overall identity through interest and external recognition. The same mediational relationship between the identity constructs was also observed in the study of Verdín [18], in which the interrelations among engineering identity, interest, recognition, self-efficacy beliefs, sense of belonging, and persistence in the engineering career were examined. Thus, in the model of this study, the paths among the identity components and overall identity were proposed based on these research findings. Specifically, we hypothesized that interest and recognition are directly related to physics identity, and interest and recognition mediate the relation of self-efficacy to physics identity.

B. Metacognition

Metacognition refers to knowledge and regulation of an individual's own cognition [19,20]. Brown categorized metacognition into two components: knowledge of cognition and regulation of cognition. Knowledge of cognition refers to declarative information regarding one's cognition, whereas regulation of cognition refers to the ability to plan, monitor, control, and evaluate one's own cognition. Following Brown's framework, Schraw and Dennison [21] proposed an eight-dimensional framework to operationalize metacognitive awareness. According to this framework, knowledge of cognition has three levels:

- declarative knowledge (knowledge about facts and strategies).
- procedural knowledge (knowledge about how to apply strategies).
- conditional knowledge (knowledge about when to apply strategies and why).

For the regulation of cognition, five skills are necessary: planning, information management strategies, comprehension monitoring, debugging strategies, and evaluation [21]. The present study employed this framework to determine students' metacognition.

C. Epistemic cognition

Epistemic cognition refers to one's view of the nature of knowledge, knowing, and learning [22,23]. Different frameworks are used to probe students' epistemic cognition in physics [24–26]. For example, Hammer [25] (p. 155) conceptualizes students' epistemic cognition in physics as follows:

1. Beliefs about the structure of physics knowledge which can be a group made of individual parts or a sole organized system.
2. Beliefs about the content of physics knowledge that can consist of formulas or concepts.
3. Beliefs about learning physics in such a way that by getting the information passively or being actively involved in managing one's learning and shaping understanding.

The latest framework developed by Ozmen and Ozdemir [27] (p. 1215) is built on the literature on epistemic cognition in science and physics. The framework included six dimensions. Table I indicates the dimensions and descriptions of the dimensions.

The current study used this framework to measure students' epistemic cognition in physics. In the following sections, the interrelations among the study variables are discussed.

D. The relation of metacognition to identity, epistemic cognition, and self-efficacy

The sophistication in metacognition is considered a prerequisite for identity formation [28]. According to Marcia [29], individuals exhibiting a developed identity have more awareness of their own strengths and weaknesses when they make their path in life. Those features are compatible with the characteristics of individuals with high metacognitive knowledge, identified as an awareness of one's own strengths and weaknesses [21,30,31]. Likewise, Irving and Sayre [32] found that students in different identity development stages indicated different levels of metacognition. Students classified into the lowest stage of identity development indicated a lack of self-awareness of different approaches to learning, while students classified into the highest stage of identity development in the group demonstrated a completed self-awareness of different approaches to learning physics. Moreover, research revealed a positive relationship between decision making, which is necessary for

TABLE I. The dimensions of epistemic cognition in physics and explanations of them. Note that the table was adapted from K. Özmen, and Ö. F. Özdemir, Conceptualisation and development of the physics related personal epistemology questionnaire (PPEQ), Int. J. Sci. Educ., 41, 1207 (2019).

Dimensions	Description of what dimensions probe
Structure of knowledge coherence (SKC)	The degree to which the student views physics knowledge as a coherent vs incoherent structure.
Structure of knowledge hierarchical (SKH)	The degree to which the student views physics knowledge is formed by establishing a link between previous and new physics knowledge with a hierarchical vs fragmented structure.
Justification of knowledge and knowing (JK)	The degree to which the student views physics knowledge can be justified using mental processes (i.e., logical reasoning), evidence from experimentation, and inquiry emanating from conflicts between previous experiences and novel situations.
Changeability of knowledge (CK)	The degree to which the student views physics knowledge is subject to change or fixed (unchangeable).
Quick learning (QL)	The degree to which the student views constructing physics knowledge takes time (a gradual process of meaning-making), or learning happens very quickly.
Source of knowledge (source)	The degree to which the student views physics knowledge as constructed or is accepted directly from authority (i.e., textbooks, teachers, and scientists).

successful identity formation, and metacognition [33,34], and metacognitive interventions fostered individuals' decision-making performance [34,35]. Studies [36,37] showed that individuals with a developed identity demonstrated a high level of self-reflection, which is a metacognitive process ([38–40]. The studies employing self-reflection activities in training preservice teachers and learning assistants fostered identity construction [39,41–44]. According to Beauchamp and Thomas [45], reflection shapes teacher identity because by self-reflecting, they can better understand their sense of self and how that self is positioned in a larger community, including others. Furthermore, metacognition can indirectly influence identity formation through its impact on learning. The intertwining nature of learning and identity construction has been acknowledged in the literature [46–49]. According to Vareles [49], the learning process includes both content learning and identity formation. Many studies depicted that metacognitive interventions promoted student learning [50–53]. Thus, metacognitive activities could directly and indirectly improve students' identity formation.

Researchers have also pointed out metacognition as a necessary construct for epistemological development [54–58]. For instance, Bendixen and Rule [54] have proposed a model for explaining epistemic belief change and development. Metacognition is a critical factor of this model. The researchers assert that metacognition is vital for effective and durable epistemological development. In another integrated model of epistemic cognition and self-regulation, Muis [57] argues that metacognitive strategy training is crucial for epistemic development. Similarly, Elby and Hammer [56] claim that metacognitive monitoring facilitates epistemological change and development, including co-activation and stabilization of epistemological resources that individuals already have. Research studies investigating the effect of metacognitive strategies on students' epistemic views support the antecedent role of metacognition for epistemic development [59–61].

Finally, the link between self-efficacy and metacognition has also been highlighted in the literature [62]. Moores *et al.* [62] discuss the relationship between metacognition and self-efficacy as predictors of performance. According to the researchers, self-efficacy determines behavior and indirectly influences performance, while metacognition initiates behavior, monitors the level of performance, and controls subsequent behavior, which informs the benefit of metacognitive training for reaching a desired level of performance. Thus, instruction should promote this metacognitive feedback loop in which metacognition, performance, and self-efficacy can interact with each other. In this loop, metacognitive monitoring of performance can regulate subsequent behavior, which in turn influences one's sense of self-efficacy and stimulates the next cycle of behavior that can be re-evaluated by metacognitive processes [62]. The role of metacognition in self-efficacy development can be attributed to the relationship between past achievement and self-efficacy. According to Bandura [14], past achievement is the most influential source of self-efficacy. Based on this fact, a variable contributing to students' achievement could also contribute to their sense of self-efficacy. In this sense, metacognition-enhancing activities can potentially improve self-efficacy beliefs as well. Experimental studies indicated that metacognition-enhancing activities in instruction led to improved self-efficacy beliefs [63–67]. The relationship between self-efficacy and metacognition has also been found in correlational studies [68–70].

E. The relation of epistemic cognition to identity, self-efficacy, and interest

Similar to metacognition, epistemic cognition is key to identity development. Several researchers observed a positive relationship between epistemic development and identity formation [71–74]. For example, Faber *et al.* [75] found that students' perceptions of themselves as researchers were affected by their initial epistemic thinking about researchers and research, and reflection on research experiences promoted both their research identity and epistemic thinking.

Furthermore, research studies showed that students with sophisticated epistemic cognition possess higher self-efficacy beliefs [76–78]. In a conceptual model, Muis [57] hypothesizes that epistemic cognition is a precursor to motivational beliefs, including self-efficacy, achievement goal orientations, interest, task value, and anxiety. The role of epistemic cognition in self-efficacy development can be further justified, considering the relation of epistemic cognition to learning approaches. Studies revealed that individuals with sophisticated epistemic cognition are more likely to employ deep learning approaches [79–82], positively influencing their learning outcomes [83–86], which in turn might increase their self-efficacy beliefs. Later experimental studies investigating the effectiveness of epistemic interventions on students' self-efficacy beliefs [65,87] and correlational studies using structural equation models [78,88,89] provided supporting evidence for the antecedent role of epistemic cognition. Finally, consistent with Muis' theoretical model, a positive correlation was revealed between epistemic cognition and interest [76,77,90].

F. Gender differences in study variables

Many studies revealed gender differences in science and physics identity and science and physics-related career choices [1,91–95]. Male students showed higher levels of physics identity than female students [1,93,95]. Similarly, males chose physics as a career more than females [94,95]. Gender differences in favor of male students were also found in recognition [13,96], interest [13,97,98], and physics self-efficacy [13,99,100]. Thus, examining the indirect effects of gender on physics identity through

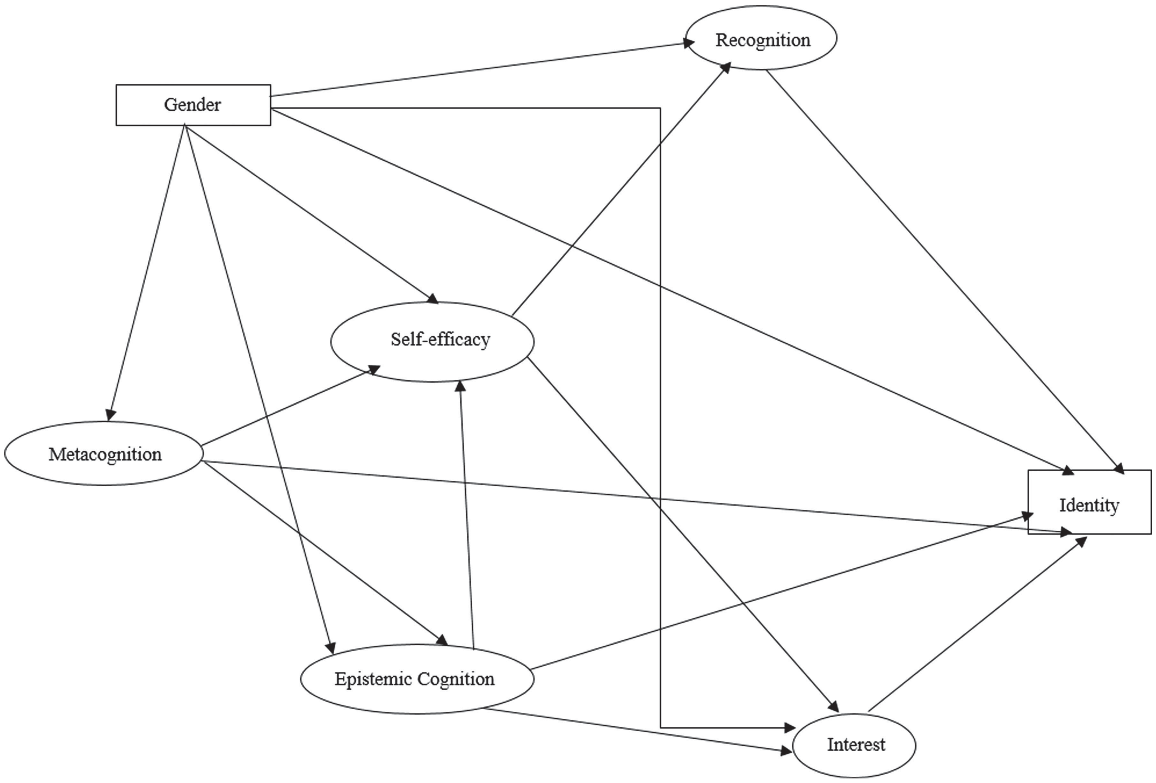


FIG. 1. The hypothesized theoretical model.

competence, recognition, and interest can provide information about underlying reasons for gender differences in physics identity.

On the other hand, a consistent gender difference has not been observed in metacognition and epistemic cognition. For instance, Yerdelen-Damar and Peşman [70] did not observe gender differences in metacognition, while Topçu and Yılmaz-Tüzün [101] showed that female students had higher metacognition than males. Similarly, while some studies showed that female students had more sophisticated epistemic beliefs than males [101,102], another study revealed that male students had more developed epistemic beliefs [103]. On the contrary, girls and boys tended to hold similar beliefs regarding the source or certainty and development dimensions, despite girls having more complex beliefs regarding the justification of knowledge than boys [104]. Due to contradictions in the results, it is also necessary to inspect gender differences in these two variables.

In conclusion, prior studies observed significant relations among identity, physics self-efficacy, interest, and recognition constructs [2,8,13] in other contexts. On the other hand, further research is needed to examine these relationships in other cultures and to inspect the relations of these constructs to other constructs. Metacognition and epistemic cognition are two essential variables that the research suggests to be used in instruction to improve identity. However, few studies examined the interrelations among metacognition, epistemic cognition, and identity through structural equation modeling (SEM) [76,105]. Furthermore, to the best of researchers' knowledge, there is no large-scale research examining the relation of physics identity to either metacognition or epistemic cognition in physics, although it is well-known that both epistemic cognition and identity are domain-specific constructs [106–108].

Therefore, the present study proposed a structural model based on the above studies (see Fig. 1) to investigate the interrelations among physics identity, recognition, physics self-efficacy, interest, epistemic cognition, metacognition, and gender. The current study extended the body of knowledge on physics identity by inspecting the direct and indirect relations of epistemic cognition in physics and metacognition to identity-related constructs, which could further motivate intervention studies to get a more comprehensive description of identity development. In addition, the mediating role of physics self-efficacy in the relation of physics identity to epistemic cognition, metacognition, and gender was pointed out in this study. This study answered the following research questions:

1. How are Turkish high school students' perceptions of physics self-efficacy, recognition, and interest related to their physics identity?
2. How is epistemic cognition related to physics identity?
3. How is metacognition related to physics identity?

4. How is gender related to physics identity?
5. How are the interrelations among gender, metacognition, epistemic cognition, and other identity constructs?

Based on the direct relation of physics self-efficacy to epistemic cognition and metacognition and gender revealed in previous studies,

6. Does physics self-efficacy mediate the relation of epistemic cognition to physics identity?
7. Does physics self-efficacy mediate the relation of metacognition to physics identity?
8. Does physics self-efficacy mediate the relation of gender to physics identity?

III. METHOD

A. Participants

The data were collected from 1197 high school students from six high schools in Istanbul, Turkey. While 58.2% of these students were female, 41.8% were male. The students' ages ranged from 14 to 18 or above, and 24.9% were in 9th grade, 40.8% were in 10th grade, 33.2% were in 11th grade, and 1% were in 12th grade. Of the participants, only 1% were 12th-grade students because senior students prepare for the university entrance exam, and they come to school less often since they have extra courses out of school.

The success level of the students ranged from low to high levels according to their high school entrance exam scores. All the students were taking physics lectures based on the Turkish curriculum. According to the students' reports on the socioeconomic status questionnaire, 99.5% of the students indicated they had Internet and technological tools, such as telephone, tablet, and computer, and 94.2% had a suitable environment to study. The education levels of their parents ranged from elementary to graduate level. When the educational status of their mothers was examined, it was seen that 17.1% of them were in primary school, 12.7% were in secondary school, 35.8% were in high school, 30.5% were undergraduate, and 3.8% were graduate or doctoral graduates. When the educational status of their fathers was examined, it was seen that 13% were in primary school, 13% were in secondary school, 36.4% were in high school, 31.2% were undergraduate, and 6.3% were graduate or doctoral graduates.

The surveys of the study were administered in physics classes that the students were taking. Before data collection, the students were informed by the first author regarding what the surveys measure, the importance of obtaining students' responses to the surveys for physics education research, voluntary participation in the research, participant confidentiality, and the right to withdraw their data at any time. Students were not rewarded with extra credit or points. However, no student in attendance refused to answer the surveys during the data collection. The students completed the surveys in one class hour. The entire data collection process was completed in 1 month.

B. Instruments

1. Physics identity survey

The persistence research in science and engineering study, as developed and validated by Hazari *et al.* [1], provided the specific items used to measure physics identity, including the dimensions of interest, self-efficacy (performance/competence), and recognition beliefs. Furthermore, it added an item measuring the overall physics identity [15]. The physics identity survey was further developed by Cheng *et al.* [2], including one identity item, four for recognition, six for self-efficacy, and four for interest. The dimensions of the Physics Identity Survey and one example item for each dimension are presented in Table II. The present study employed the Turkish version of the identity scale validated by Ulu and Yerdelen-Damar [109] to determine high school students' physics identity and their conceptions of identity-formation constructs. The confirmatory factor analysis (CFA) results of the Turkish scale revealed the same factor structure as that in the original scale. The multiple fit indices used to evaluate the results were within the acceptable range ($\chi^2(187, N = 361) = 510.12$; $\chi^2/\text{d.o.f.} = 2.72$; root mean square error of approximation (RMSEA) $= 0.07$ [90% confidence interval (CI) $= 0.06$, 0.0), standardized root mean square residual (SRMR) $= 0.05$; comparative fit index (CFI) $= 0.99$; normed fit index (NFI) $= 0.98$]. Items had significant factor loadings ($p < 0.05$). The magnitude of the factor loadings varied between 0.70 and 0.98. These values are greater than the minimum required value of 0.40. Cronbach's alpha ranged from 0.90 to 0.97 for the dimensions [109]. Similar to the original survey, the Turkish identity scale is an 11-point Likert scale ranging from 0 (Not at all) to 10 (Very much so).

2. Physics-related personal epistemology questionnaire

The physics related personal epistemology questionnaire (PPEQ) developed by Özmen and Özdemir [27] was used to probe students' epistemic cognition in physics. The questionnaire was a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) and included six dimensions: structure of knowledge

TABLE II. The dimensions of the Physics Identity Survey and one example item for each dimension.

Dimensions	Example item
Identity	I see myself as a physics person.
Recognition	My physics teacher sees me as a physics person.
Interest	Physics is fun for me.
Self-efficacy	I can overcome setbacks in physics.

TABLE III. The dimensions of PPEQ and one example item for each dimension.

Dimensions	Example item
SKC	To understand a subject in physics, I need to understand the basic concepts of the subject.
SKH	I understand a subject in the physics lesson through the knowledge I have already learned.
JK	If the information given in the physics course contradicts what I know as correct, I question the rationale of this information.
CK	The knowledge I learned in the physics course is never-changing facts; so my knowledge will not change either.
SOURCE	I accept what my physics teacher says in class without question.
QL	If I spare enough time to study, I can understand the rationale of the knowledge given in physics class.

coherence (SKC), structure of knowledge hierarchical (SKH), justification of knowledge (JK), changeability of knowledge (CK), quick learning (QL), and source of knowledge (SOURCE). PPEQ included 27 items. Cronbach's alpha was estimated as 0.92 for the scale. Table III shows the dimensions of PPEQ and one example item for each dimension.

3. Metacognitive awareness inventory (MAI)

The MAI was initially developed by Schraw and Dennison [21], and it was adapted to Turkish by Akın *et al.* [110]. It includes 52 items on a 5-point Likert scale ranging from 1 (never true) to 5 (always true). The MAI consists of two dimensions: knowledge of cognition and regulation of cognition. Knowledge of cognition dimension includes knowledge about facts and strategies (declarative), how to apply strategies (procedural), and when and why to apply them (conditional). The regulation of cognition dimension includes planning, information management strategies, comprehension monitoring, debugging strategies, and evaluation. Table IV indicates the dimensions and sub-dimensions of MAI and one example item for each sub-dimension. The Cronbach's alpha for the entire scale was 0.95, while it ranged from 0.93 to 0.98 for the subscales.

C. Procedure

This study applied a correlational research design to investigate interrelationships among study variables. Confirmatory factor analyses (CFAs) were conducted to examine the construct validity of students' responses to the scales in the current study. In other words, with CFAs, we evaluated the extent to which the theoretical factor structure, measurement model of metacognition, epistemic cognition, and identity constructs fit the data collected in the present study. After CFA analyses, we performed a structural equation modeling (SEM) to investigate the relations among the latent constructs in the hypothesized model developed based on theoretical and empirical studies. SEM enables us to decompose the total relation of a predictor variable to a dependent variable into direct and indirect relations [111,112]. The direct relation indicates a relation between the predictor and dependent variable after controlling for all other predictors of the dependent variable [111,113]. It can also be defined as a relation unmediated by other variables in the model [112,113]. The path coefficient in the path diagram estimates the direct relation [111]. However, the indirect relation refers to the relation of the predictor variable to the dependent variable through the intervening variable(s) after controlling for the corresponding direct relation [111,112]. It is estimated as the products of path coefficients for each direct relation composing the indirect pathway. If there is more than one indirect pathway between the predictor and the dependent variable, the total indirect relation is estimated by the sum of each specific indirect relation. Finally, the total relation refers to the sum of the direct and total

TABLE IV. The dimensions and sub-dimensions of MAI and one example item for each subdimension.

Dimensions	
Knowledge of cognition	*Example item*
Declarative knowledge	I understand my intellectual strengths and weaknesses.
Procedural knowledge	I find myself using helpful learning strategies automatically.
Conditional knowledge	I can motivate myself to learn when I need to.
Regulation of cognition	*Example item*
Planning	I read instructions carefully before I begin a task.
Information management strategies	I try to break studying down into smaller steps.
Comprehension monitoring	I ask myself periodically if I am meeting my goals.
Debugging strategies	I stop and go back over new information that is not clear.
Evaluation	I know how well I did once I finish a test.

indirect relations of the predictor variable to the dependent variable [111].

Furthermore, the mediation analysis with the bias-corrected bootstrap method was carried out to examine the mediating relation of epistemic cognition and physics self-efficacy specified in the proposed SEM (see Fig. 1). The mediating relations with 95% confidence intervals, not including the value of zero, were considered significant.

The practical significance, the effect size of the relationships observed among the constructs in the hypothesized SEM, was evaluated based on the magnitude of the standardized path coefficient (β), the predicted change in the standard deviation unit of the dependent variable for every standard deviation change in the predictor variable when the other predictors are held constant [114]. We used the standards recommended by Kline [111]. A β value of 0.10 indicates a small effect size, a β value of 0.30 indicates a medium effect, and *a* β value of 0.50 or larger indicates a large effect. Another practical significance measure, the amount of explained variance (R^2) on dependent variables accounted for by the hypothesized model, was evaluated using the threshold values proposed by Cohen and Cohen [115]. An $R^2 \leq 0.01$ indicates a small effect size, an R^2 around 0.09 suggests a medium effect size, and an $R^2 \geq 0.25$ is taken as a large effect size.

By convention, in path diagrams, observed variables are represented by rectangles, and latent variables or constructs estimated by observed indicators are represented by ovals. Our hypothesized model includes a structural model indicating hypothesized relationships among variables and measurement models indicating the relationships between the latent constructs and their measured indicators. The structural model in the figure included two observed variables, which are physics identity and gender, and five latent constructs, which are metacognition, epistemic cognition in physics, interest, recognition, and physics self-efficacy. For simplicity, measurement models presenting the indicators of the latent constructs are not shown in Fig. 1. The entire hypothesized model is given in Appendix A.

The data for the indicators of the latent constructs in the model of the present study were ordered categorical data, with the number of categories being more than ten. Finney and DiStefano [116] recommended that when the number of ordered categories is six or more, the data can be treated as continuous, and the Satorra-Bentler (S-B) scaling method can be employed as an estimation method. Thus, the analyses were carried out with maximum likelihood parameter estimates with standard errors and a mean-adjusted chi-square test statistic that are robust to nonnormality (MLM) [117]. Multiple fit indices, which are comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR), were employed for evaluating the degree to which measurement models and the hypothesized model fit the observed data. The rule of thumb for model fit is that RMSEA ≤ 0.05, CFI ≥ 0.95, TLI ≥ 0.95, and SRMR ≤ 0.05 suggest a good fit, while RMSEA ≤ 0.08, CFI ≥ 0.90, TLI ≥ 0.90, and SRMR ≤ 0.10 suggests an acceptable fit [118–120].

Descriptive statistics, correlation, and reliability analyses were carried out in SPSS 27. Cronbach's alpha and mean interitem correlation (MIIC), measures of internal consistency across items, were used as reliability measures. A value of Cronbach's alpha bigger than 0.70 is required for reliable results [121]. As the size of Cronbach's alpha is also influenced by the number of items for short scales, Briggs and Cheek [122] suggest MIIC, which is independent of the length of scales. Therefore, MIIC was employed to estimate the reliability of the subdimensions of the scales. Briggs and Cheek recommended the minimum magnitude of MIIC as 0.20 for reliable results.

All students completing the scales of the study were included in the study. However, there were missing data per item. The portions of missing data ranged from 0.8% to 5.1% per item across the scales. We used multiple imputations in SPSS 27 to fill in missing values in the data before the CFA and SEM analyses [123].

Students reported their gender as male or female by selecting a binary gender option. In the data, female students were represented with 1, while male students were coded with 2. Thus, gender entered the analysis as a dichotomous variable, the baseline category of which is female students. As the baseline category represents female students, a positive sign in a correlation or a path coefficient indicates that male students had higher scores than female students.

IV. RESULTS

In this section, the results regarding the measurement model were given; descriptive statistics and correlations among study variables were presented, and the results related to the hypothesized model were discussed.

A. Measurement models

Considering the recommendation of Anderson and Gerbing [124], first, the measurement part of the proposed SEM was examined by CFA to determine the degree to which the hypothesized factor structure of metacognition, epistemic cognition, and identity constructs fit the observed data. As seen in the model given in Appendix A, the indicators of metacognition and epistemic cognition are subdimensions discussed in the previous sections. The subdimensions were entered into the model as observed variables whose scores were estimated by the sum of scores across items significantly loading on their hypothesized subdimensions. Before estimating the total scores, we conducted CFA for the metacognition and epistemic cognition scales to check whether all items were

TABLE V. Fit indices for the measurement model of metacognition, epistemic cognition, and physics identity.

Scale	CFI	TLI	RMSEA (90% CI)	SRMR
Metacognition	0.99	0.99	0.06 (0.046, 0.071)	0.01
Epistemic cognition	0.99	0.98	0.05 (0.028, 0.073)	0.02
Identity	0.97	0.97	0.06 (0.051, 0.063)	0.03

significantly loaded on the respective subdimensions. In addition, MIIC for each subconstruct was estimated to evaluate the measurement error of the indicators. The CFA results indicated that all items significantly loaded on the hypothesized subconstructs. According to MIIC values, the reliability level of each indicator was also satisfactory. Appendix B presents the CFA and MIIC results for the subdimensions. Thus, after ensuring a good level of internal consistency among the items in each subscale, the total score of each subdimension was calculated, summing scores of all items intending to measure the respective subdimension. Then, the second CFAs were employed to test the eight-indictor measurement model of metacognition, the five-indicator measurement model of epistemic cognition, and the factor structure of the physics identity framework (see Appendix A). The CFI, TLI, SRMR, and RMSEA values for all scales are presented in Table V. All fit indices suggest that the measurement models fit the data well based on the aforementioned cutoff values [118–120].

B. Descriptive statistics and correlations

The student's total score for each construct was obtained by summing the scores of all items measuring the construct and dividing the total by the number of items. For example, the total score on epistemic cognition was obtained by adding the scores of 27 items and dividing the sum by 27. The possible minimum and maximum scores that students can have on physics identity, recognition, self-efficacy, and interest are 0.00 and 10.0, respectively. The possible minimum and maximum scores that students can obtain on metacognition and epistemic cognition are 1.00 and 5.00, respectively. Table VI shows the mean, standard

TABLE VI. Descriptive statistics, reliabilities, and correlations among all study variables. Correlations in bold are significant at the 0.001 level.

	Minimum	Maximum	Mean	SD	Reliability (Cronbach's alpha)	1	2	3	4	5	6	7
1. Gender						**1**						
2. Identity	0.00	10.0	5.56	2.73		**0.26**	**1**					
3. Recognition	0.00	10.0	4.86	2.57	0.88	**0.19**	**0.87**	**1**				
4. Physics Self-Efficacy	0.00	10.0	5.82	2.40	0.92	**0.28**	**0.82**	**0.88**	**1**			
5. Interest	0.00	10.0	5.38	2.92	0.95	**0.22**	**0.75**	**0.72**	**0.82**	**1**		
6. Metacognition	1.00	5.00	3.38	0.63	0.96	0.02	**0.38**	**0.40**	**0.45**	**0.42**	**1**	
7. Epistemic cognition	2.48	5.00	3.89	0.45	0.88	0.01	**0.46**	**0.48**	**0.53**	**0.54**	**0.62**	**1**

TABLE VII. Descriptive statistics according to gender.

Gender	Variable	Mean	Standard deviation
Females	Identity	4.96	2.65
Males		6.40	2.61
Females	Interest	4.82	2.90
Males		6.17	2.78
Females	Recognition	4.49	2.56
Males		5.39	2.50
Females	Self-efficacy	5.29	2.39
Males		6.56	2.22
Females	Metacognition	3.38	0.63
Males		3.38	0.63

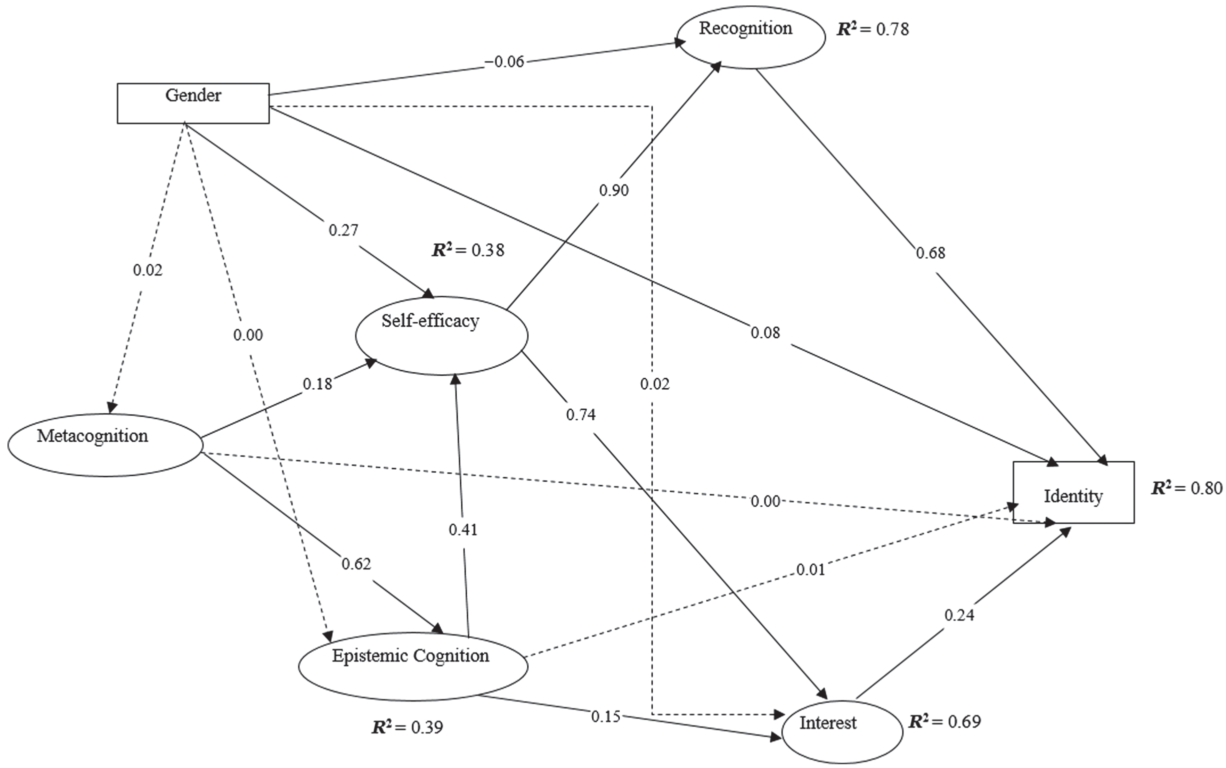


FIG. 2. The model with the solid and dashed lines representing significant and nonsignificant relations, path estimates on lines, and the explained variances.

deviation (SD), minimum, and maximum observed score for each construct, reliabilities, and correlations among all study variables. All mean scores were above the midpoint of the scale except for recognition. The mean score of recognition was slightly below the midpoint of the 11-point Likert scale. Table VII presents the mean and standard deviation of male and female students' scores on each construct. The mean scores for male students were higher than the midpoint for all constructs, whereas only the mean of female students' self-efficacy scores was above the midpoint; however, it was still smaller than that of male students' self-efficacy.

The reliability analysis of the scales measuring the related constructs revealed that Cronbach's alpha was bigger than 0.70 for each scale; thus, the internal consistency reliability for each scale was satisfactory [121].

Table VI shows that all correlations are statistically significant except the correlations of gender with metacognition and epistemic cognition. As the reference group of the dichotomous-gender variable was female students, a significant positive correlation of gender with a variable indicates that male students exhibited significantly higher scores than female students on the variable. Thus, male students had significantly higher scores than female students on all constructs except metacognition and epistemic cognition. Gender differences in the study variables are discussed in more detail in Sec. IV.C.4. Based on the cutoff values recommended by Cohen and Cohen [115], there was a very high positive correlation between identity, recognition, self-efficacy, and interest constructs. In contrast, identity, recognition, self-efficacy, and interest were moderately correlated with epistemic cognition and metacognition. Finally, there was a high positive correlation between metacognition and epistemic cognition.

C. The analysis of the hypothesized structural model

After establishing the construct validity of the questionnaire results with CFAs, the measurement models of the constructs were combined in a single model, and the hypothesized paths were added among the latent constructs of the study. Then, SEM was performed to analyze the resulting model (see Fig. 1). Considering the cutoff values, all goodness of fit measures were within the acceptable range, which suggested the proposed model adequately fitted the data (CFI = 0.95, TLI = 0.94, RMSEA = 0.05 (90% CI = 0.050, 0.055) SRMR = 0.04). Figure 2 indicates the model with significant and insignificant path estimates in dashed lines and explained variances (R^2) of dependent variables. The model accounted for 80%, 78%, 69%, 38%, and 39% of the variance in physics identity, recognition, interest, physics self-efficacy, and epistemic

TABLE VIII. Path coefficients and standard error of measurement (SE) for direct, indirect, and total relations. All path coefficients in bold are significant at 0.001, except the coefficient of the path from gender to recognition is significant at 0.05.

		Metacognition			Epistemic Cognition			Self-efficacy			Recognition			Interest			Identity		
Variables		Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Gender	β	0.02	⋯	0.02	0.00	0.01	0.01	**0.27**	0.01	**0.28**	**−0.06**	**0.25**	**0.19**	0.02	**0.20**	**0.22**	**0.08**	**0.18**	**0.26**
	SE	0.03	⋯	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.03	0.03
Metacognition	β				**0.62**	⋯	**0.62**	**0.18**	**0.26**	**0.44**	⋯	**0.40**	**0.40**	⋯	**0.42**	**0.42**	0.00	**0.38**	**0.38**
	SE				0.03	⋯	0.03	0.04	0.03	0.03	⋯	0.03	0.03	⋯	0.02	0.02	0.02	0.03	0.03
Epistemic Cognition	β							**0.41**	⋯	**0.41**	⋯	**0.37**	**0.37**	**0.15**	**0.31**	**0.46**	0.01	**0.36**	**0.37**
	SE							0.04	⋯	0.04		0.04	0.04	0.03	0.03	0.04	0.03	0.04	0.04
Self-efficacy	β										**0.90**	⋯	**0.90**	**0.74**	⋯	**0.74**	⋯	**0.78**	**0.78**
	SE										0.01	⋯	0.01	0.03	⋯	0.03	⋯	0.02	0.02
Recognition	β																**0.68**	⋯	**0.68**
	SE																0.03	⋯	0.03
Interest	β																**0.24**	⋯	**0.24**
	SE																0.03	⋯	0.03

cognition, respectively, corresponding to a large effect size [115]. Table VIII indicates direct, indirect, and total relations to the dependent variables in the structural model. Among hypothesized direct relations to identity, only recognition, interest, and gender had significant direct relations to physics identity. In contrast, metacognition and epistemic cognition did not have significant direct associations with physics identity. On the other hand, as seen from Table VIII, all indirect and total relations to physics identity reached statistical significance, suggesting the existence of mediating relations we discussed in the following sections.

1. Relationships among identity constructs

This study observed path coefficients that are in good agreement with those found by Duo and Cain [17]. Physics identity was significantly predicted by interest ($\beta = 0.24$) and recognition ($\beta = 0.68$). Based on recommended effect size measures for path coefficients, the relations of interest and recognition had a small to medium and large effect size, respectively. Physics self-efficacy had a significant indirect relation to physics identity through interest and recognition ($\beta = 0.78$, Bootstrap % 95 CI = 0.74, 0.82). This indirect relation had a very large effect size. Physics self-efficacy significantly predicted recognition ($\beta = 0.90$) and interest ($\beta = 0.73$). Both relations had a very large effect size.

2. The relationship between metacognition and physics identity

Metacognition did not directly predict physics identity ($\beta = -0.001$) in the model. In contrast, the indirect relation through epistemic cognition, physics self-efficacy, recognition, and interest was significant ($\beta = 0.38$, Bootstrap % 95 CI = 0.32, 0.42), which made the total contribution of metacognition to physics identity significant ($\beta = 0.37$). This indirect relation had a medium to large effect size. As the direct relation of epistemic cognition on physics identity was insignificant, the mediating role of epistemic cognition was not significant in this total indirect relation. The specific indirect relation of metacognition to physics identity through epistemic cognition was insignificant ($\beta = 0.007$). When other specific indirect relations of metacognition were examined, it was seen that indirect relation through recognition, physics self-efficacy, and epistemic cognition contributed mainly to total indirect relation ($\beta = 0.16$, Bootstrap % 95 CI = 0.13, 0.20). These results suggest the importance of a mediating role of physics self-efficacy in the association between metacognition and physics identity.

3. The relationship between epistemic cognition and physics identity

The direct contribution of epistemic cognition to physics identity was insignificant ($\beta = 0.01$). On the other hand, its indirect relation through physics self-efficacy, interest, and recognition was significant ($\beta = 0.36$, Bootstrap % 95 CI = 0.30, 0.43). The effect size of this relation was medium to large. The specific indirect relation through interest was significant ($\beta = 0.04$, Bootstrap % 95 CI = 0.02, 0.05), but its size was very small. On the other hand, the specific indirect relation through self-efficacy and recognition was significant ($\beta = 0.25$, Bootstrap % 95 CI = 0.20, 0.31) and had a small to medium effect size. Similarly, these results supported the mediating effect of physics self-efficacy on the relation of epistemic cognition to physics identity.

4. Gender differences in physics identity and other study variables

A significant total relation of gender to a variable indicates that one group reported significantly higher scores than the other group in the variable. In contrast, a significant direct relation of gender to a variable suggests there would be a significant gender difference in the variable after controlling for other predictors of that variable, which is similar to a significant difference obtained with the analysis of covariance. Thus, splitting the total relation into direct and indirect relations helps us to see this distinction.

The gender analysis on physics self-efficacy revealed that gender had a significant direct ($\beta = 0.27$) and total relation ($\beta = 0.28$) to physics self-efficacy with a medium effect size. In contrast, its indirect relation to self-efficacy through metacognition and epistemic cognition was almost nonexistent ($\beta = 0.01$). That is, in terms of the total relation, male students had significantly higher scores in physics self-efficacy than female students, and after controlling for metacognition and epistemic cognition, male students would still have higher self-efficacy scores.

Gender also had a significant direct relation to physics identity ($\beta = 0.08$), with a small effect size after controlling for other predictors. After adjusting for other predictors, male students would have slightly higher physics identity than female students. However, as seen from Table VIII, according to the total relation, male students possessed significantly higher physics identity scores with a medium effect size ($\beta = 0.26$, Bootstrap % 95 CI = 0.21, 0.32). This total relation mainly arose from the significant indirect relation of gender to physics identity through other study variables ($\beta = 0.18$, bootstrap % 95 CI = 0.13, 0.23). As a result of the indirect relations, we observed significant and notable gender differences in the identity scores of male and female students. When the direct relations of gender were inspected (see Fig. 2), it was seen that the significant indirect relation mainly occurred because of the direct relation of gender to physics self-efficacy. In other words, gender-related differences in physics identity might mainly be explained by gender differences in physics self-efficacy.

The mediating effect of physics self-efficacy was also observed in the relationship between gender and recognition, gender and interest. The total relation of gender to recognition was significant and positive with a small to medium effect size ($\beta = 0.19$). That is, female students had significantly less recognition. However, according to the direct relation ($\beta = -0.06$), female students would have slightly higher recognition after controlling for self-efficacy. ($\beta = 0.25$, bootstrap % 95 CI $= 0.19$, 0.30). In other words, if female students got higher physics self-efficacy, their perceptions of recognition would be better.

Likewise, a significant indirect effect of gender through physics self-efficacy was observed on interest in favor of male students ($\beta = 0.20$, bootstrap % 95 CI $= 0.15$, 0.25), which in turn led the total relation to be positive and small to medium size ($\beta = 0.22$). Thus, based on the total relation, male students indicated a significantly higher interest in physics. However, gender did not directly relate significantly to interest ($\beta = 0.02$). If male and female students did not differ in physics self-efficacy, they would indicate similar interest in physics.

Finally, we did not observe a significant direct and total relation of gender to metacognition and epistemic cognition (see Table VIII). Thus, male and female students did not differ in metacognition and epistemic cognition.

Gender differences observed in the present study may raise the question of whether there is an equivalence of the structural regression paths for females and males. Thus, a moderation analysis (a multigroup analysis of structural invariance) for gender was also conducted to answer this question. The analysis results (see Appendix C) supported the invariance of the structural model for males and females.

5. The relation of metacognition to other study variables

Metacognition significantly predicted both physics self-efficacy ($\beta = 0.18$) with a small to medium effect size and epistemic cognition ($\beta = 0.62$) with a large effect size. Although the direct relation of metacognition on physics self-efficacy was small, its indirect relation through epistemic cognition was small to medium ($\beta = 0.26$, bootstrap % 95 CI $= 0.20$, 0.33), which made the total relation of being a medium to large effect size ($\beta = 0.44$).

Metacognition was also indirectly related to recognition ($\beta = 0.40$, bootstrap % 95 CI $= 0.35$, 0.45) and interest ($\beta = 0.42$, bootstrap % 95 CI $= 0.37$, 0.46) due to its direct relation to physics self-efficacy and epistemic cognition. Both relations had a medium to large effect size.

6. The relation of epistemic cognition to physics self-efficacy, interest, and recognition

Epistemic cognition had a significant direct relation to physics self-efficacy ($\beta = 0.41$, a medium to large effect size) and to interest ($\beta = 0.15$, a small effect size). Its indirect relation to interest through physics self-efficacy was also significant ($\beta = 0.30$, bootstrap % 95 CI $= 0.25$, 0.37) with a medium effect size, increasing the total relation of epistemic cognition to interest ($\beta = 0.45$). Thus, physics self-efficacy also mediated the relationship between epistemic cognition and interest.

Moreover, epistemic cognition indirectly contributed to recognition through physics self-efficacy ($\beta = 0.37$, bootstrap % 95 CI $= 0.30$, 0.45) with a medium to large effect size.

V. DISCUSSION

The analysis of Turkish high school students' data indicated that path coefficients among physics self-efficacy, recognition, interest, and identity were similar to those observed for different groups of students [2,17,18]. In addition, the significant direct and indirect relations of metacognition, epistemic cognition, and gender to physics identity constructs were found in this study, which motivates future experimental studies to test the causal relations in the model. Thus, assuming the proposed model of the current study is correct, the following implications would be suggested:

Previous research studies pointed out the vital role of metacognition in developing epistemic cognition, self-efficacy, and identity [32,42,43,60,61,64,67]. In line with previous research findings, the results of the current study showed that metacognition predicted epistemic cognition and physics self-efficacy directly and physics identity indirectly through physics self-efficacy. Students with higher metacognition also exhibited sophisticated epistemic cognition, physics self-efficacy, and identity. Therefore, instruction incorporating metacognition-enhancing activities may support fostering epistemic cognition and physics self-efficacy, which in turn could promote physics identity. For example, in an inquiry-based physics curriculum, Yerdelen-Damar and Eryılmaz [52] employed several metacognitive strategies, such as the metacognitively prompted small and whole group discussions, predict-observe-explain strategy, error analysis, and journal writing, to trigger students to engage in metacognitive thinking regarding their conceptual understandings and epistemic cognition. The researchers found a significant improvement in students' conceptual and epistemic understandings [52,61]. In the same curriculum, the researchers also observed that the experimental group students exhibited higher self-efficacy than the control group students [65].

Likewise, epistemic cognition significantly predicted identity formation variables (physics self-efficacy, recognition, and interest), similar to the results of previous studies [77,78,87,89]. Epistemic cognition was not directly related to physics identity; it indirectly predicted it via the mediation of physics self-efficacy. Similarly, Guo *et al.* found a significant indirect relationship between chemistry identity and epistemic cognition through self-efficacy [76]. In addition, it was also observed that epistemic cognition in physics was mediating the relation of metacognition to physics self-efficacy. Based on these findings, epistemic cognition-enhancing strategies could promote identity formation variables, which in turn might foster physics identity. They could also increase the effect of metacognitive strategies on physics self-efficacy. However, research revealed that implicitly addressing students' epistemic cognition does not facilitate students' views about the nature of physics knowledge, knowing, and learning [125–127]. Therefore, it is recommended that the instruction should explicitly consider students' epistemic cognition. Several studies provided evidence indicating the effectiveness of direct interventions [61,128–131]. For instance, Redish and Hammer [131] designed an introductory algebra-based physics course explicitly addressing students' epistemic cognition to help students view physics learning as the reconciliation of everyday intuitive thinking and physics knowledge as a coherent system of ideas. Epistemic cognition-enhancing activities used by the researchers were explicit epistemic discussions, epistemically modified peer instruction, and interactive lecture demonstrations and homework assignments, prompting students to reflect on the nature of physics learning and knowledge. The result of the study indicated that students demonstrated significant gains on an epistemic cognition survey.

The fact that epistemic cognition and metacognition were only indirectly related to physics identity through self-efficacy could suggest that the effectiveness of metacognition and epistemic cognition-enhancing activities in developing physics identity may rely on students' level of self-efficacy. In those interventions, students should also feel confident in their abilities to achieve physics-related tasks to build their physics identity. Thus, for effective identity construction, metacognition or epistemic cognition-enhancing interventions can also be enriched with self-efficacy-supporting strategies aligning with Bandura's [14] four sources of self-efficacy: enactive mastery experience, vicarious experience, social persuasion, and physiological and affective states. Vicarious experiences through modeling [87,132–135], anxiety coping strategies [133,136], providing positive feedback about performance [132,133], providing a learner-friendly environment in which every student can ask questions and express their ideas [132], adjusting assignments according to student's level of understanding [132], providing scaffolding [137–139] are some of the research-proven self-efficacy-supporting strategies.

The gender differences observed in study variables also align with previous studies. Both male and female students demonstrated similar metacognition and epistemic cognition [70,104]. When considering total relation (direct plus indirect relation), we observed a similar gender effect. The male students had higher scores in physics identity, self-efficacy, interest, and recognition [1,13,93,96–100]. However, when the mediation analysis results were further inspected, the mediating role of physics self-efficacy in gender differences was observed in other identity constructs. The superiority of male students in physics identity, interest, and recognition might stem from their superiority in physics self-efficacy. Therefore, physics self-efficacy could be a key to overcoming gender differences in physics identity constructs. However, a literature review study conducted by Henderson *et al.* [140] indicated that, in general, traditional physics courses negatively influenced students' physics self-efficacy. In addition, male students reported higher self-efficacy in physics courses, and gender differences tended to increase after physics instruction [140]. Thus, we need special teaching strategies and classroom activities to address students' self-efficacy and decrease gender differences. Sawtelle *et al.* [135] found that modeling instruction, including collaborating learning environments, positively influenced female students' self-efficacy. Similarly, Espinosa *et al.* [141] indicated that a project-based introductory physics class, including inquiry-driven projects blended with peer instruction, tutorials, estimation, and experimental design activities and problem sets reduced the gender gap in physics self-efficacy. Furthermore, Hazari *et al.* [1] recommended emphasizing conceptual understanding and real-world or contextual relevance in physics instruction, and the discussion of women's underrepresentation in science can promote females' physics self-efficacy.

Finally, the current study had some limitations. First, the study was correlational. Thus, in contrast to an experimental study, the present study did not establish causal connections among study variables. In addition, there are also other prior studies using different SEM models for physics identity [142–144]. Thus, future experimental studies can be conducted to test the relationships casually suggested in SEM studies on physics identity [144,145]. Second, the model in the current study did not include teacher or learning environment-related variables. Future research can also include such variables in the proposed model of the present study. Third, instrumentation decay [146] could be a threat to the results of the study. Survey fatigue might occur during the study as multiple surveys were simultaneously administered to the students. However, this threat was controlled by selecting a schedule when students felt more energized during the earlier hours of school. The researchers gave students one class hour to ensure they took time while answering the items. In addition, the epistemic cognition survey, placed at the end of the survey list, included reverse items to check if students read all items. Fourth, the researchers did not gather data regarding the nonattendance rate during the data collection period. However, the data were collected after the COVID period, on regular class days when no exams were coming up, and the lectures continued. During the application of the surveys, the first author received no comments from teachers about a high nonattendance rate in the classes where students completed the surveys. Furthermore, students in participating schools were not informed beforehand whether there would be data collection in the upcoming days. Therefore, we assumed that the nonattendance rate, which might threaten the results observed in this study, was negligible and random. Finally, gender data were collected with only binary options (male versus female). That binary model of gender may limit the generalizability of gender-related conclusions in this study and prevent drawing more profound conclusions about gender differences discussed elsewhere [147].

VI. CONCLUSION

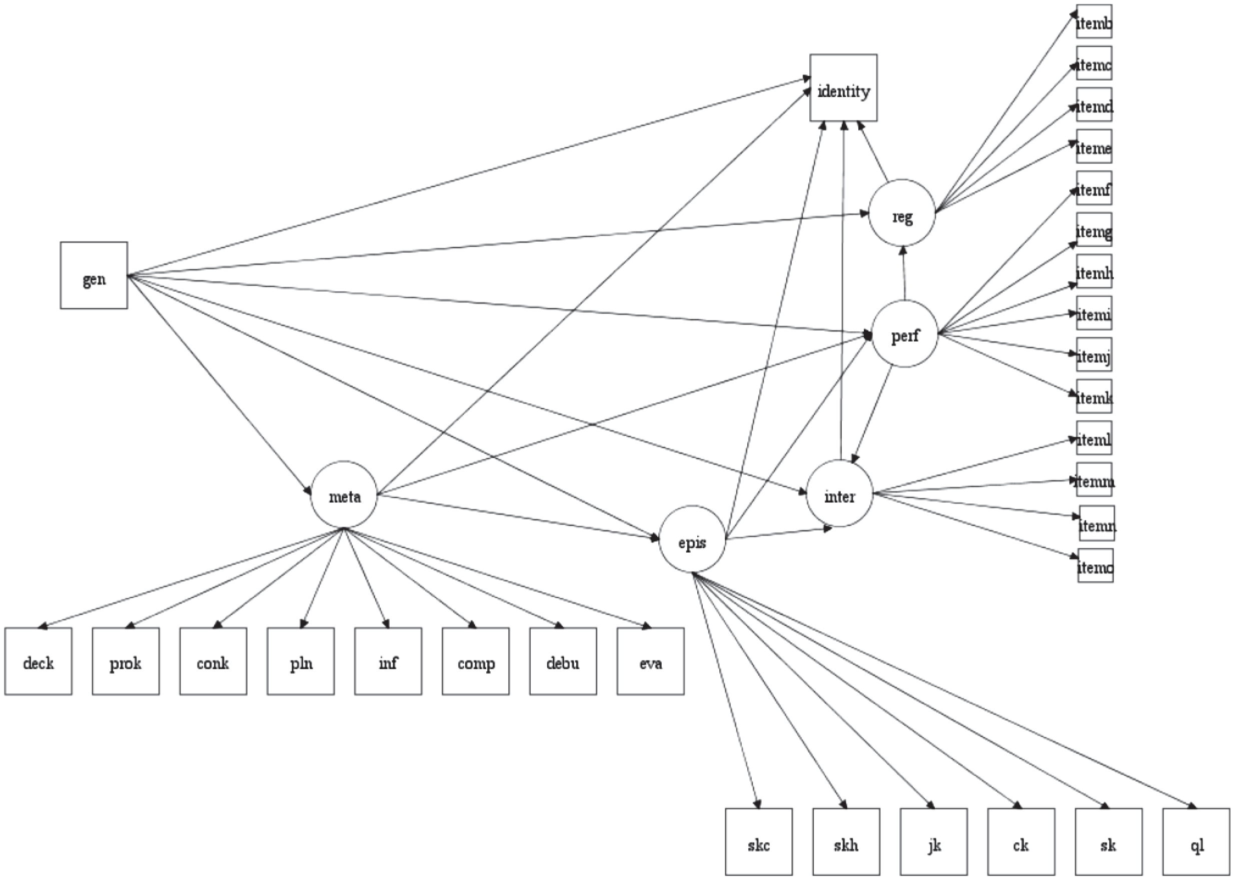
This study, analyzing the data from Turkish high school students, observed relations among physics self-efficacy, recognition, interest, and physics identity consistent with those found in other contexts. Recognition and interest directly predicted physics identity and mediated the relation of physics self-efficacy to it. The study extended the current literature by investigating the relation of epistemic cognition and metacognition to physics identity and identity-formation constructs, which could motivate future experimental interventions to promote the understanding of physics identity development. The results revealed that metacognition and epistemic cognition in physics indirectly predict physics identity through the mediation of physics self-efficacy, which suggests that metacognition and epistemic cognition-enhancing strategies could be used to foster physics identity; however, the success of those strategies may depend on the sophistication of physics self-efficacy, which further motivates the design of experimental studies to test these relations. The study also observed significant direct and indirect relations among metacognition, epistemic cognition, self-efficacy, recognition, and interest. Metacognition directly predicted epistemic cognition and physics self-efficacy. It also indirectly contributed to recognition and interest through physics self-efficacy and epistemic cognition. Epistemic cognition was directly associated with physics self-efficacy and interest and partially mediated the relationship between physics self-efficacy and metacognition. It also indirectly contributed to interest and recognition via the mediating relation of physics self-efficacy. These significant interrelations could further highlight the indirect contribution of metacognition and epistemic cognition to the formation of physics identity. Gender differences were also observed in the current study. Male students scored higher than female students in physics identity, self-efficacy, recognition, and interest. However, the mediation analysis further indicated that gender differences in physics self-efficacy might explain gender differences in physics identity, recognition, and interest, which advocates experimental interventions to test whether practices that reduce the gender gap in physics self-efficacy will also eliminate the gender gap in physics identity, recognition, and interest.

ACKNOWLEDGMENTS

This study is produced from the first author's Master's thesis.

APPENDIX A

The entire hypothesized model of this study.



Abbreviations: gen= Gender, Meta: Metacognition, deck: Declarative knowledge, prok: Procedural knowledge, conk: Conditional knowledge, pln: Planning, inf: Information management, comp: comprehension monitoring, debu: Debugging, eva: Evaluation, reg: Recognition, perf: Performance, inter: Interest; epis: Epistemic Cognition, skc: Structure of knowledge Coherence, skh: Structure of knowledge Hierarchical, jk: Justification of knowledge and knowing, ck: Changeability of knowledge, sk: Source of knowledge, ql: Quick learning

APPENDIX B

As the data on epistemic cognition and metacognition surveys were collected with a five-point Likert scale, weighted least squares mean- and variance-adjusted (WLSMV) estimator in Mplus 8.10 was used for the CFA analyses [116]. The CFA results supported the factor structures of the surveys. The goodness of fit indices; CFI = 0.95, TLI = 0.93, RMSEA = 0.05 (90%CI = 0.048, 0.055) SRMR = 0.04 for epistemic cognition survey; CFI = 0.93, TLI = 0.93, RMSEA = 0.04 (90%CI = 0.041 0.044) SRMR = 0.04.

CFA results of the Epistemic Cognition Scale

	Factor loading	SE	p value	MIIC
	Structure of knowledge coherence			
Item3	0.74	0.02	0.000	0.28
Item4	0.34	0.03	0.000	
Item6	0.81	0.02	0.000	
Item7	0.44	0.03	0.000	
Item9	0.64	0.02	0.000	
	Structure of knowledge hierarchical			
Item1	0.39	0.02	0.000	0.30
Item2	0.77	0.02	0.000	
Item5	0.55	0.02	0.000	
Item8	0.81	0.02	0.000	
	Justification of knowledge			
Item10	0.73	0.02	0.000	0.29
Item11	0.56	0.03	0.000	
Item12	0.62	0.02	0.000	
Item13	0.67	0.02	0.000	
Item14	0.52	0.03	0.000	
	Changeability of knowledge			
Item15	0.20	0.03	0.000	0.26
Item16	0.68	0.02	0.000	
Item17	0.74	0.02	0.000	
Item18	0.32	0.03	0.000	
Item19	0.79	0.02	0.000	
	Source of knowledge			
Item20	0.33	0.03	0.000	0.35
Item21	0.43	0.03	0.000	
Item22	0.46	0.03	0.000	
Item23	0.69	0.03	0.000	
	Quick learning			
Item24	0.81	0.02	0.000	0.29
Item25	0.32	0.03	0.000	
Item26	0.66	0.02	0.000	
Item27	0.70	0.02	0.000	

CFA results of the Metacognition Scale

	Factor loading	SE	p value	MIIC
	Declarative knowledge			
Item5	0.49	0.02	0.000	0.34
Item10	0.68	0.02	0.000	
Item12	0.69	0.02	0.000	
Item16	0.59	0.02	0.000	
Item17	0.57	0.02	0.000	
Item20	0.70	0.02	0.000	
Item32	0.68	0.02	0.000	
Item46	0.56	0.02	0.000	
	Procedural knowledge			
Item3	0.61	0.02	0.000	0.39
Item14	0.67	0.02	0.000	
Item27	0.76	0.01	0.000	
Item33	0.66	0.02	0.000	
	Conditional knowledge			
Item15	0.53	0.02	0.000	0.33
Item18	0.71	0.02	0.000	
Item26	0.60	0.02	0.000	
Item29	0.64	0.02	0.000	
Item35	0.67	0.02	0.000	
	Planning			
Item4	0.52	0.02	0.000	0.30
Item6	0.62	0.02	0.000	
Item8	0.57	0.02	0.000	
Item22	0.61	0.02	0.000	
Item23	0.67	0.02	0.000	
Item42	0.54	0.02	0.000	
Item45	0.60	0.02	0.000	
	Information management strategies			
Item9	0.51	0.02	0.000	0.28
Item13	0.70	0.02	0.000	
Item30	0.74	0.01	0.000	
Item31	0.67	0.02	0.000	
Item37	0.37	0.03		
Item39	0.67	0.02		
Item41	0.59	0.02		
Item43	0.65	0.02		
Item47	0.52	0.02		
Item48	0.36	0.03		
	Comprehension monitoring			
Item1	0.59	0.02	0.000	0.34
Item2	0.63	0.02	0.000	
Item11	0.64	0.02	0.000	
Item21	0.66	0.02	0.000	
Item28	0.65	0.02	0.000	
Item34	0.49	0.02	0.000	
Item49	0.65	0.02	0.000	

(Table continued)

(Continued)

	Factor loading	SE	*p* value	MIIC
	Debugging strategies			
Item25	0.47	0.03	0.000	0.29
Item40	0.71	0.02	0.000	
Item44	0.69	0.02	0.000	
Item51	0.38	0.03	0.000	
Item52	0.47	0.02	0.000	
	Evaluation			
Item7	0.40	0.02	0.000	0.28
Item19	0.57	0.02	0.000	
Item24	0.55	0.02	0.000	
Item36	0.66	0.02	0.000	
Item38	0.61	0.02	0.000	
Item50	0.61	0.02	0.000	

APPENDIX C

The multigroup invariance analysis of the proposed model for males and females was conducted following the guidelines of Byrne [148]. First, the baseline model was tested for female students. The baseline model fits the data well (CFI = 0.947, TLI = 0.941, and RMSEA = 0.055). Second, the configural model without parameter constraints was tested (CFI = 0.942, TLI = 0.939, and RMSEA = 0.055). The inspection of significant and insignificant regression coefficients across the two groups indicated that the pattern was the same for females and males. Third, the equivalence of the model for females and males was tested (CFI = 0.942, TLI = 0.940, and RMSEA = 0.054). That the value of CFI remained unchanged from that observed in the configural model and the change in the value of RMSEA was not greater than 0.015 [149,150] across two models supported the equivalence of path coefficients for males and females in this study.

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