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From science motivation to science identity: The mediating effect of science achievement according to gender

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Abstract
Science motivation and identity have been considered important in science education research literature. The role of science achievement between the motivation and identity has rarely been contemplated. Gender issues in science motivation, identity, and achievement have also been considered crucial. Although most studies hypothesized science identity would be a cause of motivation, there seems very few research that quantitatively examined their longitudinal relationship. Data from 186 students in a coeducational general high school in Seoul, Republic of Korea, was collected. Auto-regressive cross-lagged models were fitted without and with science achievement as a mediator. As results, it was shown that science motivation causes identity not the opposite. With science achievement, science motivation showed direct and indirect effects on science identity. By multiple-group analysis, it was shown that male students formulate their science identity indirectly from science motivation through the mediation of science achievement, and female students directly from science motivation.

Keywords: science motivation, science identity, science achievement, auto-regressive cross-lagged model, mediation effect, gender difference

INTRODUCTION

The macroscopic goal of K-12 science education is to cultivate scientifically literate citizens, regardless of gender, race, color, etc. These citizens should possess scientific knowledge, understanding of science, and the ability to enter the workforce, while also participating democratically in the decision-making process on social agendas (AAAS, 1990). To achieve this goal, it has been considered necessary to assess whether students who are learning science have acquired a sufficient level of scientific knowledge. Science achievement is considered one of the representative goals of science education.

However, measuring a student's science achievement at a specific point in time alone does not fully capture the success of science education. Emotional factors such as motivation, identity, self-efficacy, and attitude related to science or science learning also play important roles (Trujillo & Tanner, 2014). For instance, a student's motivation to study science predicts their long-term academic achievement in science subjects, their pursuit of science and engineering (STEM) fields in college, and their career choices. In recent years, science identity has also been actively studied in relation to these affective factors. Identifying oneself as a 'scientist' or a 'science person' helps marginalized students, such as women, Blacks, and Hispanics, continue their engagement with science, make science-related learning and career decisions (Brickhouse et al., 2000; Carlone & Johnson, 2007; Chen et al., 2021). Therefore, examining changes in science achievement, science motivation, and science identity is necessary for students to successfully learn science (Hernandez et al., 2017; Starr, 2018; Starr et al., 2020; White et al., 2019) and to prepare a high school science curriculum that promotes scientific literacy for all.

This provides a rationale for examining the causal relationship between science achievement and affective factors. While the causal relationship between science achievement, science motivation, and science identity has been discussed in the literature, few empirical studies have comprehensively investigated these

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Contribution to the literature

- This study quantitatively examined the causal relationship between science motivation and science identity using an auto-regressive cross-lagged model and found that science motivation affects science identity, challenging the prevailing view in science education research that science identity promotes science motivation.
- Previous studies have suggested that science identity leads to higher science achievement, with students who identify themselves as "science person" more likely to achieve better - however, the results of this study reveal the opposite pattern.
- The multiple-group analysis showed that male students tend to form their science identity based on their science achievement, while female students form their science identity based on their science motivation.

relationships and examined gender differences. This calls for new research designs to synthesize the findings of previous studies. Simply analyzing data at a particular point in time corresponds to a correlation study, making it challenging to accurately infer causality (e.g., Chen et al., 2021; Jiang et al., 2022; Kalender et al., 2019). Even studies based on pre- and post-tests may struggle to examine the detailed interactions between variables, highlighting the need for longitudinal studies to understand the mechanisms involved (Oliver & Simpson, 1988). Notably, studies examining the longitudinal relationship between motivation and identity have been extremely rare, particularly in the context of science education, with only a few reported instances in English education (Lee, 2014; Xu & Gao, 2014) and physical education (Ntoumanis et al., 2017).

Furthermore, the concept of science identity, which has gained attention in recent years, is context-dependent and can vary culturally (Hazari et al., 2020). Therefore, research on science identity needs to consider students' gender and age. Others' perceptions of women play an important role in the three science identity trajectories of research scientists, altruist scientists, and disruptive scientists. These trajectories, even when successful, can be hindered by factors such as gender, ethnicity, and race, making them challenging to pursue (Carlone & Johnson, 2007). Additionally, studying science identity across different school levels and subjects is essential (Gibbons & Raker, 2019). While science identity studies have been relatively numerous in elementary and middle school contexts (e.g., Brickhouse et al., 2000; Carlone et al., 2014; Walls, 2012) or university contexts (e.g., Carlone & Johnson, 2007; Chen et al., 2021; Kalender et al., 2019), there have been a lack of studies in high school contexts (cf. Shin et al., 2017). Early high school education represents a stage of learning before specialization, aligning with the goal of science education for all, and it is an important time when students are preparing to make decisions about STEM careers in the future. Therefore, conducting science identity research in the high school context is highly desirable.

Considering the above considerations, the researchers determined that it was necessary to examine the longitudinal development of science achievement, motivation, and identity (auto-regressive) and the causal relationship (cross-lagged) effects between them using a statistical model. Additionally, it was crucial to investigate gender differences, which are considered important factors across all three constructs, within the model. In this regard, the auto-regressive cross-lagged (ARCL) model, a type of structural equation model, enables more sophisticated inference of causal relationships between variables through longitudinal measurements. It also allows for examining how male and female students develop their science motivation, science identity, and science achievement through multi-group analysis based on gender within the structural equation model.

Research Questions

The research questions (RQs) for this study are as follows:

RQ-1. What are the cross-lagged effects between science motivation and science identity?

RQ-2. What is the mediating effect of science achievement between science motivation and science identity?

RQ-3. Does the relationship between science motivation, science identity, and science achievement vary based on gender?

THEORETICAL BACKGROUND

Science Motivation

Motivation, as defined in social cognitive theory, is an internal state that triggers, directs, and sustains goal-oriented behavior (Schunk, 2012). Science motivation, in particular, refers to the internal state that triggers, directs, and sustains science learning behavior (Glynn et al., 2011). Science motivation plays a significant role in predicting students' long-term engagement in science learning and can help identify students who may need support in their science learning journey. Science motivation is based on various psychological theories such as Bandura's (1986) social cognitive theory and self-determination theory.

Social cognitive theory is a psychological perspective that emphasizes the importance of the social environment in motivation, learning, and self-regulation (Schunk & Usher, 2019). Bandura (1986) proposed that human functioning depends on the interaction between actions, thoughts, and the environment. In other words, individuals' thoughts influence their actions and environment, actions influence their thoughts and environment, and the environment influences their thoughts and actions. Self-regulation is a process in which individuals choose environments that they perceive as beneficial for their learning, rather than simply acting based on external factors (Bandura, 1997). Self-regulated learning involves goal setting, self-observation, self-evaluation, and self-reaction (Bandura, 1991). According to Schunk and DiBenedetto (2020), social cognitive theory can be divided into personal, behavioral, and environmental influences. Within this framework, the motivation process falls under the category of personal influences, which include goals, self-evaluation of progress, self-efficacy, social comparisons, values, expectations for outcomes, and attributions.

Self-determination theory distinguishes between self-determined and controlled motivational behavior (Deci & Ryan, 1991; Deci et al., 1991). According to self-determination theory, individuals have innate needs for competence, autonomy, and relatedness. Meeting these needs enhances self-determination, leading to increased intrinsic motivation and, subsequently, increased learning motivation (Deci et al., 1991). While external motivation has been traditionally considered as not self-determined, Deci et al. (1991) argue that external motivation can also be self-determined through a process called internalization. Internalization involves actively transforming external control into internal control (Schaper, 1968). Internalization goes beyond mere adaptation; it fully assimilates regulatory processes and structures and consistently applies them to other needs, processes, and values (Deci & Ryan, 1991). This internalized motivation, combined with intrinsic motivation, can foster students' interest in learning (Deci et al., 1991).

Science motivation studies have continued into the 21st century, with a particular focus on developing science motivation questionnaires that capture the multidimensional nature of science motivation. One notable example is Science Motivation Questionnaire (SMQ) developed by Glynn et al. (2009). Based on social cognitive theory, SMQ defines science motivation as comprising five sub-elements: intrinsic motivation, extrinsic motivation, personal relevance of learning science, self-efficacy in learning science, and anxiety about science assessment. Later, Glynn et al. (2011) expanded on the concept and developed SMQ II, which broadened the definition of science motivation. Similar to SMQ, SMQ II is rooted in Bandura's (1986) social cognitive theory but also incorporates elements related to self-determination. Glynn et al. (2011) define learning motivation, as discussed in social cognitive theory, as a multi-component construct consisting of intrinsic motivation (satisfaction with learning science itself), self-determination (students' sense of control over their science learning), and self-efficacy (a crucial variable for predicting students' achievement based on social cognition theory or the expectation-value theory). Extrinsic motivation refers to learning science as a means to an external goal, such as career motivation or grade motivation. These five sub-factors collectively form the construct of science motivation. SMQ II, incorporating these constructs, has been widely used with high reliability and validity in science education research worldwide.

Science motivation has been extensively studied in science education for a long time, with empirical and longitudinal studies accumulating. For example, Shin et al. (2018) conducted a semester-by-semester investigation of Korean high school students' science motivation, focusing on SMQ II. The study found that self-efficacy, intrinsic motivation, and grade motivation tended to decrease over time, while self-determination and career motivation exhibited both decreasing and increasing trends. Liu et al. (2019) examined the longitudinal effects of intrinsic and identified motivation on students' mathematics and science performance and found that intrinsic motivation had a long-term positive impact on subsequent achievement, self-efficacy, identity, and course effort. In contrast, identified motivation was found to be more context-sensitive and vulnerable to change over the long term. Fortus and Weiss (2014) investigated the persistence of motivation for science among students in different types of schools and found that, overall, girls had lower persistence of motivation for science compared to boys. Additionally, in traditional schools, both boys and girls showed a decrease in motivation between 5th and 8th grade, whereas students in democratic schools maintained a consistent level of motivation during that period.

Science Identity

Science identity refers to the self-identification of students as a "scientist" or a "science person" (Carlone & Johnson, 2007). It is a construct that has been actively studied in science education because it influences students' engagement and continuation in science learning, as well as their intention to pursue careers in science and engineering (STEM) fields (Chen & Wei, 2020). The perspective that views science as culturally mediated thinking and knowledge suggests that learning can be defined as participation in scientific practices, and how students perceive themselves as participants in science can influence their engagement in school science (Brickhouse et al., 2000).

Defining the scope of science identity requires careful consideration. Carlone and Johnson (2007) identified three aspects of science identity: performance, competence, and recognition. Hazari et al. (2010) added an interest aspect to this definition, which has been widely used in many studies (e.g., Chen & Wei, 2020). Performance refers to the social competencies or practices associated with scientific work, such as the use of scientific tools, proficiency in scientific language or behavior, and interactions in various formal and informal scientific settings. Competence refers to a scientific understanding of the world and the ability to explain meaningful knowledge and concepts related to science. Recognition refers to being acknowledged as a "science person" by oneself or others, while interest pertains to the desire and curiosity to think about and understand science. It is evident that the definition of science identity, which encompasses performance, competence, and interest, is quite broad and can overlap with other affective factors such as motivation and attitude.

Ultimately, the most distinctive element of science identity lies in recognition. Chemers et al. (2011) developed and used six questions related to self-recognition as a scientist for undergraduate students, graduate students, and postdoctoral researchers. These questions encompass self-image, a sense of belonging, and other related aspects. The National Center for Education Statistics' high school longitudinal study also included two items related to self-recognition and recognition from others in their assessments of science identity (Ingels et al., 2011). Buontempo et al. (2017) measured engineering identity among students by modifying the self-recognition questions from Ingels et al. (2011). Vincent-Ruz and Schunn (2018) explored the science identity of 7th and 9th graders in the United States using four questions that examined perceived personal science identity and perceived recognized science identity. Kalender et al. (2019) found that female STEM college students may not identify themselves as physicists due to a lack of recognition from others.

Studies on science identity, which can be shaped by contextual and cultural factors, have primarily focused on marginalized students based on gender and race (e.g., Carlone & Johnson, 2007; Lee & Kang, 2018). This focus aims to promote their participation in science learning and help them navigate their future STEM career paths. However, there is also evidence that students with high abilities may disidentify with science (Anderson & Chen, 2016). In other words, science identity is an aspect that needs exploration for all students, and research in this area should continue. While science identity has been extensively studied in higher education contexts, particularly in physics (e.g., Hazari et al., 2020), biology (e.g., Le et al., 2019), and engineering (e.g., Godwin et al., 2013), there have also been cases of studying science identity at the K-12 level. For example, Walls (2012) proposed identify-a-scientist (IAS) activities to explore the science identity of third-grade African-American students. The formation of science identity among high school students is influenced by their participation in various scientific experiences within the classroom and a shift away from narrow stereotypes of who can become a scientist (Chapman & Feldman, 2017). In the 4th and 6th grades, interactions with teachers and peers have an impact on science identity (Kim, 2018).

The examination of science identity needs to encompass both qualitative and quantitative approaches. Many studies on science identity have adopted a qualitative approach, such as Carlone and Johnson's (2007) investigation using interviews with undergraduate women of color, and the use of IAS (Walls, 2012) as a qualitative tool to explore science identity. Some studies have combined qualitative data with the IAS (Chapman & Feldman, 2017) or conducted qualitative interviews (Carlone et al., 2014; Jiang et al., 2020a; Kim, 2018). However, recent efforts have also been made to adopt a quantitative approach to studying science identity. Chemers et al. (2011) developed a 5-point Likert scale questionnaire focusing on self-recognition. Some studies have utilized questions from the high school longitudinal study (Ingels et al., 2011) to assess science identity (Buontempo et al., 2017). Nevertheless, due to the nature of panel surveys, these studies have been limited by the inclusion of only two questions, which restricts the exploration of the development of science identity within the context of specific courses. Recent developments include the creation of science/chemistry identity assessments for undergraduate students based on the framework of Hazari et al. (2010) and Hosbein and Barbera (2020), as well as the development of a 24-item science identity measurement tool for high school students based on Hazari et al.'s (2010) framework (Chen & Wei, 2020). However, there is still a limited number of quantitative studies examining the within-course development of science identity among high school students.

A closer examination of the process of science identity development among high school students is crucial. Science identity studies have predominantly focused on elementary and middle school contexts or higher education contexts (e.g., Brickhouse et al., 2000; Carlone & Johnson, 2007; Carlone et al., 2014; Chen et al., 2021; Kalender et al., 2019; Starr, 2018; Walls, 2012). However, given the importance of forming a science identity early in pre-university years (Chen et al., 2021), it is also crucial to investigate science identity formation among high school students. Jiang et al. (2022) surveyed high school students (7th-12th graders) and found that multidimensional STEM-PBL (science, technology, engineering, and mathematics-project-based learning) experiences, such as science exploration, technology application, and mathematical processing, significantly predicted science identity. Furthermore, it remains to be seen whether science identity is stable or flexible when examined longitudinally. Carlone et al. (2014) reported changes in students' science identity from 4th to 6th grade. In 4th grade, all students participated as learners with excellent science education experiences, science abilities, self-recognition, and recognition from others. However, by 6th grade, students' science identity significantly decreased, primarily influenced by factors such as race, class, and gender, rather than scientific thinking or practices. Nonetheless, there appears to be a lack of evidence regarding the longitudinal development of science identity. Therefore, it is necessary to examine the dynamics of affective factor development in science learning through longitudinal studies (Gibbons & Raker, 2019).

Relationship Between Science Motivation & Identity

The relationship between science motivation and science identity is an area that has received limited attention in research, particularly within the field of science education. While there is a considerable amount of qualitative evidence and some quantitative studies that touch upon this relationship, there is a need for more focused research in the context of science education.

In general, the existing literature tends to support the notion that identity plays a role in shaping motivation. The perspectives of self-determination theory and identity-based motivation theory suggest that students' current self-identification influences their motivation (Faye & Sharpe, 2008; Nurra & Oyserman, 2018). Moreover, several studies have indicated that science identity can have a positive impact on students' motivation to pursue careers in science (Deemer et al., 2016; Jiang et al., 2020a; Starr, 2018). These studies suggest that identity serves as a factor in the formation and enhancement of motivation within the realm of science education.

However, it is important to acknowledge that there are also diverging perspectives in the literature. For example, Hernandez et al. (2017) reported findings from a mentoring program for female undergraduate students, suggesting that science identity did not directly affect science motivation. Additionally, Mahfood (2014) proposed that science motivation could be considered as a component of science identity.

Given the limited number of studies specifically examining the relationship between science motivation and science identity in the context of science education, further research is needed to deepen our understanding of this relationship. Conducting empirical studies that quantitatively investigate the interplay between motivation and identity within the domain of science education would contribute to a more comprehensive understanding of these constructs and their implications for student engagement and career aspirations.

Role of Science Achievement in Motivation & Identity Formation

The relationship between science achievement and motivation is well-established in the literature, indicating a reciprocal causal relationship between the two constructs. Studies have shown that students' achievement motivation predicts their science achievement (Oliver & Simpson, 1988), and early motivational beliefs in mathematics and science have significant effects on STEM achievement and college major choice (Jiang et al., 2020b). Additionally, intrinsic motivation has been found to be positively related to achievement over time (Liu et al., 2017), and motivational beliefs such as self-efficacy and self-concept have been shown to have a positive effect on science achievement (Areepattamannil et al., 2011; Leong et al., 2018). Meanwhile, there are empirical studies that report higher achievement can again lead to higher motivation (e.g., Gibbons & Raker, 2019), echoing the flow theory (Vu et al., 2019).

Similarly, science achievement has been found to be related to identity formation. Studies have demonstrated that science identity significantly explains science achievement, with science self-efficacy mediating the relationship between science identity and achievement (White et al., 2019). Minority undergraduate students' science identity has been found to have a positive effect on their sense of belonging and biology grades (Chen et al., 2021). However, it is important to note that there may be divergent findings in the literature, as Mahfood (2014) reported that science motivation and achievement influence the development of science identity among black and Latino undergraduate students in an opposite manner based on the most qualitative explorations.

Furthermore, the role of achievement in identity formation is complex. It is suggested that perceived achievement can influence identity development, and the nature of this relationship may be retrospective or prospective. For instance, if science identity is related to a retrospective self-concept about achievement, it may also be retrospective in relation to achievement (Gibbons & Raker, 2019). Conversely, if science identity is related to prospective self-efficacy, it may also be prospective in relation to achievement (Chen & Wei, 2020; Hazari et al., 2010). The specific relationship between identity and achievement, particularly in the context of recognition-based identity, calls for further research.

Based on these considerations, it can be hypothesized that science achievement, which exhibits a reciprocal causal relationship with motivation, may mediate the relationship between motivation and identity. Investigating the mediating role of science achievement between motivation and identity could provide valuable insights into the complex interplay among these constructs in the context of science education.

Gender Issue in Science Motivation & Identity

Gender issues play a significant role in the domains of science achievement, science motivation, and science identity. It has long been recognized that female students face unjustifiable barriers and stereotypes that hinder their engagement and success in science learning. Research has shown that female students often perceive science as more difficult to understand compared to their male counterparts, leading to gender differences in science experience, attitudes, course selection, and career aspirations (Brickhouse et al., 2000; Carlon & Johnson, 2007). Male students are often perceived as being more suited for science, creating a gender imbalance in the field.

Studies have revealed gender disparities in science motivation and achievement. For example, Fortus and Vedder-Weiss (2014) found that female students exhibit lower levels of continuous motivation for science learning compared to males, and this gender gap persists from elementary to middle school. In addition, research by Jiang et al. (2020b) demonstrated that female students and first-generation college students have lower self-concepts in math and science, leading to lower likelihoods of pursuing STEM majors in college. These findings suggest that gender and college generation differences influence motivation, achievement, and career choices in STEM fields, starting as early as high school.

The perception of science as a masculine, competitive, and objective domain creates a conflict with the stereotypical image of females, contributing to the marginalization of women in science and their lower affinity and performance in the field (Brickhouse et al., 2000; Jiang et al., 2022). Carlone and Johnson (2007) emphasized the impact of others' perceptions on science identities, highlighting that women pursuing research or altruistic scientist identities face obstacles related to gender, ethnicity, and race, despite their ultimate success. These gender stereotypes perpetuate the notion that women lack the essential skills for success in STEM or that STEM careers deviate from traditional gender roles (Deemer et al., 2016). Moreover, studies have shown that women, especially Hispanic women, tend to have lower self-perceptions of physics and experience higher levels of discouragement regarding their views on science (Hazari et al., 2013).

Addressing gender disparities and challenging gender stereotypes in science education is crucial for promoting inclusivity and ensuring equal opportunities for all students. Efforts should focus on creating supportive learning environments, providing equitable access to resources and opportunities, and promoting diverse role models to inspire and empower female students in science and STEM fields.

METHODS

Research Field and Participants

This study was conducted in a coeducational general high school located in Seoul, Republic of Korea. The participants included 212 first-year students from 10 classes who were enrolled in the school. The students were studying "integrated science" according to the 2015 revised national curriculum. The fall semester of 2021 focused on the chapters "ecosystem and environment" and "electricity generation and new renewable energy." The teaching methods included lectures, student-led information search, student-led presentations, hands-on experiments, and demonstration experiments. The science teachers also incorporated socio-scientific issues related to climate change, such as carbon neutrality.

Instrument

Science motivation

To measure students' science motivation, SMQ II developed by Glynn et al. (2011) was utilized. The questionnaire consists of five constructs: intrinsic motivation, self-determination, self-efficacy, career motivation, and grade motivation. Each construct includes five items rated on a 5-point Likert scale. The translation and validation of SMQ II in Korean was conducted by Ha and Lee (2013). Two items in the original questionnaire were found to hinder its uni-dimensionality, and they were excluded in this study based on the findings by You et al. (2018). Therefore, a total of 23 items from SMQ II were used to measure student science motivation.

Science identity

To measure students' science identity, four items related to self-recognition and recognition from others as a scientist were adapted from Chen and Wei (2020). These items were translated into Korean by experts and tested for readability by four general high school students who did not participate in the main research. Some expressions were revised based on their feedback. It is important to note that science identity was narrowly defined in this study. The items were rated on a 5-point Likert scale. **Figure 1** shows the examples of items used in this study to measure science motivation and science identity.

Science achievement

Students' science achievement was assessed using their final exam scores. The final exam covered the content chapters of "integrated science" related to "the change in earth environment," "energy use and environment," and "electricity generation and new renewable energy." The exam consisted of 24 multiple-choice items, and the total score was 100. The items were

Science Motivation (# of items = 23) (from Glynn et al., 2011)
Intrinsic motivation
- Learning science is interesting
Career motivation
- Learning science will help me get a good job
Self-determination
- I study hard to learn science
Self-efficacy
- I am confident I will do well on science tests
Grade motivation
- Getting a good science grade is important to me

Science Identity (# of items = 4) (from Chen & Wei, 2020)
Science recognition
- I think myself as a science person.
- My classmates recognize me as a science person.
- My science teachers recognize me as a science person.
- My family and friends recognize me as a science person.

Figure 1. Examples of items used in this study to measure science motivation and science identity (Source: Authors' own elaboration)

developed and validated by four science teachers at the school who held PhD or master's degrees in science education. The final exam scores were treated as a unidimensional measure of student science achievement. The items were not categorized into different levels of difficulty but were equivalent in their measurement of cognitive achievement.

Data Collection

A pilot test was conducted on 20 general high school students who were not part of the main research to assess the 27 items measuring student science motivation and identity. The items were found to have high reliability, with a Cronbach's alpha value greater than 0.8, indicating good internal consistency.

The survey for science motivation and science identity was administered using Google Survey. The statistical validity of the instruments was preliminarily tested in August 2021. After removing missing values, a total of 207 observations remained out of the initial 212 participants. The first survey was conducted in late October, followed by the final exam in early December, and the second survey was conducted in late December. The time lag between the final exam and the two surveys was similar. It took students approximately 15 minutes to complete each survey. The students' final exam scores were collected anonymously. After excluding missing values, there were 186 observations available for analysis across the two survey periods.

Measurement Stability and Equivalence

Measurement stability of the science motivation and science identity instruments was assessed using confirmatory factor analysis (CFA). CFA examines the stability of the measurement structure over time, providing evidence for the uni-dimensionality of the constructs (Gibbons & Raker, 2019). Additionally, measurement equivalence across different survey periods (first and second) and gender was examined through multiple-group analysis.

Path Models

Auto-regressive cross-lagged model

An ARCL model was constructed to explore whether science motivation influences science identity or vice versa (**Figure 2**). The term 'auto-regressive' refers to paths from science motivation to science motivation and from science identity to science identity, capturing the stability of each construct over time. The term 'cross-lagged' signifies paths from science motivation to science identity and from science identity to science motivation, examining the causal relationships between the two constructs. ARCL models are advantageous as they go beyond mere correlations and provide insights into the causal dynamics between variables by considering the time-lagged effects (Schlueter et al., 2017).

Mediation model

The mediation model incorporates the final exam score as a mediator between the initial science motivation and science identity and the subsequent science motivation and science identity (**Figure 3**). This

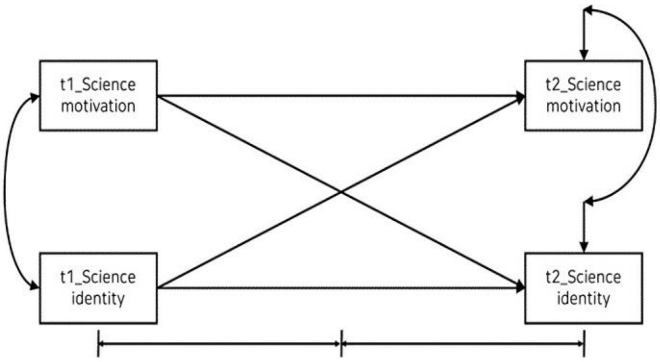

Figure 2. ARCL model of science motivation & science identity mediated by final exam score (Source: Authors' own elaboration)

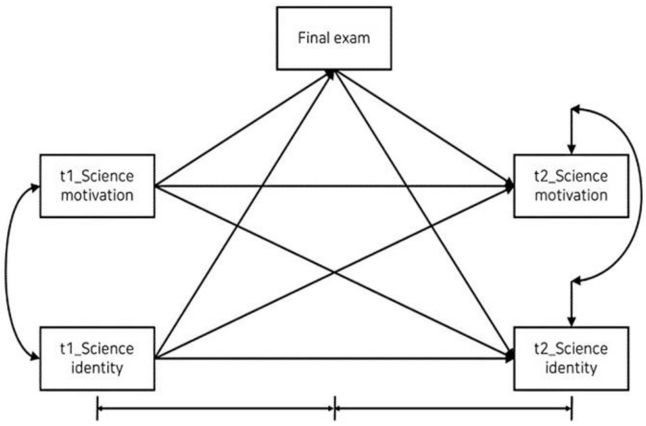

Figure 3. ARCL model of science motivation and science identity mediated by final exam score (Source: Authors' own elaboration)

model allows for an examination of how the initial levels of motivation and identity influence students' performance on the final exam, and how the exam score, in turn, affects the subsequent levels of motivation and identity. By considering the mediating role of achievement, the model provides insights into the potential mechanisms through which motivation, identity, and academic outcomes are interconnected in the context of science education.

Multiple-Group Analysis by Gender

A multiple-group analysis was conducted to examine potential gender differences in the paths influencing student science identity within the mediated model. Out of the 186 observations, 87 respondents identified as male and 99 as female.

Descriptive statistics and correlations were computed using STATA 16, while CFA, path model analysis, and multiple-group analysis were performed using AMOS 21. Note that the standard coefficient, standard error, and *p*-value of indirect and total effects were yielded by bootstrapping with 2,000 samples.

RESULTS

Descriptive Statistics

The descriptive statistics of the first and second surveys are summarized in **Table 1**. In the first survey period, the average score for science motivation was 3.41 (standard deviation [SD]=0.87), while the average score for science identity was 2.51 (SD=1.12). In the second survey period, the average score for science motivation was 3.35 (SD=0.90), and the average score for science identity was 2.56 (SD=1.17). The average score on the final exam was 53.46 (SD=22.86). The absolute values of skewness for all variables were below three, and the kurtosis values were below 10, indicating adherence to the criteria for multivariate normality assumption (Kline, 2015). Additionally, the Pearson's correlations between the variables are presented in **Table 2**, showing highly significant correlations ($p<.001$) between all observed variables.

Confirmatory Factor Analysis

The statistics of CFA are presented in **Table 3**. Following Hu and Bentler's (1998) guidelines, acceptable fit indices for the structural model include $\chi^2/\mathrm{df}<3.0$ ($p>.05$), comparative fit index (CFI) and Tucker-Lewis index (TLI)≥.09, and standardized root mean square residual (SRMR) and root mean square error of approximation (RMSEA)≤.080. The results of CFA using the preliminary data, which had the largest number of observations ($n=207$), showed a χ^2/df ratio of 2.286 ($p<.001$), CFI of .935, TLI of .919, SRMR of .056, and RMSEA of .079. Although the p-value was less than .001, χ^2/df tends to reject the null hypothesis when the sample size is large. Considering the overall fit indices, it was concluded that the instruments have acceptable measurement stability and were used consistently throughout the surveys. Additionally, CFA results using the first and second survey data ($n=186$ for both) showed χ^2/df ratios of 2.483-2.737 ($p<.001$), CFIs of .914-.923, TLIs of .892-.904, SRMRs of .058-.065, and RMSEAs of .090-.097. Although the RMSEA values were slightly

Table 1. Descriptive statistics of the first & second surveys

	Period	Mean	SD	Skewness	Kurtosis	Reliability (Cronbach's alpha)
Science motivation	First	3.41	.87	-.316	3.040	.97
	Second	3.35	.90	-.169	3.030	.97
Science identity	First	2.51	1.12	.420	2.480	.95
	Second	2.56	1.17	.365	2.346	.97
Final exam		53.45	22.86	.317	2.076	-

Table 2. Pearson's correlations between the variables

		Science motivation		Science identity		Science achievement
		First	Second	First	Second	
Science motivation	First	1				
	Second	.6906***	1			
Science identity	First	.8006***	.5784***	1		
	Second	.5992***	.6839***	.7251***	1	
Science achievement		.5542***	.3591***	.6079***	.4467***	1

Note.*** $p<.001$

Table 3. Statistics of confirmatory factor analysis

Model	χ^2/df	CFI	TLI	SRMR	RMSEA
Preliminary survey confirmatory factor analysis ($n=207$)	644.517/282=2.286***	.935	.919	.056	.079
First survey confirmatory factor analysis ($n=186$)	700.069/282=2.483***	.923	.904	.065	.090
Second survey confirmatory factor analysis ($n=186$)	771.919/282=2.737***	.914	.892	.058	.097
Acceptable range	<3.0, $p>.05$	≥.90	≥.90	≤.080	≤.080

Note.*** $p<.001$

Table 4. Result of measurement invariance examination according to survey period or student gender via multiple-group analysis

Group	Constraint	χ^2/df	CFI	TLI	SRMR	RMSEA
Survey period (first or second)	Unconstrained	1,471.988/564=2.610***	.918	.898	.065	.066
	Measurement weights	1,488.087/589=2.526***	.919	.903	.065	.064
	Structural covariances	1,488.668/592=2.525***	.919	.904	.067	.064
	Measurement residual	1,625.138/660=2.462***	.913	.907	.070	.063
Student gender (male or female)	Unconstrained	996.660/564=1.767***	.924	.905	.066	.061
	Measurement weights	1,027.424/589=1.744***	.923	.908	.071	.060
	Structural covariances	1,029.422/592=1.739***	.923	.909	.070	.060
	Measurement residual	1,139.760/660=1.727***	.915	.910	.075	.060

Note.*** p<.001

higher than the acceptance criteria, most other fit indices fell within the acceptable range. Therefore, it was concluded that the measurement remained stable during both the first and second survey periods. It is worth noting that a correlation larger than .70 between the two latent variables may indicate harmful multicollinearity. In our CFA models, the correlation between science motivation and science identity was estimated to be .679 in the preliminary survey, .606 in the first survey, and .768 in the second survey. Considering the overall range of these values, it can be concluded that science motivation and science identity can be statistically distinguished (as well as theoretically) (see Gibbons & Raker, 2019).

Measurement invariance according to the survey period was conducted using multiple-group analysis (**Table 4**). The survey data from each period were utilized, with a sample size of 186 for each period. Typically, the significance of the χ^2 distribution, based on the difference in degrees of freedom (df) between the unconstrained model and the measurement constraint model, is used as a criterion for group difference. However, according to Chen's (2007) guidelines, ΔCFI≥.010 and ΔSRMR≥.030 between the two models are considered the criteria for detecting measurement invariance.

The results of the multiple-group analysis based on the survey period indicated that the difference between the unconstrained model and the measurement weights constraint model was not significant ($\Delta\chi^2(25)=16.099$, $p>.05$). Moreover, the small values of ΔCFI (.001) and ΔSRMR (.000) further support the conclusion that the measurements remained stable throughout the survey periods. Similarly, measurement invariance according to student gender was examined using multiple-group analysis (**Table 4**).

The preliminary survey data, which had the highest number of observations (n=207, M=99, F=108), were used for this analysis. The results of the multiple-group analysis based on student gender indicated that the difference between the unconstrained model and the measurement weights constraint model was not significant ($\Delta\chi^2(25)=30.764$, $p>.05$). Additionally, the small values of ΔCFI (.001) and ΔSRMR (.005) provide further evidence that the measurements remained stable across student gender.

ARCL Model

The results of the non-mediated ARCL model fitting are presented in **Table 5** and visualized in **Figure 4-a**.

Since the model considers all possible relationships between the variables, fit indices are not applicable for ARCL model. This indicates that the model is a saturated path model with a "perfect fit," which is common when exploring every possible theoretical relationships between psychological constructs (Hu & Bentler, 1998; Stajkovic et al., 2018).

Auto-regressive effect

The auto-regressive effects indicated that science motivation at the first period (SM_{t1}) has a highly significant and positive effect on science motivation at the second period (SM_{t2}) (β=.670, SE=.065, p<.001). Similarly, science identity at the first period (SI_{t1}) had a highly significant and positive effect on science identity at the second period (SI_{t2}) (β=.499, SE=.072, p<.001).

Table 5. Path coefficients of the non-mediated & mediated ARCL model

Path			Non-mediated ARCL model			Mediated ARCL model		
			β	SE	p	β	SE	p
Auto-regressive								
SM_{t1}	→	SM_{t2}	.670	.065	<.001	.532	.067	<.001
SI_{t1}	→	SI_{t2}	.499	.072	<.001	.495	.070	<.001
Cross-lagged								
SM_{t1}	→	SI_{t2}	.253	.091	<.001	.167	.098	.026
SI_{t1}	→	SM_{t2}	.124	.052	.051	.273	.048	.050

Table 5 (continued). Path coefficients of the non-mediated & mediated ARCL model

Path	Non-mediated ARCL model			Mediated ARCL model		
	β	SE	p	β	SE	p
Mediation						
SM_{t1} → SA	-	-	-	.505	2.038	<.001
SA → SM_{t2}	-	-	-	.273	.002	<.001
SM_{t1} → SA → SM_{t2}†	-	-	-	.138	.046	.001
SM_{t1} → SA → SI_{t2}†	-	-	-	.086	.041	.022
SM_{t1} → SA→ → SI_{t2}‡	-	-	-	.253	.071	.002
SI_{t1} → SA	-	-	-	.028	1.608	.732
SA → SI_{t2}	-	-	-	.171	.003	.005
SI_{t1} → SA → SI_{t2}†	-	-	-	.005	.016	.771
SI_{t1} → SA → SM_{t2}†	-	-	-	.008	.023	.759
SI_{t1} → SA→ → SM_{t2}‡	-	-	-	.124	.071	.089
Correlation						
SM_{t1} ↔ SI_{t1}	.650	.095	<.001	.650	.095	<.001
SM_{t2} ↔ SI_{t2}	.470	.044	<.001	.435	.040	<.001

Note. SM: Science motivation; SI: Science identity; SA: Science achievement; $_{t1}$: First period; $_{t2}$: Second period; †Indirect effect; & ‡Total effect

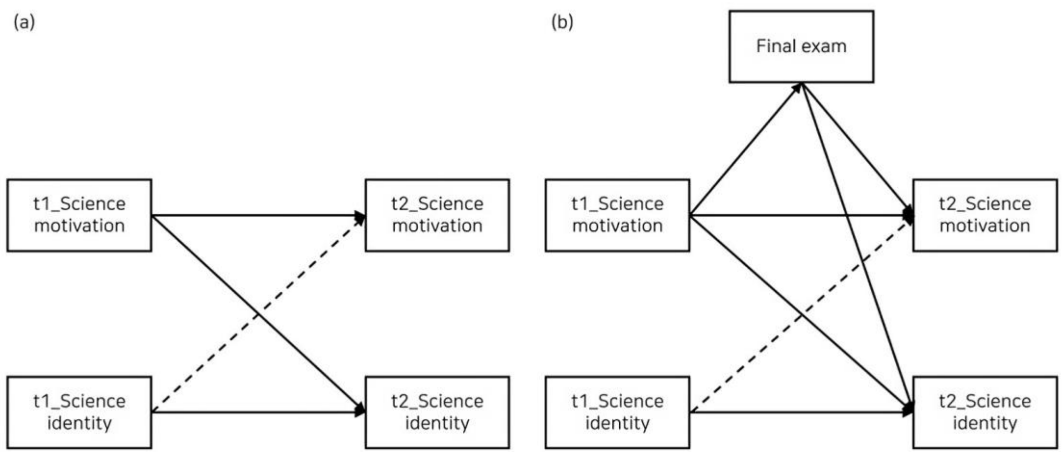

Figure 4. ARCL model of science motivation & identity (a) & Mediation model of science motivation & identity (b) (normal arrow: p<.05, dashed arrow: p≃.05)

Cross-lagged effect

Regarding the cross-lagged effects, SM_{t1} had a highly significant and positive effect on SI_{t2} (β=.253, SE=.091, p<.001). However, SI_{t1} had a non-significant effect on SM_{t2} (β=.124, SE=.052, p=.051).

The correlations between science motivation and science identity at the first and second periods were highly significant (p<.001), with the correlation coefficient being higher at the first period (β=.650, SE=.095) compared to the second period (β=.470, SE=.044).

Mediation Model

The results of the mediated ARCL model fitting are presented in **Table 5** and in **Figure 4-b**. Similar to the non-mediated ARCL model, fit indices are not applicable for the mediation model.

Auto-regressive effect

The auto-regressive effects indicated that science motivation at the first period (SM_{t1}) has a highly significant and positive effect on science motivation at the second period (SM_{t2}) (β=.532, SE=.067, p<.001). Similarly, science identity at the first period (SI_{t1}) had a highly significant and positive effect on science identity at the second period (SI_{t2}) (β=.495, SE=.070, p<.001).

Cross-lagged effect

Regarding the cross-lagged effects, SM_{t1} had a highly significant and positive effect on SI_{t2} (β=.167, SE=.098, p<.001). However, SI_{t1} had a non-significant effect on SM_{t2} (β=.273, SE=.048, p=.050).

Mediation effect

The mediation analysis shows that only SM_{t1} had a significant path towards science achievement (SA) (β=.505, SE=2.038, p<.001), while SI_{t1} did not have a significant path. In turn, SA had significant paths

Table 6. Path coefficients of the mediation model

Path			Male			Female		
			β	SE	p	β	SE	p
Auto-regressive								
SM_{t1}	→	SM_{t2}	.409	.103	<.001	.702	.081	<.001
SI_{t1}	→	SI_{t2}	.424	.108	<.001	.548	.092	<.001
Cross-lagged								
SM_{t1}	**→**	**SI_{t2}**	**.148**	**.141**	**.193**	**.220**	**.135**	**.026**
SI_{t1}	→	SM_{t2}	.126	.079	.201	.093	.055	.160
Mediation								
SM_{t1} →	SA		.377	2.831	.003	.602	2.810	<.001
	SA	→ SM_{t2}	.359	.004	<.001	.148	.003	.022
SM_{t1} →	SA	→ SM_{t2}†	.136	.053	.003	.089	.050	.030
SM_{t1} →	**SA**	**→ SI_{t2}†**	**.089**	**.048**	**.041**	**.053**	**.051**	**.283**
SM_{t1} →	SA→	→ SI_{t2}‡	.545	.104	<.001	.273	.100	.005
SI_{t1} →	SA		.138	2.264	.283	-.010	2.210	.924
	SA	**→ SI_{t2}**	**.236**	**.005**	**.009**	**.088**	**.004**	**.290**
SI_{t1} →	SA	→ SI_{t2}†	.033	.037	.321	-.001	.010	.940
SI_{t1} →	SA	→ SM_{t2}†	.050	.051	.297	-.001	.015	.890
SI_{t1} →	SA→	→ SM_{t2}‡	.175	.112	.135	.091	.074	.214
Correlation								
SM_{t1}	↔	SI_{t1}	.678	.160	<.001	.620	.111	<.001
SM_{t2}	↔	SI_{t2}	.529	.073	<.001	.280	.038	.008

Note. SM: Science motivation; SI: Science identity; SA: Science achievement; $_{t1}$: First period; $_{t2}$: Second period; †Indirect effect; & ‡Total effect (**bold and underline**: Difference in significance between male and female groups)

towards SMt2 (β=.273, SE=.002, p<.001) and SI_{t2} (β=.171, SE=.003, p<.01).

Mediated by SA, SM_{t1} indirectly affected SM_{t2} (β=.138, SE=.046, p<.01), while SI_{t1} does not have an indirect effect on SI_{t2}. Consequently, the indirect effects of SM_{t1} on SI_{t2} were significant (β=.086, SE=.041, p<.05) as well as the total effects (β=.253, SE=.071, p<.01). However, the indirect and total effects of SI_{t1} on SM_{t2} were not significant (p>.05).

The correlations between science motivation and science identity at the first and second periods were highly significant (p<.001), with the correlation coefficient being larger at the first period (β=.650, SE=.095) compared to the second period (β=.435, SE=.040).

Multiple-Group Analysis by Gender

The results of the multiple-group analysis by gender are presented in **Table 6** and visualized in **Figure 5**. Fit indices are not applicable for this analysis due to the reasons explained earlier.

Auto-regressive effect

The auto-regressive effects showed that science motivation at the first period (SM_{t1}) had a highly significant and positive effect on science motivation at the second period (SM_{t2}) in both the male (β=.409, SE=.103, p<.001) and female (β=.702, SE=.081, p<.001) groups. Similarly, science identity at the first period (SI_{t1})

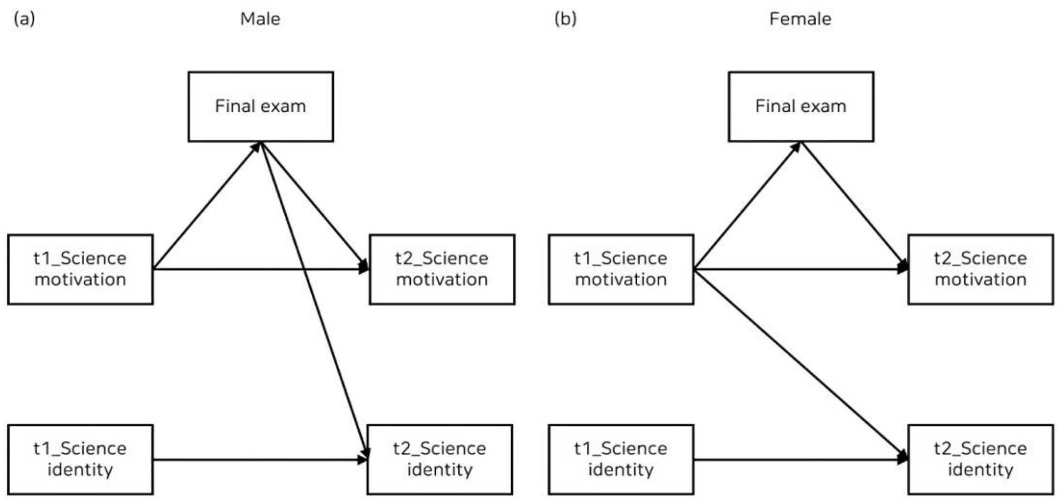

Figure 5. Multiple-group analysis by gender on the mediation model (normal arrow: p<.05)

had a highly significant and positive effect on science identity at the second period (SI_{t2}) in both the male (β=.424, SE=.108, p<.001) and female (β=.548, SE=.092, p<.001) groups.

Cross-lagged effect

Regarding the cross-lagged effects, SM_{t1} had a highly significant and positive effect on SI_{t2} only in the female group (β=.220, SE=.135, p<.05), while it was non-significant in the male group. Meanwhile, SI_{t1} had a non-significant effect on SM_{t2} in both the male and female groups.

Mediation effect

In terms of mediation effects, only SM_{t1} had a significant path towards science achievement (SA) in both the male (β=.377, SE=2.831, p<.01) and female (β=.602, SE=2.810, p<.001) groups, while SI_{t1} did not have a significant path. SA had significant paths towards both SM_{t2} (β=.359, SE=.004, p<.001) and SI_{t2} (β=.236, SE=.005, p<.01) in the male group. On the other hand, SA had a significant path towards SM_{t2} only in the female group (β=.148, SE=.003, p<.05).

Mediated by SA, SM_{t1} indirectly affected SM_{t2} in both the male (β=.136, SE=.053, p<.01) and female (β=.089, SE=.050, p<.05) groups, while SI_{t1} did not have an indirect effect on SI_{t2}. Consequently, the effects of SM_{t1} on SI_{t2} were significant indirectly only in the male group (β=.089, SE=.048, p<.05) and totally in both the male (β=.545, SE=.104, p<.010) and female (β=.273, SE=.100, p<.01) groups. However, the effects of SI_{t1} on SM_{t2} were not significant.

The correlations between science motivation and science identity at the first and second periods were highly significant (p<.01 or less), with the correlation coefficients being larger at the first period (male: β=.678, SE=.160; female: β=.620, SE=.073) compared to the second period (male: β=.529, SE=.073; female: β=.280, SE=.038).

DISCUSSION

This study employed an ARCL model to investigate the relationships between science motivation and science identity. By considering the temporal sequence between the two constructs, the significant paths identified in the model can be interpreted as causal relationships rather than mere correlations.

Science Motivation Affects Science Identity, Rather Than the Opposite

In the literature review, it was noted that there are conflicting views regarding the causal relationship between science motivation and science identity. While the majority of the literature suggests that science identity fosters science motivation (Deemer et al., 2016; Faye & Sharpe, 2008; Jiang et al., 2020a; Nurra & Oyserman, 2018; Starr, 2018), some studies present a contrary view (Hernandez et al., 2017; Mahfood, 2014). To address this issue, this study investigated the cross-lagged effects between science motivation and science identity (**RQ-1**). The results indicated that science motivation affects science identity, rather than the opposite (**Table 5**, **Table 6**, **Figure 4**, and **Figure 5**). These findings support the viewpoint that higher levels of science motivation led to the identification of oneself as a 'science person.' This challenges the prevailing perspective in science education research that suggests science identity fosters science motivation. Consequently, the significance of science motivation should be re-evaluated, and a re-examination of the majority viewpoint on science identity is warranted. Although science identity is considered crucial for students' pursuit of STEM careers, it has been acknowledged that it is difficult to develop (Brickhouse et al., 2000; Carlone & Johnson, 2007; Kalender et al., 2019). Given that science motivation is a well-studied construct that influences science identity, it is suggested that focusing on science motivation in the science classroom could be an effective approach. By employing various teaching strategies to enhance students' science motivation, educators can also promote the development of their science identity.

Science Achievement Mediates Science Motivation and Science Identity

In addition to examining the relationship between science motivation and science identity, this study also investigated the mediating role of science achievement (**RQ-2**). Previous studies have suggested that science identity leads to higher science achievement, with students who identify themselves as 'science persons' more likely to achieve better (Chen et al., 2021; White et al., 2019). However, the results of this study reveal the opposite pattern (**Table 5** and **Table 6**). Significant direct paths were found from science motivation to science achievement, and from science achievement to both science motivation and science identity. Consequently, science achievement mediated the indirect path from science motivation to science identity, but not the other way around. These findings shed light on the process by which science motivation influences science identity. Students with higher levels of science motivation are more likely to achieve higher science scores, and in turn, are more likely to identify themselves as 'science persons.' Additionally, the direct path from science achievement to science identity suggests that efforts to improve student science achievement can contribute to the formation of their science identity. Therefore, fostering students' science motivation in the classroom can have a positive impact on their science achievement, which in turn directly and indirectly influences their science identity (**Table 5** and **Table 6**). This further supports the notion that science motivation is a crucial factor in shaping science identity and suggests the need for further exploration of the relationship between these two constructs.

Gender Difference in Science Identity Formation

This study also investigated whether there is a gender difference in science identity formation (**RQ-3**). The results indicate that male students tend to form their science identity based on their science achievement, while female students form their science identity based on their science motivation (**Table 6** and **Figure 5**). These findings are consistent with previous studies that have reported differences in the formation of science identity between male and female students (Brickhouse et al., 2000; Carlone & Johnson, 2007; Jiang et al., 2020b; Jones et al., 2000). However, this study provides a unique contribution by specifically identifying how the process of science identity formation can differ according to gender using a statistical model. It is noteworthy that if female students have lower science identity compared to male students (Fortus & Vedder-Weiss, 2014; Jones et al., 2000), it may be attributed to lower science motivation among female students and higher science achievement among male students due to various sociocultural beliefs and supports (**Table 6**) (Deemer et al., 2016; Fortus & Vedder-Weiss, 2014). However, it is important to recognize that these gender differences in science identity are not innate or unchangeable. If efforts are being made in the community to foster the science identity of female students for more equitable science education, it is recommended to address both their science motivation and science achievement. Additionally, further qualitative research can explore the reasons why male students do not formulate their science identity on their science motivation, providing a potential research agenda for future investigations.

Limitations and Future Suggestions

This study has several limitations that should be acknowledged. Firstly, the definitions and operationalizations of science motivation, science identity, and science achievement used in this study may be subject to debate. Science identity was narrowly defined as self-recognition and recognition from others, while science motivation followed the framework embedded in SMQ II. Science achievement was operationalized based on the final exam score, which relied on multiple-choice items. Although these definitions were necessary to ensure conceptual and measurement clarity, alternative definitions and measurements could yield different results. For example, if we define science achievement incorporating the eight science and engineering practices (NGSS Lead States, 2013) or other STEM-related competencies, the statistical analysis could show different patterns from this study. Therefore, exploring the relationship between more broadly defined science ‘achievement’ with motivation or identity is recommended.

Another limitation is the relatively small sample size of this study (n=186). The marginally significant effect of SI_{t1} on SM_{t2} ($p\simeq.05$) observed in **Table 5** and **Figure 4** may have reached significance with a larger sample. While the sample size in this study marginally meets the requirements considering the number of parameters, larger sample sizes would provide more robust validation of the findings. Furthermore, it is important to note that the participants in this study were exclusively Korean, limiting the generalizability of the findings to other cultural and racial backgrounds. Future research should consider quantitative studies of science identity formation that consider various sociocultural factors, as highlighted by previous literature (Carlone & Johnson, 2007; Lee & Kang, 2018).

Consequently, conducting replication studies that examine the relationships between science motivation, science identity, and science achievement while considering different definitions and measurements, larger sample sizes, and diverse participant characteristics will contribute to advancing our understanding of these longitudinal relationships. Such studies would further enhance our knowledge in this field based on the initial findings of this study.

CONCLUSIONS

In conclusion, this study sheds light on the longitudinal relationships between science motivation and science identity. The findings indicate that science motivation has a significant effect on science identity, rather than the other way around. Furthermore, science achievement was found to mediate the relationship between science motivation and science identity. The study also revealed gender differences in the process of science identity formation, with male students forming their identity indirectly through the mediation of science achievement, while female students formed their identity directly from science motivation. These findings challenge previous assumptions about the relationship between science motivation and identity, emphasize the importance of science achievement in shaping identity, and highlight the gender-specific processes of science identity formation. The study contributes to our understanding of the complex dynamics involved in science motivation and identity and provides insights for educators to promote science motivation and identity development among students. Further research is needed to replicate and expand upon these findings, considering different measurement approaches, larger sample sizes, and diverse cultural contexts.

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Ethical statement: Authors stated that the study followed the principles of informed consent, voluntary participation and confidentiality. The purpose of the study and the procedures for participation and withdrawal were explained to the students. Participants were over 16 years of age and consented to participate in the study by voluntarily completing an online questionnaire. No identifying or traceable data was collected.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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