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Synergistic effects of students' mathematics and science motivational beliefs on achievement, and their determinants

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Abstract

Background Students' mathematics and science motivational beliefs are crucial determinants of their school academic achievement in math and science. The current study aimed to identify the group memberships of students' motivational beliefs in math and science, which are closely related. Furthermore, this study probed the predictive effects of individual students' experiences at school on forming group membership. We also tested the mean differences of the identified latent groups in math and science achievement.

Results Using latent profile analysis modeling, we examined data from 3857 Korean eighth-grade students participating in the 2019 Trends in International Mathematics and Science Study. The theoretical rationale and supplementary statistical indices showed a five-group membership as the optimal solution. The five groups are high motivation, medium motivation, low math/high science motivation, low motivation, and very low motivation. Students' sense of school belonging was the most crucial predictor in forming group membership, whereas perceived student bullying did not predict group membership. Finally, students in distinct motivational belief groups exhibited differences in their math and science achievements.

Conclusions This study identified five subgroups of students based on their distinct motivational beliefs in math and science, and variations in their association with achievements. In terms of policy development and intervention, it is important to nurture students' sense of school belonging. This study advances motivational theories in science, technology, engineering, and mathematics education, and provides practical suggestions for improving educational practices to enhance student math and science motivational beliefs.

Keywords Motivational beliefs, Latent profile analysis, Trends in International Mathematics and Science Study, School belonging, Mathematics and science achievement

Introduction

Students' math and science motivational beliefs are imperative psychological constructs for their learning engagement, majors, and career choices in science, technology, engineering, and mathematics (STEM). Economically, it would be easier for individuals to obtain higher incomes with STEM-related jobs. From a country's perspective, high quantity and quality human resources in STEM are essential for economic growth and national sustainability (Podobnik et al., 2020). To serve these purposes, understanding how to educate students to perform well in both cognitive and psychological aspects (e.g., motivational beliefs) in math and science is particularly important, and is thus drawing the attention of many policymakers, education researchers, and stakeholders worldwide.

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Students' academic motivational beliefs are a set of psychological constructs. Theories suggest that when students' motivational beliefs (e.g., self-concepts) are high in one domain, the relationship between academic achievement in this domain and self-concept in another domain would be low or even negative (Marsh, 1986; Möller et al., 2020). However, the nature of math and science are close in terms of disciplinary domains. Whether students have high motivational beliefs in both math and science simultaneously, or have high motivational beliefs in only one of the domains is implicit. Thus, further investigation is necessary to determine how the synergistic patterns of students' motivational beliefs clusters associate with their math and science cognitive scores. Therefore, the current study used person-centered modeling to investigate the typologies or group memberships of students' math and science motivational beliefs, and the relationship with their academic achievement, using a nationally representative sample of Korean eighth graders participating in the 2019 Trends in International Mathematics and Science Study (TIMSS).

Students' experiences at school is a crucial antecedent in forming their motivational beliefs (Eccles & Wigfield, 2020). Policy initiatives view students' experiences at school such as a sense of school belonging and student bullying, as malleable. These experiences have therefore caught the attention of policymakers and education practitioners. Thus, this study also explored the predictive effects of students' experiences at school on forming group memberships of students' math and science motivational beliefs. The study's findings provide empirical-based evidence for practitioners to plan and implement individualized and effective strategies to foster students' motivational beliefs in math and science within Korea, and have theoretical implications internationally.

Students' motivational beliefs regarding mathematics and science

Motivation is a complex construct. This study adopted the theoretical operationalization of students' motivational beliefs following the Situated Expectancy–Value Theory (SEVT). SEVT emphasizes the role of sociocultural contexts (e.g., a country) in forming motivational beliefs (Eccles & Wigfield, 2020). The SEVT identified the dual importance of expectations for success and value beliefs in explaining individuals' motivations. We conceptualized the former as academic self-concept, that is, individuals' beliefs about how well they do on an impending task. Students continually evaluate and refine their academic self-concept through personal inferences about themselves in school, using external peers and internal dimensional comparisons. The latter comprises four task values: intrinsic value, utility value, attainment value, and cost (Eccles & Wigfield, 2002). Intrinsic value is individuals' enjoyment gained from participating in an activity. Utility value reflects how well a task relates to one's current and future goals, such as those in academia and in one's career. Attainment value is the personal importance or value of doing well on a task. The last value, cost, symbolizes the negative aspect of performing a given task, such as anxiety about performance or the effort and time the task requires. This study focused on self-concept, intrinsic value, and utility value due to the limited constructs of the TIMSS survey.

Academic motivational beliefs are domain-specific (Eccles & Wigfield, 2002; Marsh & Shavelson, 1985). Research has used a person-centered statistical technique to create typologies of students' math motivational beliefs or science motivational beliefs. For instance, Hsieh and Simpkins (2022) examined the four types of math motivational beliefs (i.e., expectancy, intrinsic value, utility value, and attainment value) of 16,120 US 11th graders surveyed in the US High School Longitudinal Study (HSLS). The patterns of their math motivational beliefs comprised six groups (e.g., above average but not identified, identified but average value, and identified but average value). Generally, students' expectancy, intrinsic value, and utility value are interconnected. In contrast, attainment value is a distinct factor, so group naming primarily signals the levels of student attainment value. Ma (2022) examined Hong Kong eighth graders' self-concept, intrinsic value, and utility value patterns regarding science motivational beliefs and their perceptions of what constitutes engaging teaching using the TIMSS 2015 data. The results revealed five groups: negative motivational beliefs with particularly low self-concept, negative motivational beliefs with particularly low utility value, moderate motivational beliefs, positive motivational beliefs, and high-positive motivational beliefs.

Math and science are distinct yet complementary academic domains. Recently, some studies based on large-scale assessments have investigated how combined math motivational beliefs and science motivational beliefs work together using person-centered methods, offering a nuanced understanding of the dynamics and features of distinct groups. Using data from HSLS, Fong et al. (2021) revealed five profiles: low math/low science (11%), moderate math/moderate science (48%), high math/high science (29%), low math/high science (7%), and high math/low science (5%). With a focus on first-generation college students from the HSLS dataset, Snodgrass Rangel et al. (2020) identified four groups: low math/low science (15%), high math/high science (24%), medium–high math/medium–low science (40%), and medium–low math/medium–high science (22%). Watt et al. (2019) classified 1,172 Australian grade 10 students into three profiles: positively engaged (55%), struggling ambitious (14%), and disengaged (31%), based on their expectancies, values, and perceived costs for STEM subjects. In addition, Berger et al.'s (2020) study of Australian eighth graders' data in TIMSS 2015 revealed six groups: very enthusiastic (14%), enthusiastic (23%), receptive (45%), resistant (6%), prefer mathematics (6%), and prefer science (11%). The first four groups had equivalent levels of math motivational beliefs and science motivational beliefs, but the remaining two showed a relative preference for one of the domains. While the profile names in these studies are not identical, we could conclude that most students have almost equivalent preferences for math and science (i.e., students expressing high math motivational beliefs also tend to have high science motivational beliefs). Few students have opposite magnitudes of math and science motivational beliefs.

Relationships between cross-domain student motivational beliefs and achievement

Self-concept is probably the most studied construct among these motivational beliefs (e.g., Marsh, 2023; Wu et al., 2021). Students' academic self-concepts develop through social comparisons and branch into distinct self-concepts for each domain (Marsh & Shavelson, 1985). Research has shown that a student's specific academic self-concept has a significantly positive relationship with achievement in this specific domain, and has a near-zero or even negative correlation with achievement in other domains. For instance, examining nationally representative data from 26 countries, Marsh and Hau (2004) showed that 15-year-old students' math self-concepts had a positive relationship with math achievement but a negative relationship with verbal achievement, while math and verbal achievement showed a highly positive correlation, and vice versa. Chiu (2012) further investigated the relationship between math and science using TIMSS 2003 data from 27 countries. While the nature of the relationship between the two domains is more supplementary than dissimilar, the relationship between student math self-concept and science achievement, and vice versa, is still negative in many countries.

The internal/external frame of reference model (I/E model) (Marsh, 1986) can explain this phenomenon. According to the meta-analysis study composed of 505 datasets, Möller et al. (2020) concluded that the negative relationship between one domain's motivational beliefs and the other domain's achievement was strongest when the domains were distinctly different and close to zero when both domains belonged to math and science. Furthermore, Arens and Preckel (2018) tested the generalization of the I/E model from self-concept to intrinsic value by examining German third graders' math and verbal domains. Their results replicated the I/E model of self-concept, and extended the I/E model to intrinsic value; that is, there was a positive within-domain relationship between achievement and intrinsic value and negative cross-domain relationships. How these combined effects of math motivational beliefs and science motivational beliefs correlate with math and science achievement deserves further investigation.

The above studies have provided some findings about the associations of synergistic interactions between math and science motivational beliefs and STEM-related achievement. Fong et al.'s (2021) study categorized students into one of three levels of math and science motivational beliefs (i.e., high, moderate, and low). Students' grade 12 GPAs in math and science usually corresponded to their levels of motivational beliefs; that is, the higher the students' math and science motivational beliefs, the higher their math and science achievements. Specifically, student math motivational beliefs predicted their science achievement more accurately than did their science motivational beliefs. For instance, the student group with low science motivational beliefs and high math motivational beliefs had an identical level of science GPA as the high science motivational beliefs and low math motivational beliefs group, while the former group had a higher math GPA than the latter group with lower math motivational beliefs. Similarly, Snodgrass Rangel et al.'s (2020) study showed that the high school student group with medium–high math motivational beliefs and medium–low science motivational beliefs had higher math GPA ($M=2.42$) and higher science GPA ($M=2.36$) than the group with medium–low math motivational beliefs and medium–high science motivational beliefs (i.e., math GPA = 1.93 and science GPA = 2.28). The findings suggest that the association between motivational beliefs and academic achievement might vary due to the incremental nature of math and science, requiring further exploration of the dynamics between motivational beliefs and achievement in math and science.

Scholars have observed the outstanding achievements of Korean students in math and science in the national education system (Mullis et al., 2020; Wahono et al., 2020). Nonetheless, Korean students have been at the bottom of international large-scale assessments regarding math and science motivational beliefs (Mullis et al., 2020; Organisation for Economic Co-operation and Development [OECD], 2017). Employing variable-centered statistical modeling, Liou (2017) demonstrated a noteworthy departure from the international norm in Korea's educational landscape. Specifically, Korean students' science utility value exhibits a stronger association with science achievement, while the prevalent international pattern presents the opposite. The current study advances our understanding by using a person-centered approach to scrutinize the intricate interplay between math and science motivational beliefs and the achievements of Korean students.

The role of student experiences at school in their mathematics and science motivational beliefs

Environmental characteristics affect individual behaviors (Bandura, 1986). SEVT also emphasizes that broader cultural and social contexts deeply influence students' motivations (Eccles & Wigfield, 2020). Accordingly, previous studies have investigated the relationship between students' motivational beliefs and environmental factors (e.g., Urdan & Schoenfelder, 2006). Students' experiences at school may play a role in shaping their motivational beliefs. Students' sense of school belonging and their experience of bullying are examples.

Researchers have investigated the sense of belonging to the school, which indicates students' connectedness to a supportive and respectful school. They found that school belonging increased students' general well-being, including their academic motivational beliefs (Joyce & Early, 2014; Walker & Greene, 2009). Previous studies have demonstrated that persistent mental and physical harm caused by student bullying leads to distress for victims, resulting in lower academic achievement and diminished self-efficacy (Kokkinos & Kipritsi, 2012; Laith & Vaillancourt, 2022). In sum, how the school environmental factors predict the formation of students' math and science motivational beliefs demands further investigation given limited empirical evidence. Thus, this study aimed to explore the roles of students' experiences at school in forming distinct groups based on the levels of students' math and science motivational beliefs.

Research questions

The present study examined the configuration of different student groups, taken by distinct facets of cross-domain motivational beliefs in math and science. We also explored the predictive effects of individual school experience factors on the profiles of student math and science motivational beliefs. Finally, we tested the mean differences of the identified groups of motivational beliefs in terms of their math and science achievement. This study diverges from the prevailing literature on the profiles of student math motivational beliefs, science motivational beliefs, or math and science motivational beliefs primarily studied in Western contexts, as it concentrates on a sample from a less investigated sociocultural context—Korea. The three research questions (RQ) are proposed:

RQ1: What is the optimal number of latent profiles for characterizing students?

RQ2: To what extent do students' experiences at school differentiate the latent profiles of their math and science motivational beliefs?

RQ3: To what extent are the latent profiles of students' motivational beliefs associated with their academic achievement in math and science?

Method

Data

The data for the study came from the Korean portion of the TIMSS 2019 database (https://timss2019.org/international-database/). TIMSS, a quadrennial international survey, assesses math and science achievement and contextual factors of eighth and fourth graders in participating countries. Research has shown that the middle school years are a critical period in which students make more accurate judgments about their perceptions (i.e., math and science motivational beliefs) than in elementary school. Thus, eighth graders were the target of this study. TIMSS uses a stratified sampling method and collects data from a nationally representative grade-based sample (Martin et al., 2020). The sample size of the Korean data is 3857, with 1938 (50.2%) males and 1919 (49.8%) females. We excluded four students from the original sample (i.e., $n=3861$) because they did not answer all math and science motivational belief items. These data represent 444,287 eighth graders in Korea in 2019.

Measures

This study included six math and science motivational belief indicators for profiling students, two predictors for the estimated latent profiles, two outcome variables, and four control variables. Detailed information on items of each indicator is provided in "Appendix". The six math and science motivational belief indicators are students' self-concepts, utility values, and intrinsic values in math and science. TIMSS 2019 asked how confident students are in their math ability, with nine items, and in their science ability with eight items, to measure their self-concept (e.g., "I usually do well in mathematics/science"). TIMSS measured utility value with nine items asking about students' values regarding math and science (e.g., "I think learning mathematics/science will help me in daily life"). Finally, nine items asked whether students liked learning math and science to measure intrinsic value (e.g., "I enjoy learning mathematics/science"). The survey measured all variables on a 4-point Likert scale from 1 (*disagree a lot*) to 4 (*agree a lot*). The reliability values for self-concept, utility value, and intrinsic value for math were 0.90, 0.90, and 0.94, and for science they were 0.92, 0.92, and 0.93, respectively.

We utilized the six math and science motivational belief indicators, which are variables derived from item response theory scaling (IRT). A higher value indicated a more positive perception of each math and science motivational beliefs (Martin et al., 2020). The resulting distribution of these variables across all participating countries had a mean of 10 and a standard deviation of 2. Specifically, the average score of math self-concept ranged from 9.2 to 10.7, the utility value ranged from 8.2 to 10.9, and the intrinsic value ranged from 9.0 to 11.1 among 39 countries. The average score of science self-concept ranged from 8.7 to 11.0, utility value from 8.8 to 11.3, and intrinsic value from 8.7 to 11.1.

In addition to the six math and science motivational belief indicators, we included predictors for the estimated latent profiles. They are two variables regarding students' experiences at school: sense of school belonging, and experiences of student bullying. Students responded to five items to measure their sense of belonging (e.g., "I like being in school"). For student bullying, 14 items measured the frequency of students' bullying experiences, including social media and cyberbullying (e.g., "Shared embarrassing photos of me online"). The two variables, school belonging and student bullying, were also derived from IRT. The reliability values for these two variables were 0.84 and 0.82.

We treated achievement in math and science as outcome variables, so-called distal outcomes. In TIMSS, five plausible values were created to represent each student's math and science proficiency. In this study, we only utilized the first plausible value of math and science proficiency. Items for measuring student math achievement are in the number (30%), algebra (30%), geometry (20%), and data and probability (20%) domains. Items for science achievement are in the biology (35%), chemistry (20%), physics (25%), and earth science (20%) domains. Of these items, 25% target reasoning, 40% target application, and 35% target knowledge in the cognitive domains.

We also included four control variables in the analyses for RQ2 and RQ3. Gender and family socioeconomic backgrounds are individual demographic characteristics. This study operationalized family socioeconomic backgrounds as three variables: the number of books in the home (i.e., Books), the number of home study supports in terms of Internet connection and own room (i.e., Home supports), and parents' highest education level (i.e., Parents' education).

Data analysis

We conducted a series of statistical analyses to examine the existence of latent profiles of student math and science motivational beliefs (RQ1), the relationships between profile membership and students' experiences at school variables (RQ2), and the degree to which math and science achievement differentiated between the latent profiles (RQ3). We conducted analyses using *Mplus* 8.7 (Muthén & Muthén, 1998–2022).

We utilized latent profile analysis (LPA) to classify groups of students with similar unobserved math and science motivational beliefs according to their observed item response pattern (Heinen, 1996; Muthén, 1992). LPA is probabilistic because it classifies the assignment of profiles based on the empirical estimation of the most probable membership (Masyn, 2013). This probabilistic approach enhances the classification accuracy (Bechter et al., 2018). LPA is a person-centered clustering approach, distinct from traditional variable-based modeling, that focuses on establishing relationships between variables. Person-centered approaches consider the configurations, a set of variables takes among discrete subpopulations (Laursen & Hoff, 2006). The approaches allow for discovering individual or group differences in the response model. Thus, LPA enables the identification of naturally occurring subgroups within the participants distinguished by key variables. LPA mitigates the loss of information or synergic effects that result from oversimplification and the multicollinearity that occurs with multiple subscales.

We did not predetermine the number of latent groups. Instead, we determined the optimal number of latent profiles by evaluating multiple fit indices and the interpretability of the solutions based on theoretical predictions (Nylund et al., 2007). We tested several latent profiles to determine the optimal number by comparing the fit indices, including Akaike's Information Criterion (AIC; Akaike, 1974), Bayesian Information Criterion (BIC; Schwartz, 1978), and the sample-size adjusted BIC (SABIC; Sclove, 1987). Lower values for these information indices (i.e., AIC, BIC, and SABIC) are generally more desirable. We also used the *p*-values of the Vuong–Lo–Mendell–Rubin (VLMR) and Lo–Mendell–Rubin (LMR) likelihood ratio tests (LRT) to compare the k profiles model to the $k-1$ profiles model (Lo et al., 2001). When the *p*-values are significant, the k profiles model is better than the $k-1$ model. Additionally, researchers consider classifications to be satisfactory when entropies exceed 0.80 (Muthén, 2004). Entropy is a standardized index of model-based classification accuracy where higher values indicate a more precise assignment of individuals to latent profiles (Wang et al., 2017a, 2017b). After determining the optimal model, we assigned students to profiles based on the probability of membership identified by the model, with each student assigned to the group with the highest membership probability. We evaluated the relative scores of students' motivational beliefs in math and science to label each profile.

We adopted the three-step LPA approach proposed by Vermunt (2010) to compensate for possible errors of a single LPA analysis, which may arise from including covariates (Nylund et al., 2014). We used logistic regression analysis to investigate the associations between the identified latent profiles and covariates. Logit values are for regression coefficients, while odds ratios are for comparing the likelihood of a predictor variable between different groups. Specifically, we examined whether students' experiences at school (e.g., school belonging) could predict the LPA estimates. To address the increased risk of Type I errors associated with conducting multiple tests, we adjusted the significance levels using the Bonferroni correction method. For instance, if the identified number of latent groups was five, we would divide the desired significant level (alpha = 0.05) by the total number of pairwise comparisons, which in this case would be 10. This adjustment yielded a more stringent criterion for determining statistical significance.

Finally, we used an auxiliary approach applying the Bolck–Croon–Hagenaars (BCH; Bolck et al., 2004) method to test the significant differences in distal outcome variables, student math and science achievement across latent profiles while controlling the covariates (e.g., gender). The BCH method alleviates the potential biases in estimating the correlations by using a weighted multigroup analysis that prevents the shifting of latent profiles (Asparouhov & Muthén, 2014). There are two versions of the BCH method: automatic and manual. In this study, we preferred to use the automatic version of BCH that evaluates the mean of a continuous distal outcome variable between groups.

We used the maximum likelihood with robust (MLR) estimator for statistical modeling. MLR is based on the maximum likelihood estimation method and utilizes robust standard errors to handle non-normality, providing more robust parameter estimates. We handled missing data using the full information maximum likelihood (FIML) method. FIML considers all available information about individuals with missing data while estimating model parameters, resulting in unbiased estimates compared to other simpler ad hoc methods (Lee & Shi, 2021). Due to the complex sampling nature of TIMSS data, we used the total student weight to assign an appropriate weight for each individual so we could generalize the statistical results from the sample to the population parameters (Liou & Hung, 2015).

Results

Descriptive statistics and correlations

The results of the descriptive statistics and correlations are shown in Table 1. The means of the math and science motivational belief indicators ranged from 8.49 to 9.54. All Korean students' motivational beliefs were relatively lower than the international average ($M = 10$, SD = 2). Especially considering the international average

Table 1 Descriptive statistics and correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Math self-concept	1													
2. Science self-concept	0.41**	1												
3. Math utility value	0.43**	0.32**	1											
4. Science utility value	0.31**	0.51**	0.67**	1										
5. Math intrinsic value	0.61**	0.33**	0.60**	0.43**	1									
6. Science intrinsic value	0.25**	0.69**	0.44**	0.66**	0.47**	1								
7. School belonging	0.18**	0.20**	0.29**	0.29**	0.34**	0.32**	1							
8. Student bullying	0.03*	0.05**	0.03**	0.01	0.06**	0.06**	0.18**	1						
9. Math achievement	0.50**	0.31**	0.40**	0.35**	0.40**	0.26**	0.14**	−0.06**	1					
10. Science achievement	0.32**	0.41**	0.36**	0.41**	0.27**	0.40**	0.13*	−0.03*	0.80**	1				
11. Gender	0.17**	0.10**	0.09**	0.11**	0.12**	0.10**	0.08**	−0.06**	0.03*	0.07**	1			
12. Books	0.21**	0.17**	0.18**	0.19**	0.13**	0.14**	0.11**	−0.03*	0.33**	0.29**	0.01	1		
13. Home supports	0.10**	0.06**	0.07**	0.06**	0.07**	0.03	0.03*	0.01	0.11**	0.06**	0.01	0.11**	1	
14. Parents' education	0.19**	0.14**	0.14**	0.13**	0.12**	0.08**	0.09**	−0.02	0.28**	0.22**	0.03	0.34**	0.15**	1
M	9.54	8.88	8.49	9.06	9.03	8.66	9.32	10.96	605.71	560.89	0.52	3.70	1.80	4.39
SD	1.89	2.03	1.80	1.69	1.69	1.78	1.73	1.75	95.42	83.55	0.50	1.24	0.41	0.89
Skewness	0.32	0.18	0.12	0.03	0.01	0.48	0.83	−0.32	−0.39	−0.25	−0.08	−0.63	−1.78	−1.01
Kurtosis	2.80	2.16	2.25	1.35	1.04	1.64	0.80	−0.79	0.14	0.16	−1.99	−0.59	1.92	−0.46

School belonging = student's sense of belonging to the school; student bullying = student's experiences of bullying; books = the number of books in the home; home support = the number of home study supports; parents' education = parents' highest education level

*$p < 0.05$, ** $p < 0.01$

of each motivational belief mentioned in the previous section, Korean students' math intrinsic value ($M = 9.03$, SD = 1.69) and science intrinsic value ($M = 8.66$, SD = 1.78) showed the lowest scores among countries. The bivariate correlations among the variables were statistically significant ($p < 0.05$). All skewness and kurtosis values of the variables satisfied the criteria for normality–skewness lower than 3 and kurtosis lower than 10 (Kline, 2011).

Profile identification

To determine the number of latent profiles, we tested the number of profiles and comprehensively checked the information indices, model fit, and classification quality. The results of each model fit index and the classification proportion of each latent profile are given in Table 2. First, all three information indices decreased for AIC, BIC, and SABIC as we added more profiles. We decided on the number of profiles at the point where the AIC, BIC, and SABIC trends became more gradual and showed that three or more profiles are optimal. Second, we considered the LMR–LRT and VMLR, and both tests were significant for the two-, three-, and five-profile clustering ($p < 0.001$). Third, the overall classification accuracy (i.e., entropy) was above 0.90 for the two, three, five and six profiles. Overall, the evidence most clearly supported solutions with three or five profiles when considering fit, entropy, direct comparison, and model interpretability. Thus, we decided that a five-profile classification would provide more insights than the three-profile classification, and thus finalized it as optimal. The average of students' inclination to answer math and science motivational beliefs indicators according to the different profiles is illustrated in Fig. 1.

We labeled the five profiles based on the levels of motivational beliefs: the high motivation group ($n = 194$, 5.0%), the medium motivation group ($n = 519$, 13.4%), the low math/high science motivation group ($n = 161$, 4.2%), the low motivation group ($n = 2633$, 68.3%), and the very low motivation group ($n = 350$, 9.1%). The high motivation group showed the distinct feature of having significantly higher math and science self-concepts than other profiles. The medium motivation group displayed moderate scores on all indicators. Especially compared to the previous group, this group showed lower science self-concept and science intrinsic value. On the other hand, the low math/high science motivation group showed a similar level of science motivational beliefs to the high motivation group, but their math motivational beliefs was comparable to that of the low motivation group.

The low motivation group exhibited consistently low scores on all motivational belief indicators and constituted the largest group, comprising over half of the sample (i.e., 68.3%). Lastly, the very low motivation group showed the lowest on all motivational belief indicators and stood out with a relatively higher score only

Table 2 Model fit indices of the latent profile analysis

Standard	Number of latent profiles					
	2	3	4	5	6	7
Information indices						
AIC	87,871.8	85,386.9	84,488.0	83,731.4	82,971.4	82,463.7
BIC	87,990.7	85,549.6	84,694.5	83,981.7	83,265.5	82,801.6
SABIC	87,930.3	85,466.9	84,589.7	83,854.6	83,116.1	82,630.0
Model fit						
LMR-LRT	< 0.001	< 0.001	0.067	< 0.001	0.115	0.455
VMLR	< 0.001	< 0.001	0.064	< 0.001	0.109	0.451
Classification quality						
Entropy	0.902	0.906	0.886	0.905	0.912	0.893
Classification proportion						
1	82.2%	10.3%	68.6%	9.1%	4.7%	3.5%
2	17.8%	75.1%	17.5%	68.3%	6.3%	62.6%
3		14.6%	8.1%	4.2%	66.8%	4.7%
4			5.8%	13.4%	12.7%	8.1%
5				5.0%	4.5%	11.8%
6					5.0%	5.0%
7						4.5%

AIC Akaike's information criterion, *BIC* Bayesian information criterion, *SABIC* the sample-size adjusted BIC, *LMR-LRT* Lo–Mendell–Rubin (LMR) likelihood ratio test, *VMLR* Vuong–Lo–Mendell–Rubin likelihood ratio test

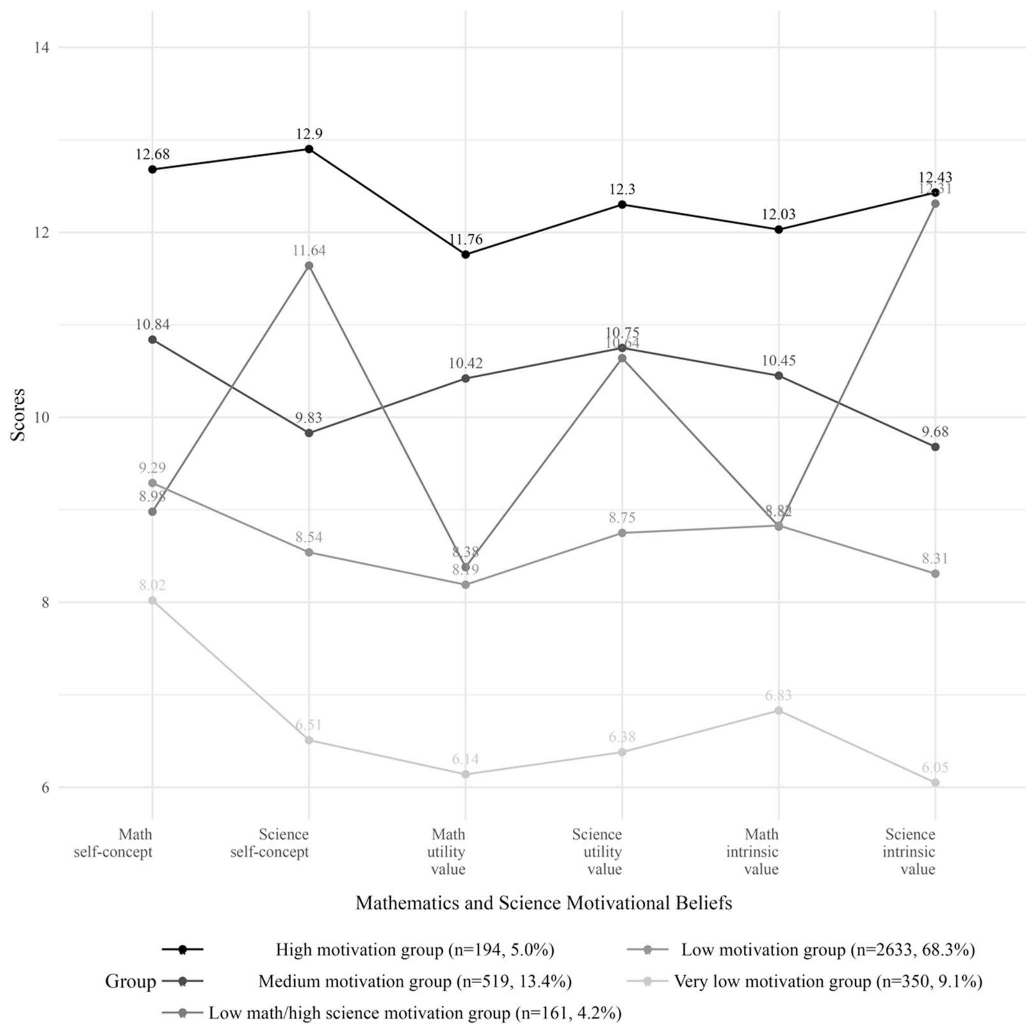

Fig. 1 Profiles of students' mathematics and science motivational beliefs

in math self-concept. The comparison of overall math and science motivational belief indicators between profiles is shown in Table 3.

Mean differences of student school experiences across the profile groups

The results of each latent profile's descriptive statistics for student school experiences are given in Table 4.

Table 3 Profiles of students' mathematics and science motivational beliefs

Profiles	Very low motivation group		Low motivation group		Low math/high science motivation group		Medium motivation group		High motivation group	
	M	SE	*M*	SE	*M*	SE	*M*	SE	*M*	SE
Math self-concept	8.02	0.19	9.29	0.05	8.98	0.27	10.84	0.12	12.68	0.23
Science self-concept	6.51	0.20	8.54	0.05	11.64	0.22	9.83	0.10	12.90	0.23
Math utility value	6.14	0.20	8.19	0.04	8.38	0.25	10.42	0.17	11.76	0.16
Science utility value	6.38	0.23	8.75	0.03	10.64	0.18	10.75	0.13	12.30	0.08
Math intrinsic value	6.83	0.14	8.83	0.05	8.82	0.22	10.45	0.11	12.03	0.14
Science intrinsic value	6.05	0.17	8.31	0.04	12.31	0.14	9.68	0.07	12.43	0.14

Table 4 Descriptive statistics for predictors and control variables according to the latent profiles

	Very low group		Low motivation group		Low math/high science motivation group		Medium motivation group		High motivation group	
	M	SE	*M*	SE	*M*	SE	*M*	SE	*M*	SE
School belonging	8.21	0.10	9.16	0.04	9.89	0.18	10.09	0.10	11.00	0.16
Student bullying	10.89	0.10	10.93	0.05	10.99	0.16	11.03	0.10	11.34	0.14
Gender	0.49	0.04	0.49	0.02	0.51	0.05	0.61	0.03	0.76	0.04
Books	3.44	0.09	3.59	0.04	4.06	0.12	4.08	0.05	4.41	0.07
Home supports	1.80	0.02	1.79	0.01	1.84	0.03	1.85	0.02	1.89	0.02
Parents' education	4.30	0.07	4.32	0.03	4.52	0.08	4.60	0.05	4.71	0.06

School belonging = student's sense of belonging to the school; student bullying = student's experiences of bullying; books = the number of books in the home; home support = the number of home study supports; parents' education = parents' highest education level

The results of mean differences between school belonging and student bullying across the profiles are shown in Table 5. Overall, the level of school belonging increased, and the likelihood of belonging to higher motivational belief groups also increased. In all comparisons among the groups, there were no significant differences in student bullying.

The results of comparing the very low motivation group as the reference group are as follows: higher levels of school belonging were associated with a 1.85 times higher likelihood of belonging to the low motivation group, a 2.26 times higher likelihood of belonging to the low math/high science motivation group, a 2.37 times higher likelihood of belonging to the medium motivation group, and a 2.93 times higher likelihood of belonging to the high motivation group.

The results of comparing the low motivation group as the reference group are as follows: higher levels of school belonging were associated with a 1.22 times higher likelihood of belonging to the low math/high science motivation group, a 1.28 times higher likelihood of belonging to the medium motivation group, and a 1.58 times higher likelihood of belonging to the high motivation group.

The results of comparing the low math/high science motivation group as the reference group are as follows: higher levels of school belonging were associated with a 1.30 times higher likelihood of belonging to the high motivation group. The results of comparing the medium motivation group as the reference group are as follows: higher levels of school belonging were associated with a 1.23 times higher likelihood of belonging to the high motivation group.

Profile memberships and distal outcomes

When it comes to the math and science achievement mean, Korean students showed relatively higher math achievement across the five groups (ranging from $M = 708.30$ to $M = 541.54$) compared to science achievement (ranging from $M = 498.43$ to $M = 652.38$) in terms of the international average ($M = 500$). The very low motivation group showed the lowest math achievement ($M = 541.54$, SE = 6.37) and science achievement ($M = 498.43$, SE = 5.49). The low motivation group showed the second lowest mean of math achievement ($M = 606.11$, SE = 3.21) and science achievement ($M = 559.57$, SE = 2.62). The low math/high science motivation group obtained median scores in math ($M = 622.81$, SE = 9.96) and in science ($M = 618.20$, SE = 6.91). The high motivation group showed the highest math achievement ($M = 708.30$, SE = 6.57) and science achievement ($M = 652.38$, SE = 5.78). The medium motivation group showed slightly higher achievements than the low math/high science motivation group, but a lower mean than the high motivation group in math achievement ($M = 671.12$, SE = 4.39) and science achievement ($M = 615.28$, SE = 4.37).

Comparing the results showed statistically significant differences in the overall test for achievement. Specifically, in terms of math achievement, there were statistically significant differences among all profiles except for the difference between the low motivation group and the low math/high science motivation group ($\chi^2 = 3.06$, $p = 0.214$). Regarding science achievement, there were statistically significant differences among all profiles except for the difference between the low math/high science motivation group and the medium motivation group ($\chi^2 = 0.14$, $p = 0.707$). Consistently, the low math/high science motivation group was the only group that showed non-significant results compared to the other profiles. We can attribute this result to the relatively higher science achievement than math achievement, resulting in minimal differences between science achievement in the low math/high science motivation group and the high motivation group. Conversely, math

Table 5 Predictors and control variables in each latent profile

Reference group	Comparison group	Predictor and control variable	Logit	SE	Logit/SE	*p*-value	OR
Very low motivation	Low motivation	School belonging	0.62**	0.08	7.54	0.000	1.85
		Student bullying	−0.04	0.04	−0.94	0.346	0.96
		Gender	−0.11	0.16	−0.69	0.489	0.90
		Books	0.05	0.08	0.58	0.562	1.05
		Home supports	0.05	0.19	0.24	0.813	1.05
		Parents' education	−0.02	0.09	−0.18	0.856	0.99
	Low math/high science motivation	School belonging	0.81**	0.11	7.51	0.000	2.26
		Student bullying	−0.08	0.07	−1.26	0.206	0.92
		Gender	0.00	0.30	0.01	0.990	1.00
		Books	0.35	0.14	2.51	0.012	1.41
		Home supports	0.30	0.33	0.90	0.369	1.35
		Parents' education	0.10	0.15	0.65	0.519	1.10
	Medium motivation	School belonging	0.87**	0.09	9.45	0.000	2.37
		Student bullying	−0.04	0.05	−0.78	0.437	0.96
		Gender	0.28	0.19	1.47	0.141	1.32
		Books	0.33**	0.09	3.77	0.000	1.39
		Home supports	0.36	0.27	1.32	0.186	1.43
		Parents' education	0.20	0.11	1.79	0.074	1.22
	High motivation	School belonging	1.07**	0.10	10.42	0.000	2.93
		Student bullying	−0.01	0.07	−0.19	0.853	0.99
		Gender	0.95*	0.31	3.02	0.003	2.58
		Books	0.55**	0.13	4.19	0.000	1.73
		Home supports	0.41	0.33	1.25	0.212	1.50
		Parents' education	0.35	0.16	2.15	0.032	1.42
Low motivation	Low math/high science motivation	School belonging	0.20*	0.06	3.29	0.001	1.22
		Student bullying	−0.05	0.06	−0.79	0.427	0.96
		Gender	0.12	0.24	0.47	0.637	1.12
		Books	0.30	0.11	2.67	0.008	1.35
		Home supports	0.25	0.28	0.90	0.366	1.29
		Parents' education	0.11	0.12	0.90	0.369	1.12
	Medium motivation	School belonging	0.25**	0.04	7.11	0.000	1.28
		Student bullying	0.00	0.04	−0.10	0.917	1.00
		Gender	0.39*	0.13	2.95	0.003	1.47
		Books	0.28**	0.06	5.07	0.000	1.33
		Home supports	0.31	0.18	1.76	0.079	1.37
		Parents' education	0.22	0.08	2.67	0.008	1.24
	High motivation	School belonging	0.46**	0.05	9.09	0.000	1.58
		Student bullying	0.03	0.06	0.42	0.676	1.03
		Gender	1.06**	0.24	4.34	0.000	2.88
		Books	0.51**	0.11	4.60	0.000	1.66
		Home supports	0.36	0.28	1.29	0.196	1.43
		Parents' education	0.37	0.14	2.59	0.010	1.44

Table 5 (continued)

Reference group	Comparison group	Predictor and control variable	Logit	SE	Logit/SE	*p*-value	OR
Low math/high science motivation	Medium motivation	School belonging	0.05	0.07	0.75	0.456	1.05
		Student bullying	0.04	0.07	0.61	0.539	1.04
		Gender	0.27	0.25	1.11	0.266	1.31
		Books	−0.02	0.13	−0.14	0.892	0.98
		Home supports	0.06	0.29	0.21	0.836	1.06
		Parents' education	0.11	0.14	0.78	0.436	1.11
	High motivation	School belonging	0.26*	0.08	3.42	0.001	1.30
		Student bullying	0.07	0.08	0.88	0.379	1.07
		Gender	0.94	0.34	2.75	0.006	2.57
		Books	0.21	0.16	1.31	0.191	1.23
		Home supports	0.11	0.40	0.27	0.785	1.12
		Parents' education	0.25	0.19	1.33	0.185	1.29
Medium motivation	High motivation	School belonging	0.21**	0.05	4.17	0.000	1.23
		Student bullying	0.03	0.06	0.48	0.632	1.03
		Gender	0.67	0.28	2.42	0.016	1.96
		Books	0.22	0.11	2.09	0.037	1.25
		Home supports	0.05	0.30	0.16	0.870	1.05
		Parents' education	0.15	0.16	0.94	0.348	1.16

School belonging = student's sense of belonging to the school; student bullying = student's experiences of bullying; books = the number of books in the home; home support = the number of home study supports; parents' education = parents' highest education level

*$p < .005$, ** $p < .001$

achievement exhibited no statistically significant difference compared to the low motivation group. The descriptive statistics and inferential statistics for group comparisons are shown in Table 6.

Discussion

Motivational beliefs, while universal, manifest differently across domains and sociocultural contexts. Our investigation unveiled five distinct profiles of Korean eighth graders' math and science motivational beliefs. The results serve as a useful heuristic for math and science teachers to understand the different types of students in their classrooms. Moreover, the study's findings showed that the pivotal role of school belonging predicted the formation of these motivational groups. We further validated the connections between student motivational beliefs and achievement in math and science using representative national data. Overall, this study contributes to a deeper understanding of the mechanisms of student motivational beliefs, and offers practical strategies for policies and practices to cultivate student math and science motivational beliefs.

The following sections provide extensive discussions of the three research questions. The first one addresses the patterns of student math and science motivational beliefs. The second section elaborates on the student school experience variables shaping student math and science motivational beliefs. The third section discusses the link between patterns of motivational beliefs and achievement in math and science. The last section lists the current study's limitations and offers suggestions for future research.

Patterns of student mathematics and science motivational beliefs

Like math and science, distinct yet intertwined academic subjects, student math and science motivational beliefs are intricately linked and uniquely differentiated. Against the backdrop of the Situated Expectancy–Value Theory (SEVT) (Eccles & Wigfield, 2020), the role of sociocultural contexts in sharpening motivational beliefs, including self-concept, intrinsic value, and utility value, becomes evident. Compared with other countries using the same metrics of the most contemporary Trends in International Mathematics and Science Study (TIMSS) data, the results of this study correspond to patterns of the past two decades, which indicate that Korean middle school students' math and science motivational beliefs

Table 6 Differences in mathematics and science achievement across the five profiles

Profile	Math achievement		Science achievement	
	M	SE	*M*	SE
1. Very low motivation	541.54	6.37	498.43	5.49
2. Low motivation	606.11	3.21	559.57	2.62
3. Low math/high science motivation	622.81	9.96	618.20	6.91
4. Medium motivation	671.12	4.39	615.28	4.37
5. High motivation	708.30	6.57	652.38	5.78
	Chi-square	***p***	**Chi-square**	***p***
Overall test	554.13	< 0.001	541.42	< 0.001
Profile 1 vs 2	102.17	< 0.001	139.34	< 0.001
Profile 1 vs 3	50.29	< 0.001	204.01	< 0.001
Profile 1 vs 4	297.16	< 0.001	303.44	< 0.001
Profile 1 vs 5	441.30	< 0.001	406.21	< 0.001
Profile 2 vs 3	3.06	0.214	69.88	< 0.001
Profile 2 vs 4	215.37	< 0.001	144.86	< 0.001
Profile 2 vs 5	238.90	< 0.001	238.97	< 0.001
Profile 3 vs 4	21.85	< 0.001	0.14	0.707
Profile 3 vs 5	59.47	< 0.001	17.97	< 0.001
Profile 4 vs 5	28.60	< 0.001	27.70	< 0.001

are below the international average, while Korean students rank at the top in math and science achievement (Liou, 2017; Mullis et al., 2020).

Unlike most literature (e.g., Marsh et al., 2024), which focuses on variable-oriented approaches, this study utilized a person-oriented approach to group students. This approach provides an effective framework for exploring intricate interactions of students' self-concepts, utility values, and intrinsic values of math and science in naturally occurring contexts. Our results suggest five distinct profiles: high motivation, medium motivation, low math/high science motivation, lower motivation, and very low motivation groups. It paints a nuanced picture of the motivational landscape. One significant result is that less than 20% of students belong to the high motivation (5%) and medium motivation (13%) groups. The low motivation group accounts for 70% of the sample, and is notably the largest group, highlighting a prevailing trend of subdued math and science motivational beliefs among Korean students. In light of these existing frameworks and findings, our study ventured into the complex tapestry of motivational beliefs among Korean eighth graders whose math and science motivational beliefs stands out as particularly low compared to the international average. This observation—juxtaposed against the international average—underscores the potential cultural or educational influences.

Existing research on the intertwined nature of math and science motivational beliefs, primarily from Western contexts (Berger et al., 2020; Fong et al., 2021; Snodgrass Rangel et al., 2020), provides a framework to understand our findings from Korea. While our results generally resonate with these Western studies, certain unique patterns emerged. The overarching agreement across studies is the positive interconnection between math and science domains. Students with higher math motivational beliefs often exhibit heightened science motivational beliefs and vice versa. Only a few students from a population displayed a skew in their motivational beliefs toward one domain. For instance, 8% of eighth graders in Australia displayed higher math motivational beliefs than science motivational beliefs, and another 11% leaned the other way (Berger et al., 2020). Contrastingly, our study highlighted only a segment of students (4%) with elevated science motivational beliefs paired with lower math motivational beliefs, with no observable group presenting the opposite trend.

This unique pattern (i.e., low math/high science motivation group) may epitomize Korean educational phenomena. Math, English, and Korean Language are generally considered the most important academic subjects for students from elementary to high school in Korea (Ministry of Education, 2015). Most students attend after-school cram schools (called hagwon in Korean; see Choi & Choi, 2016) for math, but not science before high school. Thus, many students tend to learn science at a similar level, engaging more actively and enjoying laboratory experiments. In contrast, for math, there is a significant knowledge gap among students who have pre-learned materials at cram schools. As a result, this group of students who focus intensively on math may not develop corresponding math motivational beliefs compared to their science motivational beliefs. We need more nuanced studies to explain the distinct pattern unique to the Korean educational context and STEM education in shaping students' math and science motivational beliefs.

Enablers of mathematics and science motivational beliefs

The SEVT suggests that broader cultural and societal contexts shape students' motivational beliefs (Eccles & Wigfield, 2020). While previous studies (e.g., Berger et al., 2020; Fong et al., 2021; Snodgrass Rangel et al., 2020) utilized a person-centered approach to tackle the profiles of student math and science motivational beliefs and their relations with personal factors, our study's uniqueness is in advancing the literature by examining the predictive effects of students' experiences at school.

Our study revealed that higher levels of school belonging, an indicator of a supportive and connected environment, correlate with an increased likelihood of students fitting into the higher math and science motivational belief profiles. School belonging is students' sensation of connectedness to the school environment. This finding echoes the results from the literature (Joyce & Early, 2014; Walker & Greene, 2009), emphasizing the importance of fostering an inclusive and supportive school atmosphere. This result shows the importance of supportive educational environments for boosting student math and science motivational beliefs (Smith et al., 2022). More research has shown the importance of belonging in higher education, particularly in STEM fields (Singer et al., 2020; Strayhorn, 2012). Surprisingly, student bullying did not significantly predict any math and science motivational belief profiles. We speculate that only a few students reported such bullying experiences, so the variance was limited.

As students' demographic variables were viewed as control variables, our analysis shed light on the distinct variations in the patterns of math and science motivational beliefs between male and female students. Male students were more likely to fall into the medium and high motivation groups, pointing to potential gender-based differences in how math and science motivational beliefs manifest. Gender dynamics, although not universally prevalent across all profiles, still hint at underlying societal or systemic factors that need further exploration (Liou et al., 2023). Gender inequality is a serious issue in Korea. Among OECD countries, Korea has the largest gender wage gap (OECD, 2023). The imbalanced proportion of females and males in higher math and science motivational belief groups (e.g., only 26% of females in the high motivation group) poses a serious challenge, given that students in higher math and science motivational belief groups are more likely to secure careers in STEM. STEM fields generally offer higher salaries than other fields, so job opportunities in STEM for women are essential for diminishing the gap. Moreover, the representation of females in STEM fields plays a vital role in diversifying the workforce, ultimately fostering creativity, productivity, innovation, and overall success. Today's dynamic and inclusive society particularly emphasizes the underrepresentation of females in STEM majors and careers.

Prediction of student mathematics and science motivational belief profiles on cognitive achievement

At the secondary schooling stage, achievements in math and science are likely the most critical outcomes for students, parents, teachers, and stakeholders. Numerous studies have shown positive associations between motivational beliefs and corresponding achievement. Our findings also corroborate previous results of relationships between motivational beliefs and achievement in math and science. Our analysis consistently highlighted that specific motivational belief patterns directly correlate with levels of achievement in math and science. Students with higher motivation profiles, buoyed by a combination of self-concept, utility value, and intrinsic value for math and science, generally exhibit superior academic outcomes.

While extant studies (Fong et al., 2021; Snodgrass Rangel et al., 2020) implicitly suggest that high motivation in math can often translate to commendable achievement in science, even when their primary science motivation is not as profound, our results confirm this pattern. The results indicated that students' math achievement did not differ in the low motivation and low math/high science motivation groups. Moreover, there were no differences in the science achievement of the low math/high science motivation and medium motivation groups. We speculate that the phenomena may be due to our categorization of the profiles as a benchmark for such a comparison.

The low math/high science motivation group exhibited a different pattern than the other four groups with similar math motivational beliefs and science motivational beliefs (i.e., very low, low, medium, and high in order). That is, students in this group have high science motivational beliefs but low math motivational beliefs. Correspondingly, the students' average science achievement ($M = 620$) is identical to the medium motivation group's science score ($M = 620$), while the math score of the low math/high science motivation group ($M = 619$) is much lower than that of the medium motivation group ($M = 678$). This result only partially confirms Marsh's

I/E model of the interplay between a student's relatively higher science motivational beliefs and science achievement, and lower math motivational beliefs and math achievement. However, most current findings align with previous studies (e.g., Berger et al., 2020) which found that math and science motivational beliefs and achievement are reciprocally beneficial or detrimental.

Students in the very low motivation group are at the bottom of the cohort regarding their math and science motivational beliefs. While their math and science achievements are also the lowest among the five groups, their science score ($M=495$) is the average of the international population ($M=500$), and their math score ($M=538$) is even higher. Our examination of Korean students sheds light on the intricate web of math and science motivational beliefs and achievement. Notably, there is an observable trend of Korean students across four profiles displaying higher math achievements than science; the low math/high science motivation group is the exception.

Limitations and directions for future studies

While this study offers substantial insights into math and science motivational beliefs, we need to acknowledge certain limitations. First, the study's data are from a cross-sectional design, so we cannot claim causality. Latent profiles and differences in profiles do not infer causal relationships between variables. Further studies should consider a longitudinal approach, tracking the evolution of math and science motivational beliefs over time and the link to students' actual careers, to confirm our results. Second, student perceived school belonging and student bullying variables in this study are considered as their personal experiences at school, and are not school-level variables. Thus, we did not employ multilevel modeling. However, future studies that focus on contextual effects or the predictive effects of school- or classroom-level variables on student motivational beliefs may utilize multilevel modeling. Third, this study did not consider school-level or classroom-level contextual factors from different data sources; instead, it relied on students' perceptions. Future research could examine data from different sources (e.g., teachers and school principals) to understand how environmental factors influence the formation of students' motivational beliefs in math and science (e.g., Liou & Myoung, 2023).

Fourth, the current study only situates students' experiences at school as predictors for the identified profiles, not their demographic backgrounds that only serve as control variables. To set these demographic variables as predictors, there may be a need to critically evaluate whether these motivational belief scales exhibit differential item functioning across the scales prior to the main analyses. The content validity of TIMSS questionnaire items was established by the quality assurance team by "clearly defining the target construct to be measured, specifying the items needed to measure it, establishing standards for items and item forms and ensuring that the assessments meet the test specifications" (Cotter et al., 2020, p. 4). However, future empirical studies are needed to validate the psychometrical properties of motivational belief scales for group comparisons within countries. Finally, the current study focuses on the Korean secondary school context. The generalizability of this study's findings and implications to other populations, such as higher education or different countries, remains uncertain. We need further studies using data documenting diversified samples to understand the mechanism of student math and science motivational beliefs on a broader scale.

Conclusion

Our study identified five distinct profiles of motivation beliefs in math and science among Korean eighth graders. These findings offer valuable insights for math and science teachers, providing a heuristic to better comprehend the diverse student types within their classrooms. Notably, school belonging played a pivotal role in predicting the formation of these motivational groups. Overall, our research deepens the understanding of the mechanisms behind student math and science motivational beliefs, and proposes practical strategies for policies and practices in educational environments to foster positive students' motivational beliefs. Our study, which focused on Korean secondary school students, contributes to the broader literature on international math and science motivational beliefs, and provides a regional perspective, indicating the unique challenges in Korean STEM education.

Appendix

Item descriptions for variables

Variable	Item description
Math self-concept	How much do you agree with these statements about mathematics? • I usually do well in mathematics • Mathematics is more difficult for me than for many of my classmates[R] • Mathematics is not one of my strengths[R] • I learn things quickly in mathematics • Mathematics makes me nervous[R] • I am good at working out difficult mathematics problems • My teacher tells me I am good at mathematics • Mathematics is harder for me than any other subject[R] • Mathematics makes me confused[R]
Science self-concept	How much do you agree with these statements about science? • I usually do well in science • Science is more difficult for me than for many of my classmates[R] • Science is not one of my strengths[R] • I learn things quickly in science • I am good at working out difficult science problems • My teacher tells me I am good at science • Science is harder for me than any other subject[R] • Science makes me confused[R]
Math utility value	How much do you agree with these statements about mathematics? • I think learning mathematics will help me in my daily life • I need mathematics to learn other school subjects • I need to do well in mathematics to get into the university of my choice • I need to do well in mathematics to get the job I want • I would like a job that involves using mathematics • It is important to learn about mathematics to get ahead in the world • Learning mathematics will give me more job opportunities when I am an adult • My parents think that it is important that I do well in mathematics It is important to do well in mathematics

Variable	Item description
Science utility value	How much do you agree with these statements about science? • I think learning science will help me in my daily life • I need science to learn other school subjects • I need to do well in science to get into the university of my choice • I need to do well in science to get the job I want • I would like a job that involves using science • It is important to learn about science to get ahead in the world • Learning science will give me more job opportunities when I am an adult • My parents think that it is important that I do well in science It is important to do well in science
Math intrinsic value	How much do you agree with these statements about learning mathematics? • I enjoy learning mathematics • I wish I did not have to study mathematics[R] • Mathematics is boring • I learn many interesting things in mathematics • I like mathematics • I like any schoolwork that involves numbers • I like to solve mathematics problems • I look forward to mathematics lessons • Mathematics is one of my favorite subjects
Science intrinsic value	How much do you agree with these statements about learning science? • I enjoy learning science • I wish I did not have to study science[R] • Science is boring[R] • I learn many interesting things in science • I like science • I look forward to learning science in school • Science teaches me how things in the world work • I like to conduct science experiments • Science is one of my favorite subjects
Gender	Sex of students • Girl (Code it as 0) • Boy (Code it as 1)

Variable	Item description
Family socioeconomic backgrounds	(1) The number of books in the home • None or very few (0–10) • Enough to fill one shelf (11–25) • Enough to fill one bookcase (26–100) • Enough to fill two bookcases (101–200) • Enough to fill three or more bookcases (more than 200) (2) The number of home study supports • None • Internet connection or own room • Both internet connection and own room (3) Highest level of education of either parent • Finished some primary or lower secondary or did not go to school • Finished lower secondary • Finished upper secondary • Finished post-secondary education • Finished university or higher
School belonging	When do you think about your school? Tell how much you agree with these statements • I like being in school • I feel safe when I am at school • I feel like I belong at this school • Teachers at my school are fair to me • I am proud to go to this school
Student bullying	During this school year, how often have other students from your school done any of the following things to you, including through texting or the Internet? • Said mean things about my physical appearance (e.g., my hair, my size) • Spread lies about me • my secrets with others • Refused to talk to me • Insulted a member of my family • Stole something from me • Made me do things I didn't want to do • Sent me nasty or hurtful messages online • Shared nasty or hurtful things about me online • Shared embarrassing photos of me online • Threatened me • Physically hurt me • Excluded me from their group • Damaged something of mine on purpose
Mathematics/science achievement	First plausible value of mathematics and science test scores

[R] Reverse coded

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Author contributions
P.-Y. Liou (first and corresponding author) conceptualized, designed, and supervised the study, interpreted the statistical results and wrote the literature review and conclusion sections. J. Jang (second author) performed the statistical analyses and wrote the method and results sections. E. Myoung (third author) assisted in performing the statistical analyses and writing the literature review and conclusion sections.

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Availability of data and materials
The data that support the findings of this study are openly available in the TIMSS 2019 International Database at https://timss2019.org/international-database/.

Declarations

Competing interests
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References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control, 19*(6), 716–723.
Arens, A. K., & Preckel, F. (2018). Testing the internal/external frame of reference model with elementary school children: Extension to physical ability and intrinsic value. *Contemporary Educational Psychology, 54*, 199–211.
Asparouhov, T., & Muthén, B. O. (2014). Auxiliary variables in mixture modeling: Using the BCH method in Mplus to estimate a distal outcome model and an arbitrary secondary model. *Mplus Web Notes, 21*, 1–22.
Bandura, A. (1986). *Social foundations of thought & action: A social cognitive theory*. Prentice-Hall Inc.
Bechter, C., Brechmann, A., & Kenne, C. (2018). Model selection with regularized LQ-likelihood ratio test in latent class analysis. *Computational Statistics & Data Analysis, 122*, 46–64.
Berger, N., Mackenzie, E., & Holmes, K. (2020). Positive attitudes towards mathematics and science are mutually beneficial for student achievement: A latent profile analysis of TIMSS 2015. *The Australian Educational Researcher, 47*(3), 409–444.
Bolck, A., Croon, M., & Hagenaars, J. (2004). Estimating latent structure models with categorical variables: One-step versus three-step estimators. *Political Analysis, 12*(1), 3–27.
Chiu, M.-S. (2012). The internal/external frame of reference model, big-fish-little-pond effect, and combined model for mathematics and science. *Journal of Educational Psychology, 104*(1), 87–107.
Choi, H., & Choi, Á. (2016). Regulating private tutoring consumption in Korea: Lessons from another failure. *International Journal of Educational Development, 49*, 144–156.
Cotter, K. E., Centurino, V. A. S., & Mullis, I. V. S. (2020). Developing the TIMSS 2019 mathematics and science achievement instruments. In M. O. Martin, M. Davier, & I. V. S. Mullis (Eds.), *Methods and procedures: TIMSS 2019 technical report* (pp. 1–36). Boston: TIMSS & PIRLS International Study Center, Lynch School of Education and Human Development.
Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53*(1), 109–132.
Eccles, J. S., & Wigfield, A. (2020). From expectancy-value theory to situated expectancy-value theory: A developmental, social cognitive, and sociocultural perspective on motivation. *Contemporary Educational Psychology, 61*, 101859.
Fong, C. J., Kremer, K. P., Cox, C. H., & Lawson, C. A. (2021). Expectancy-value profiles in math and science: A person-centered approach to cross-domain motivation with academic and STEM-related outcomes. *Contemporary Educational Psychology, 65*, 101962.

Heinen, T. (1996). *Latent class and discrete latent trait models: Similarities and differences*. Sage.
Hsieh, T. Y., & Simpkins, S. D. (2022). The patterns of adolescents' math and science motivational beliefs: Examining within–racial/ethnic group changes and their relations to STEM outcomes. *AERA Open, 8*, 23328584221083670.
Joyce, H. D., & Early, T. J. (2014). The impact of school connectedness and teacher support on depressive symptoms in adolescents: A multilevel analysis. *Children and Youth Services Review, 39*, 101–107.
Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd ed.). The Guilford Press.
Kokkinos, C. M., & Kipritsi, E. (2012). The relationship between bullying, victimization, trait emotional intelligence, self-efficacy and empathy among preadolescents. *Social Psychology of Education, 15*, 41–58.
Laith, R., & Vaillancourt, T. (2022). The temporal sequence of bullying victimization, academic achievement, and school attendance: A review of the literature. *Aggression and Violent Behavior, 64*, 101722.
Laursen, B. P., & Hoff, E. (2006). Person-centered and variable-centered approaches to longitudinal data. *Merrill-Palmer Quarterly, 52*(3), 377–389.
Lee, S., & Shi, D. (2021). A comprehensive review of missing data treatment in PLS-SEM. *Structural Equation Modeling, 28*(2), 266–280.
Liou, P.-Y. (2017). Profiles of adolescents' motivational beliefs in science learning and science achievement in 26 countries: Results from TIMSS 2011 data. *International Journal of Educational Research, 81*, 83–96.
Liou, P.-Y., & Hung, Y.-C. (2015). Statistical techniques utilized in analyzing PISA and TIMSS databases in science education from 1996 to 2013: A methodological review. *International Journal of Science and Mathematics Education, 13*(6), 1449–1468.
Liou, P.-Y., Lin, Y.-M., Huang, S.-C., & Chen, S. (2023). Gender differences in science motivational beliefs and their relations with achievement over grades 4 and 8: A multinational perspective. *International Journal of Science and Mathematics Research, 21*(1), 233–249.
Liou, P.-Y., & Myoung, E. (2023). Teacher-perceived science inquiry-based instructional practice on student achievement and motivational beliefs in classroom contexts. *Science Education, 107*(6), 1485–1506.
Lo, Y., Mendell, N. R., & Rubin, D. B. (2001). Testing the number of components in a normal mixture. *Biometrika, 88*(3), 767–778.
Ma, Y. (2022). Profiles of student science attitudes and its associations with gender and science achievement. *International Journal of Science Education, 44*(11), 1876–1895.
Marsh, H. W. (1986). Verbal and mathematics self-concepts: An internal/external frame of reference model. *American Educational Research Journal, 23*, 129–149.
Marsh, H. W. (2023). Extending the reciprocal effects model of math self-concept and achievement: Long-term implications for end-of-high-school, age-26 outcomes, and long-term expectations. *Journal of Educational Psychology, 115*(2), 193–211.
Marsh, H. W., & Hau, K.-T. (2004). Explaining paradoxical relations between academic self-concepts and achievements: Cross-cultural generalizability of the internal/external frame of reference predictions across 26 countries. *Journal of Educational Psychology, 96*(1), 56–67.
Marsh, D. D., Sharpe, S. T., & Graham, S. E. (2024). The role of mathematics and science expectancy-value attitudes in students' STEM course-taking and major choices. *Journal for STEM Education Research*. https://doi.org/10.1007/s41979-024-00125-0
Marsh, H. W., & Shavelson, R. (1985). Self-concept: Its multifaceted, hierarchical structure. *Educational Psychologist, 20*(3), 107–123.
Martin, M. O., von Davier, M., & Mullis, I. V. S. (Eds.). (2020). Methods and procedures: TIMSS 2019 technical report. Retrieved from Boston College, TIMSS & PIRLS International Study Center website. https://timssandpirls.bc.edu/timss2019/methods
Masyn, K. E. (2013). Latent class analysis and finite mixture modeling. In T. D. Little (Ed.), *The Oxford handbook of quantitative methods* (Vol. 2, pp. 551–611). Oxford University Press.
Ministry of Education. (2015). The National Curriculum for the Primary and Secondary Schools (Proclamation of the Ministry of Education #2015–74 [Annex 1]), Government of the Republic of Korea. https://www.ncic.re.kr/english.dwn.ogf.originalFileTypeDownload.do?fileNo=10000038&fileExp=PDF&refPath=%EF%BF%BD%EF%BF%BD%EF%BF%BD%EF%BF%BD+PDF+%EF%BF%BD%EF%BF%BD%EF%BF%BD%EF%BF%BD+%EF%BF%BDٿ%EF%BF%BDε%EF%BF%BD
Möller, J., Zitzmann, S., Helm, F., Machts, N., & Wolff, F. (2020). A meta-analysis of relations between achievement and self-concept. *Review of Educational Research, 90*, 376–419.
Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). *TIMSS 2019 international results in mathematics and science*. Retrieved from Boston College, TIMSS & PIRLS International Study Center website. https://timssandpirls.bc.edu/timss2019/international-results/
Muthén, B. (1992). Latent variable modeling in heterogeneous populations. *Psychometrika, 57*(4), 547–594.
Muthén, B. (2004). Latent variable analysis: Growth mixture modeling and related techniques for longitudinal data. In D. Kaplan (Ed.), *Handbook of quantitative methodology for the social sciences* (pp. 345–368). Sage Publications.
Muthén, L. K., & Muthén, B. O. (1998–2022). *Mplus (Version 8.7) [Computer software]*. Muthén & Muthén.
Nylund, K. L., Asparouhov, T., & Muthén, B. O. (2007). Deciding on the number of classes in latent class analysis and growth mixture modeling: A Monte Carlo simulation study. *Structural Equation Modeling, 14*(4), 535–569.
Nylund, K. L., Asparouhov, T., & Muthén, B. O. (2014). Correcting classification in latent class analysis based on posterior probabilities. *The British Journal of Mathematical and Statistical Psychology, 67*(3), 286–307.
Organisation for Economic Co-operation and Development (OECD). (2017). *PISA 2015 technical report*. OECD Publishing Retrieved from http://www.oecd.org/pisa/data/2015-technical-report/
Organisation for Economic Co-operation and Development (OECD). (2023). *Gender wage gap* . https://doi.org/10.1787/7cee77aa-en. Accessed on 24 Oct 2023.
Podobnik, B., Crawford, G. C., Lichtenstein, B., Lipic, T., Wild, D., Zhang, X., & Stanley, H. E. (2020). The new wealth of nations: How STEM fields generate the prosperity and inequality of individuals, companies, and countries. *Chaos, Solitons & Fractals, 141*, 110323.
Schwartz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics, 6*(2), 461–464.
Sclove, S. L. (1987). Application of model-selection criteria to some problems in multivariate analysis. *Psychometrika, 52*(3), 333–343.
Singer, A., Montgomery, G., & Schmoll, S. (2020). How to foster the formation of STEM identity: Studying diversity in an authentic learning environment. *International Journal of STEM Education, 7*(1), 1–12.
Smith, T. J., Hong, Z. R., Hsu, W. Y., & Lu, Y. Y. (2022). The relationship of sense of school belonging to physics attitude among high school students in advanced physics courses. *Science Education, 106*(4), 830–851.
Snodgrass Rangel, V., Vaval, L., & Bowers, A. (2020). Investigating underrepresented and first-generation college students' science and math motivational beliefs: A nationally representative study using latent profile analysis. *Science Education, 104*(6), 1041–1070.
Strayhorn, T. L. (2012). *College students' sense of belonging: A key to educational success for all students*. Routledge.
Urdan, T., & Schoenfelder, E. (2006). Classroom effects on student motivation: Goal structures, social relationships, and competence beliefs. *Journal of School Psychology, 44*(5), 331–349.
Vermunt, J. K. (2010). Latent class modeling with covariates: Two improved three-step approaches. *Political Analysis, 18*(4), 450–469.
Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education, 7*, 1–18.
Walker, C. O., & Greene, B. A. (2009). The relations between student motivational beliefs and cognitive engagement in high school. *The Journal of Educational Research, 102*(6), 463–472.
Wang, M.-C., Deng, Q., Bi, X., Ye, H., & Yang, W. (2017a). Performance of the entropy as an index of classification accuracy in latent profile analysis: A Monte Carlo simulation study. *Acta Psychologica Sinica, 49*(11), 1473–1482.
Wang, M. T., Ye, F., & Degol, J. L. (2017b). Who chooses STEM careers? Using a relative cognitive strength and interest model to predict careers in science, technology, engineering, and mathematics. *Journal of Youth and Adolescence, 46*, 1805–1820.
Watt, H. M. G., Bucich, M., & Dacosta, L. (2019). Adolescents' motivational profiles in mathematics and science: Associations with achievement striving,

career aspirations, and psychological well-being. *Frontiers in Psychology, 10*, 990.

Wu, H., Guo, Y., Yang, Y., Zhao, L., & Guo, C. (2021). A meta-analysis of the longitudinal relationship between academic self-concept and academic achievement. *Educational Psychology Review, 33*(4), 1749–1778.

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