Large-scale Assessments in Education

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Examining the relationship between science motivational beliefs and science achievement in Emirati early adolescents through the lens of self-determination theory

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Abstract

Background A solid foundation in science is critical to students' success in the 21st century workforce, especially in fields related to science, technology, engineering, and mathematics (STEM). Therefore, high-quality science education is critical to prepare students for the challenges of the future. However, Emirati students have consistently performed poorly on international standardized science assessments, suggesting that the underlying factors contributing to this trend need to be understood. Therefore, the present study examined the relationship between motivational beliefs in science (i.e., science self-concept and intrinsic and instrumental motivation to learn science) and science achievement in Emirati early adolescents using a self-determination theory framework.

Methods A total of 7,915 Emirati eighth-grade students ($Mean_{age}$ = 13.61 years, SD = 0.53) participated in the 2019 Trends in International Mathematics and Science Study (TIMSS). The TIMSS 2019 assessment measured students' motivational beliefs in science and their achievement in science. Path analysis and bootstrapping were used to examine the relationship between these variables and to test the mediating role of intrinsic and instrumental motivation to learn science in the relationship between science self-concept and science achievement.

Results The results of the study indicate that science self-concept is positively related to both intrinsic and instrumental motivation to learn science and science achievement. Intrinsic motivation to learn science was significantly related to science achievement, whereas instrumental motivation was not. Moreover, intrinsic motivation to learn science alone significantly mediated the relationship between science self-concept and science achievement.

Conclusions The study offers insights into the specific motivational beliefs associated with science achievement and highlights the importance of fostering positive science self-concept and intrinsic motivation in Emirati early adolescents. The study also suggests that interventions to promote positive science self-concept and intrinsic motivation to learn science may be particularly effective in improving science achievement in this population. These findings have important implications for educators and policymakers seeking to promote academic success and career opportunities for Emirati students in science.

Keywords Science motivational beliefs, Science self-concept, Intrinsic motivation, Instrumental motivation, Science achievement, Self-determination theory, TIMSS, United Arab Emirates

Adolescent students in the United Arab Emirates (UAE) have been consistently underperforming on international standardized science assessments like the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) for the past several years (Martin et al., 2012, 2016; Mullis et al., 2020a, b; Organization for Economic Cooperation and Development [OECD], 2014, 2016, 2019). Science education plays a crucial role in the development of a country's human capital, and is essential for economic growth and development (OECD, 2020). As the UAE strives for a knowledge-based economy (UAE National Committee for Sustainable Development Goals, 2017), a solid foundation in science is necessary to compete in the global market. Moreover, research has consistently shown that early adolescence is a critical period for the development of interest, motivation, and self-concept in science (Potvin & Hasni, 2014). Emirati early adolescents who lack interest, motivation, or a positive self-concept in science during adolescence may be less likely to pursue science-related careers in the future, limiting their opportunities for personal and professional growth. Despite the critical role science plays in promoting economic progress and development, there is a dearth of research examining the factors that contribute to Emirati early adolescents' underperformance in science. Understanding the underlying factors that influence Emirati early adolescents' science achievement can help inform policies and interventions aimed at improving science education in the country. In the context of science education, self-determination theory (SDT; Deci and Ryan, 2012; Ryan and Deci, 2017) provides a useful framework for understanding the factors that contribute to science achievement and engagement.

Self-determination theory (SDT)

SDT is based on the premise that individuals have three innate psychological needs: autonomy, competence, and relatedness (Deci & Ryan, 2012; Ryan and Deci, 2017). Autonomy refers to the need for individuals to feel a sense of control over their lives and choices, and to feel that their actions are self-determined rather than controlled by external factors (Ryan & Deci, 2017). Competence refers to the need for individuals to feel a sense of mastery and achievement in their activities, and to feel that they are capable of achieving their goals (Ryan & Deci, 2017). Relatedness refers to the need for individuals to feel a sense of connection and belonging with others, and to feel that they are part of a social group (Ryan & Deci, 2017). In the context of science education, meeting these needs is critical for promoting student motivation and engagement (Kaiser et al., 2020; Lavigne et al., 2007; Wood, 2019). Autonomy can be fostered by providing students with opportunities to make choices about their learning process, such as choosing topics to explore or designing their own experiments (Jang et al., 2009; Reeve, 2016; Reeve & Halusic, 2009). Competence can be enhanced by providing students with opportunities to engage in challenging and meaningful scientific activities that allow them to build and demonstrate their skills and knowledge (Jang et al., 2009; Reeve, 2016; Reeve & Halusic, 2009). Relatedness can be nurtured by creating a classroom environment that promotes collaboration and social interaction, and by highlighting the relevance and importance of science to society as a whole (Jang et al., 2009; Reeve, 2016; Reeve & Halusic, 2009).

One way to relate SDT to science education is through the concept of science motivational beliefs. Motivational beliefs in science refer to the attitudes and beliefs individuals have about their abilities and identity in science, as well as their motivation to learn and engage in science-related activities (Areepattamannil et al., 2011). These beliefs can include a number of factors, such as science self-concept, intrinsic and instrumental motivation to learn science, interest in science, and the perceived value of science in one's life (Areepattamannil et al., 2011, 2020). Science self-concept refers to a person's beliefs and attitudes about their competence in science, which affect how they view their abilities and potential in science. According to SDT, science self-concept is closely related to the need for competence (Areepattamannil et al., 2020). Individuals who feel competent in science are more likely to have a positive science self-concept, which may lead to higher motivation and engagement in scientific activities (Areepattamannil et al., 2020). According to SDT, there are two broad categories of motivation: intrinsic and extrinsic motivation (Ryan & Deci, 2017). Intrinsic motivation is performing an activity for its own sake because it is inherently enjoyable, interesting, or satisfying. Intrinsic motivation is driven by the individual's interest, curiosity, and enjoyment of the activity (Ryan & Deci, 2017). In contrast, extrinsic motivation refers to performing an activity to achieve a specific outcome or reward. Extrinsic motivation is driven by external factors such as rewards, recognition, or avoidance of punishment (Ryan & Deci, 2017). Instrumental motivation, on the other hand, is a type of extrinsic motivation that is driven by the desire to achieve a separate outcome or reward. In the context of SDT, instrumental motivation can be either autonomous or controlled (Guay, 2022; Ryan & Deci, 2017). Autonomous instrumental motivation occurs when individuals engage in an activity for extrinsic reasons, but do so because they find it interesting, enjoyable, or personally meaningful (Guay, 2022). Controlled instrumental motivation occurs when individuals engage in an activity for extrinsic reasons, but do so because they feel external pressure or are motivated by external factors such as rewards or recognition (Guay, 2022).

SDT suggests that intrinsic motivation is more likely to lead to sustained engagement and optimal performance than extrinsic motivation (Deci & Ryan, 2012; Ryan & Deci, 2017, 2020). This is because intrinsic motivation is driven by the individual's inherent interest in the activity, whereas extrinsic motivation is driven by external factors that may not always be present or effective in promoting engagement and optimal performance (Ryan & Deci, 2020). SDT assumes that the extent to which individuals feel autonomous and self-determined in their engagement in an activity is a key determinant of their intrinsic motivation (Ryan & Deci, 2020). When people feel autonomous and self-determined, they are more likely to feel intrinsic motivation and engage in an activity because they find it interesting, enjoyable, or personally meaningful (Ryan & Deci, 2020).

In summary, SDT provides a framework for understanding the relationship between intrinsic and extrinsic motivation and how the psychological needs for autonomy, competence, and relatedness influence motivation and engagement. It emphasizes the importance of supporting individuals' intrinsic motivation by promoting their autonomy and self-determination and recognizing the limitations of extrinsic motivators such as rewards and recognition. It also recognizes that instrumental motivation can be either autonomous or controlled, depending on the individual's reasons for engaging in the activity.

Science self-concept, intrinsic and instrumental motivation to learn science, and science achievement

The relationship between science self-concept and science achievement has been studied extensively in the field of educational psychology. Previous research has consistently shown that there is a positive relationship between science self-concept and science achievement (Areepattamannil, 2012; Areepattamannil et al., 2011; Areepattamannil & Kaur, 2013; Chang et al., 2007; Jansen et al., 2014; Leibham et al., 2013; Ng et al., 2012; Ustun, 2023), suggesting that individuals who have a higher science self-concept are more likely to achieve better grades in science courses, perform better on science assessments, and develop a greater interest in science activities. One of the rationales for the positive correlation between science self-concept and science achievement is that individuals with a stronger science self-concept tend to show more enthusiasm and perseverance when participating in science activities (Leibham et al., 2013). They are more inclined to challenge themselves by tackling arduous tasks, and are willing to persevere in the face of adversity (Larry & Wendt, 2022). They also tend to have more of a growth mindset (Guo et al., 2022), i.e., a belief that their skills and cognitive abilities can be improved through hard work and dedication (Yeager & Dweck, 2020). In addition, individuals with higher science self-concept tend to have more constructive and positive attitudes toward science and see it as relevant and important to their lives (Zhang et al., 2022). They have greater confidence in their ability to understand and master scientific principles and skills and are more sure of their ability to use them to solve real-world problems (Larry & Wendt, 2022; Wong et al., 2021). In contrast, people with lower science self-concept may feel anxious, intimidated, or discouraged when faced with scientific tasks or challenges (Henschel, 2021). They may believe that they are not good at science or that the subject is not relevant or interesting to them. These negative beliefs may lead to a lack of motivation, lower engagement, and a lower likelihood of being successful in science activities (Henschel, 2021; Taskinen et al., 2013; Vinni-Laakso et al., 2019).

Previous studies have also shown that there is a positive relationship between science self-concept and intrinsic motivation to learn science (Ainley & Ainley, 2011; Ustun, 2023), suggesting that individuals with higher science self-concept are more intrinsically motivated to engage in science activities. The positive relationship between science self-concept and intrinsic motivation to learn science can be explained by several factors. One of the main reasons for this relationship is that individuals who have a positive science self-concept are more likely to perceive science as an enjoyable and rewarding subject. They tend to have a greater interest in science topics and are more likely to participate in science activities outside the classroom (Ainley et al., 2002). As a result, they are more likely to feel intrinsic motivation to learn science because they personally find the subject meaningful and enjoyable (Ainley et al., 2002). In addition, individuals with higher science self-concept tend to have a greater sense of competence and confidence in their abilities to learn and understand scientific concepts (Sáinz et al., 2022). They are more likely to believe that they can successfully complete scientific tasks and challenges, leading to a greater sense of autonomy and self-determination (Lavigne et al., 2007). This, in turn, promotes intrinsic motivation to learn science because they feel they have control over their learning and can pursue their interests and goals (Ryan & Deci, 2017). In addition, people with a positive science self-concept value science as a means for personal growth and development (Schütte, 2015). They are more likely to see science as a way to solve real-world problems and make a positive impact on society. This sense of purpose and relevance can lead to greater intrinsic motivation for learning science, as they feel that their learning has a greater purpose and meaning than simply achieving good grades (Bryan et al., 2011).

A growing body of research has also demonstrated the positive correlation between science self-concept and instrumental motivation to learn science (Jansen et al., 2015), suggesting that individuals who have higher science self-concept are more instrumentally motivated to engage in science activities. One of the main reasons for the positive relationship between science self-concept and instrumental motivation to learn science is that individuals with a positive science self-concept tend to view science as important and relevant to their future goals and aspirations (Vedder-Weiss & Fortus, 2012). They may believe that a strong understanding of scientific concepts and principles will lead to better job opportunities, higher salaries, or other external rewards. As a result, they may be more instrumentally motivated to learn science, viewing it as a means to achieve these goals (Vedder-Weiss & Fortus, 2012). Moreover, individuals with a positive science self-concept tend to value achievement and recognition in science. They may seek good grades, awards, or other forms of recognition for their achievements in science activities. This desire for achievement and recognition may lead to greater instrumental motivation for learning science because they see it as a way to achieve these goals (Vedder-Weiss & Fortus, 2012). Further, individuals with a positive science self-concept may be influenced by external factors such as parental or teacher expectations, peer pressure, or cultural norms (Garn & Jolly, 2014; Wang & Neihart, 2015). These external factors may encourage them to pursue science activities even if they do not have a strong intrinsic interest in the subject. This may lead to a stronger instrumental motivation for learning science, as they see it as a way to meet external expectations or conform to social norms (Garn & Jolly, 2014).

A small but growing body of research has also documented that intrinsic motivation for learning science is positively correlated with science achievement (Areepattamannil et al., 2011), suggesting that individuals who are more intrinsically motivated to learn science tend to achieve greater success in science. Individuals who possess intrinsic motivation for science tend to show greater commitment and persistence in their pursuit of scientific knowledge (Lavigne et al., 2007). They are more likely to proactively seek challenging tasks, engage with new ideas, and willingly take calculated risks in their learning (Ryan & Deci, 2017). These characteristics facilitate deeper understanding and mastery of scientific principles, leading to higher levels of achievement. People who are intrinsically motivated to learn science also tend to exhibit a greater sense of competence and confidence in their ability to understand and internalize scientific concepts (Lavigne et al., 2007). They are more likely to believe that they can overcome science obstacles and accomplish science tasks, which strengthens their self-determination and autonomy

(Lavigne et al., 2007). This increased sense of control over their learning can promote intrinsic motivation, as they are more motivated to pursue their interests and goals (Ryan & Deci, 2017, 2020). In addition, intrinsic motivation to learn science can also lead to greater perseverance and resilience in the face of adversity (Ainley et al., 2002). Individuals who are intrinsically motivated to learn science are more inclined to seek additional resources and support when faced with obstacles (Taylor et al., 2014). They also have a greater ability to adapt their learning techniques to their individual needs and preferences (Ainley et al., 2002). This adaptability and resilience are important factors for success in science activities and can improve performance. Finally, intrinsic motivation to learn science can also result in higher levels of interest and enjoyment in the subject matter (Areepattamannil et al., 2011). Those who are intrinsically motivated to learn science view it as a fascinating and meaningful pursuit. As a result, they are more engaged and motivated to learn about science, which may ultimately lead to greater success in science activities and better performance (Areepattamannil et al., 2011).

While there is a positive relationship between instrumental motivation to learn science and science achievement (Yu, 2012), research has also found that this relationship is either relatively weak or not significant compared to other motivational factors in certain contexts (Huang et al., 2021; Lau & Ho, 2022; Lee et al., 2016). The weak relationship between instrumental motivation and science achievement can be attributed to several factors. One of the main reasons for the weak or nonsignificant relationship is that instrumental motivation for learning science is primarily focused on obtaining external rewards or avoiding negative consequences (Lee et al., 2016). While this may lead to short-term performance gains, it may not necessarily lead to long-term success in science activities. Individuals who are primarily motivated by external rewards are less likely to adopt deep learning strategies or develop a genuine interest and passion for science (Kwarikunda et al., 2021). Moreover, instrumental motivation for learning science could be influenced by external circumstances, such as parental or teacher expectations, peer pressure, or cultural customs (Garn & Jolly, 2014; Wang & Neihart, 2015). These environmental factors might encourage students to engage in science activities even if they have no innate interest in the subject. As a result, the relationship between instrumental motivation and science achievement may be weak because students may not be fully engaged or invested in their learning. Furthermore, instrumental motivation may not be sufficient to sustain long-term interest and engagement in science activities (Covington & Müeller, 2001). Individuals who are primarily motivated by external rewards may lose interest once they have achieved desired outcomes or if the rewards are not sufficient to sustain their interest. This can lead to a decline in performance over time, even if the initial successes were achieved through instrumental motivation (Ryan & Deci, 2020).

In summary, a review of existing research on the relationships between science self-concept, intrinsic and instrumental motivation, and science achievement leads to the conclusion that individuals with higher science self-concept tend to be more motivated to engage in science activities and have positive attitudes toward science, leading to greater success in science. Moreover, intrinsic motivation for learning science has been consistently shown to correlate positively with science achievement, leading to greater engagement, persistence, and interest in science. Although a positive correlation between instrumental motivation and science achievement has also been found, this correlation is relatively weak compared to other motivational factors and may not be sufficient to sustain long-term interest and engagement in science activities. Therefore, balancing intrinsic and instrumental motivation and fostering a genuine interest and passion for science may be critical to promoting sustained engagement and success in science.

The present study

Given the poor performance of Emirati early adolescents on international standardized science assessments, the purpose of the present study was to examine the relationship between motivational beliefs in science (i.e., science self-concept, intrinsic motivation to learn science, and instrumental motivation to learn science) and science achievement among Emirati early adolescents. Furthermore, the study aimed to investigate the mediating role of both intrinsic and instrumental motivation to learn science in the relationship between science self-concept and science achievement. The following research questions served the purpose of the study:

1. How well does science self-concept predict science achievement in Emirati early adolescents?
2. How well does science self-concept predict intrinsic and instrumental motivation to learn science in Emirati early adolescents?
3. How well do intrinsic and instrumental motivation to learn science predict science achievement in Emirati early adolescents?
4. To what extent do intrinsic and instrumental motivation to learn science mediate the relationship between science self-concept and science achievement in Emirati early adolescents?

While previous research has examined the relationship between motivational beliefs in science and science achievement in other contexts, there is a lack of research on Emirati early adolescents. A study that examines the relationship between motivational beliefs in science and science achievement among Emirati adolescents will be of great benefit. First, by examining the role of science motivational beliefs, such as science self-concept, intrinsic motivation to learn science, and instrumental motivation to learn science, the study can provide insight into the factors that influence science achievement among Emirati early adolescents. This knowledge can help educators and policymakers develop targeted interventions to improve science achievement among this population. Second, the study can help raise awareness of the importance of motivational beliefs in science in predicting science achievement. By showing that science self-concept, intrinsic motivation, and instrumental motivation are all positively related to science achievement, the study can help prioritize the promotion of positive motivational beliefs in science education. Third, by identifying the factors that contribute to science achievement, the study can help improve science achievement and engagement among Emirati early adolescents. This can have important implications for their academic and career success in science, as well as for the advancement of science and technology in the UAE and beyond. Fourth, the study's findings can inform science education policy and practice in the UAE and beyond. By identifying the mediating role of intrinsic and instrumental motivation to learn science in the relationship between science self-concept and science achievement, the study can provide insights into effective strategies for promoting positive science motivational beliefs and improving science achievement. Finally, the study can contribute to the existing literature on science education and motivation by providing new insights into the complex relationship between science motivational beliefs and science achievement. This can help advance the field and inform future research in this area.

Methods

Data

The data for the study were obtained from the TIMSS 2019 eighth grade database. TIMSS is a large-scale international survey that measures the performance of fourth and eighth-grade students in mathematics and science. TIMSS is designed to provide a comprehensive and reliable picture of student performance in these subjects and to enable cross-national comparisons. The TIMSS assessment is administered every four years and organized by the International Association for the Evaluation of Educational Achievement (IEA). The TIMSS 2019 fourth and eighth-grade assessments were administered in 58 and 39 countries, respectively, including the United Arab Emirates (Mullis et al., 2020a, b). A total of 7,915 Emirati early adolescents ($Mean_{age}$ = 13.61 years, SD=0.53) participated in TIMSS 2019 assessment.

Measures

Science self-concept

This scale was based on students' responses to eight items that assessed their perceptions of their science skills and attributes (e.g., "I learn things quickly in science"). Students were asked to rate their level of agreement with each statement on a 4-point Likert scale, with response options ranging from "agree a lot" to "disagree a lot."

Intrinsic motivation to learn science

This scale was based on students' responses to nine items designed to measure their level of intrinsic motivation to learn science (e.g., "I enjoy learning science"). Students were asked to rate their level of agreement with each statement using a 4-point Likert scale, with response options ranging from "agree a lot" to "disagree a lot."

Instrumental motivation to learn science

This scale was based on students' responses to nine items that assessed different aspects of their values related to learning science (e.g., "I need to do well in science to get the job I want"). Students were asked to rate their level of agreement with each statement using a 4-point Likert scale, with response options ranging from "agree a lot" to "disagree a lot."

Science achievement

The TIMSS 2019 eighth grade science assessment consisted of 220 items. The science assessment included four different science domains: biology, chemistry, physics, and Earth science, each of which accounted for a different percentage of the assessment. Most of the questions in the TIMSS 2019 science assessment aimed to assess students' ability to apply and reason scientifically, and there was an inquiry strand that ran through all four content areas (Mullis et al., 2020a, b). TIMSS 2019 used five plausible values to estimate students' proficiency in science (Martin et al., 2020). Plausible values are multiple imputations of the unobservable true proficiency scores for each student (Wu, 2005). To obtain more accurate and reliable parameter estimates and the corresponding standard errors, all five plausible values were used in the current study.

The covariates in the study were gender (1=female, 0=male) and family socioeconomic status (SES). Obtaining information on the socioeconomic status of participants in large-scale studies is a difficult task. The TIMSS 2019 home educational resources scale is considered a proxy for measuring family SES. This scale includes items such as the number of books in the home, the number of home study supports, and parents' level of education that have been shown to be associated with SES (Martin et al., 2020). While the home educational resources scale is not a direct measure of family SES, it can be used as a reasonable indicator of the socioeconomic background of students participating in large-scale assessments such as TIMSS 2019.

Data analytic strategy

In this study, path analysis was used to examine the direct and indirect effects of motivational beliefs in science on science achievement. There are several reasons why path analysis is a useful method for examining relationships among variables (Foster et al., 2006). First, when a study involves multiple predictor variables that are hypothesized to influence an outcome variable, it can be difficult to determine the unique contributions of each variable using traditional regression analysis. Path analysis allows researchers to estimate the direct and indirect effects of each predictor variable on the outcome variable, while controlling for the other variables in the model. Second, path analysis can be used to model complex relationships between variables, including curvilinear or nonlinear relationships, and interactions between variables. This can be particularly useful when studying complex psychological constructs or systems. Third, path analysis is often used to test mediation models, in which an intervening variable (mediator) is hypothesized to explain the relationship between a predictor variable and an outcome variable. Mediation analysis allows researchers to determine the extent to which the relationship between the predictor variable and the outcome variable is explained by the mediator. Fourth, path analysis provides a way to test specific hypotheses about the relationships between variables, and to estimate the strength and direction of those relationships. This can help confirm or refute theoretical predictions and generate new hypotheses for future research. Finally, path analysis provides several fit indices that can be used to assess how well the model fits the data. This allows researchers to determine if the model is a good representation of the underlying relationships between variables and to refine the model if necessary.

In the present study, a path model was created that specified the hypothesized relationships among the variables. The hypothesized model is shown in Fig. 1. In this model, science self-concept, intrinsic motivation to learn science, and instrumental motivation to learn science are treated as predictor variables, and science achievement is treated as an outcome variable. The model also includes paths representing the direct effects of each predictor variable on science achievement and paths representing the indirect effects of science self-concept on science achievement through intrinsic motivation to learn science and through instrumental motivation to learn science. The model was

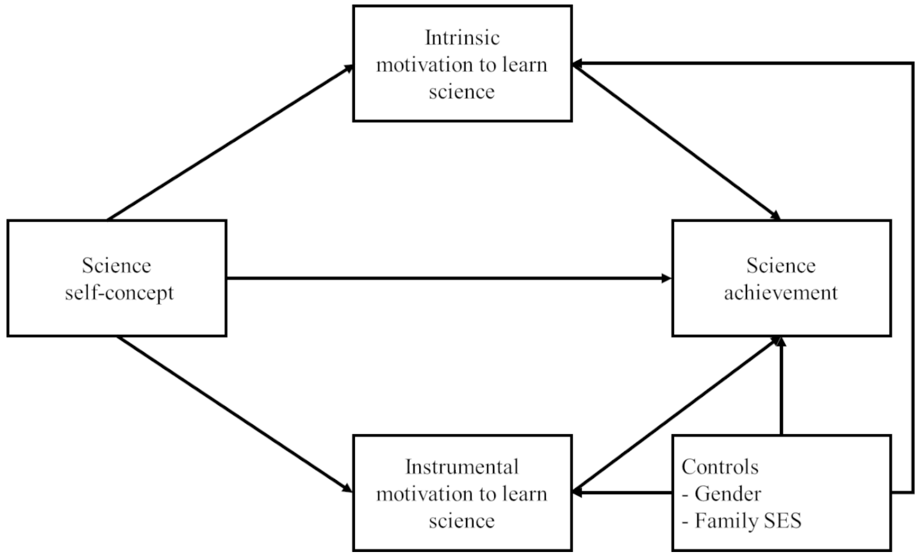

Fig. 1 The hypothesized path model

tested using regression analysis to estimate the strength and significance of the direct and indirect effects of the predictor variables on science achievement. Bootstrapping, a resampling technique, was used to test the significance of the mediating effects of intrinsic and instrumental motivation to learn science on the relationship between science self-concept and science achievement. In this study, the analysis was conducted using 10,000 bootstrapped samples. A general rule of thumb is to use at least 1000 resampled datasets for bootstrapping, although some researchers recommend using 5000 or more resampled datasets to obtain more stable and accurate estimates of the indirect effects (Hayes, 2022). Using a larger number of resampled datasets can increase the accuracy and precision of the estimates, but also increases the computational time required to analyze the data.

The traditional product-of-coefficients method estimates the indirect effect of a predictor variable on an outcome variable through an intervening variable by multiplying the coefficients for the predictor variable and the intervening variable in a regression model (Hayes, 2022). However, the product-of-coefficients method assumes that the sampling distribution of the indirect effect is normally distributed. Bootstrapping is used to overcome this limitation by estimating the distribution of the indirect effect through resampling. Bootstrapping involves randomly resampling the data with replacement from the original sample and re-estimating the path model for each resampled dataset (Hayes, 2022). This produces a distribution of indirect effects that can be used to estimate the standard error, confidence intervals, and *p*-value of the indirect effect. Bootstrapping can also provide an estimate of the bias-corrected indirect effect, which adjusts for potential bias in the estimate due to non-normality or nonlinearity of the data. By estimating the sampling distribution of the indirect effect through resampling, bootstrapping provides a more robust test of the significance of the mediating effects than the traditional product-of-coefficients method (Hayes, 2022).

If the confidence interval of the indirect effect does not include zero, then the indirect effect is considered statistically significant (Hayes, 2022). This suggests that the mediator variables significantly mediate the relationship between the predictor variable and the outcome variable. If the confidence interval includes zero, then the indirect effect is not statistically significant (Hayes, 2022), suggesting that the mediator variable do not significantly mediate the relationship between the predictor variable and the outcome variable. The fit of the hypothesized path model was assessed using various goodness-of-fit indices (Hu & Bentler, 1999): root mean square error of approximation (RMSEA, ≤ 0.06), comparative fit index (CFI, ≥ 0.95), Tucker-Lewis index (TLI, ≥ 0.95), and standardized root mean square residual (SRMR, ≤ 0.08). The statistical software package, Mplus Version 8.8 (Muthén & Muthén, 2022a, b), was used to conduct the data analyses.

Results

The descriptive statistics, bivariate correlations, and reliability coefficients of the study variables are given in Table 1. Science self-concept has a moderate positive correlation with science achievement ($r = .31$, $p < .001$). Intrinsic motivation to learn science also has a moderate positive correlation with science achievement ($r = .27$, $p < .001$). However, instrumental motivation to learn science has a weak positive correlation with science achievement ($r = .17$, $p < .001$). The table also indicates that science self-concept has a positive and statistically significant correlation with both intrinsic motivation to learn science ($r = .69$, $p < .001$) and with instrumental motivation to learn science ($r = .47$, $p < .001$).

We assessed the fit of the hypothesized path model using several fit indices. The RMSEA was 0.039, indicating a good fit of the model. The CFI and TLI were 0.993 and 0.989, respectively, both indicating a good fit of the model. Finally, the SRMR was 0.049, also indicating a good fit of the model. Taken together, these results indicate that the hypothesized path model had a good fit to the data. Path analysis (see Fig. 2) revealed that science self-concept was a significant positive predictor of science achievement (B = 10.841, $\beta = 0.207$, $p < .001$, 95% CI [9.307, 12.376]) and intrinsic motivation to learn science (B = 0.748, $\beta = 0.692$, $p < .001$, 95% CI [0.731, 0.766]) and instrumental motivation to learn science (B = 0.056, $\beta = 0.055$, $p < .001$, 95% CI [0.031, 0.081]). However, only intrinsic motivation to learn science was a significant positive predictor of science achievement (B = 3.679, $\beta = 0.076$, $p < .001$, 95% CI [2.062, 5.297]), whereas instrumental motivation to learn science was not a significant predictor of science achievement (B = −0.606, $\beta = -0.012$, $p = .392$, 95% CI [-1.994, 0.783]).

Bootstrapping analysis revealed that intrinsic motivation to learn science significantly mediated the relationship between science self-concept and science achievement, with an indirect effect of 0.052 (95% CI [0.030, 0.075]). However, instrumental motivation to

Table 1 Descriptive statistics, bivariate correlations, and reliability coefficients

	1	2	3	4	5	6
1. Science achievement	—					
2. Science self-concept	0.31**	—				
3. Intrinsic motivation to learn science	0.27**	0.69**	—			
4. Instrumental motivation to learn science	0.17**	0.47**	0.64**	—		
5. Family socioeconomic status	0.21**	0.15**	0.13**	0.13**	—	
6. Gender	0.15**	0.10**	0.09**	0.04**	0.01*	—
M	414.08	10.15	10.00	10.45	10.29	0.50
SD	103.52	1.91	2.08	2.01	1.45	0.50
α		0.81	0.90	0.92		

*$p < .05$. *$p < .001$.

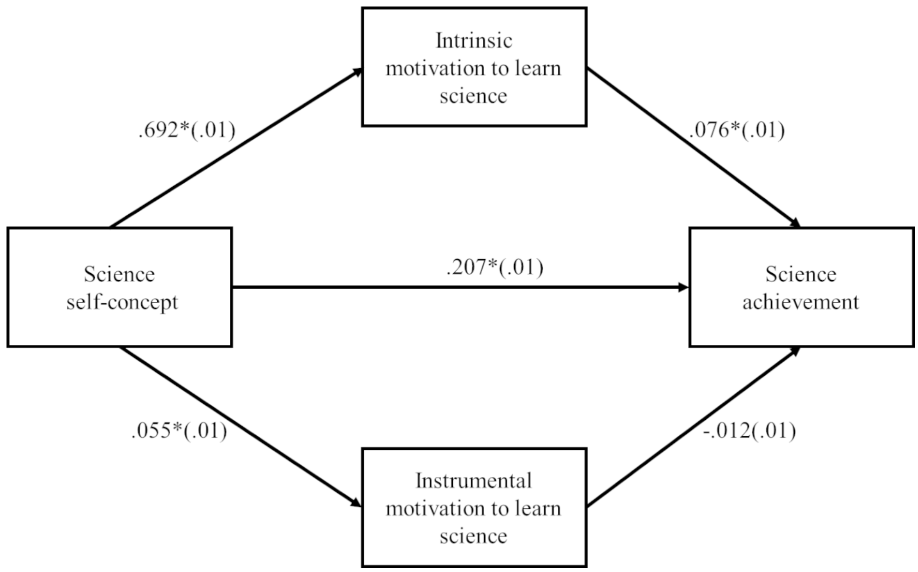

Fig. 2 Results of path analysis. Standard errors are in parentheses. The control variables were included in the analysis. For the sake of clarity, they are not included in the figure. *$p < .001$

learn science did not significantly mediate this relationship, with an indirect effect of only −0.001 (95% CI [-0.002, 0.001]).

Discussion

The present study, employing a self-determination theory framework, investigated how science motivational beliefs, such as science self-concept, intrinsic motivation to learn science, and instrumental motivation to learn science, are related to science achievement among Emirati early adolescents. In addition, the study aimed to investigate the mediating role of intrinsic and instrumental motivation to learn science in the relationship between science self-concept and science achievement.

RQ1. How well does science self-concept predict science achievement in Emirati early adolescents?

Consistent with the findings of previous research (Areepattamannil et al., 2011), the results of the present study indicate that there is a positive relationship between science self-concept and science achievement among Emirati early adolescents. In other words, students who have higher science self-concept tend to perform better on science assessments than those who have lower science self-concept. This suggests that a positive belief in one's abilities and identity in science is associated with better performance in science.

There may be several reasons for this association. First, a positive science self-concept may increase motivation and engagement in science activities. Students who have a positive science self-concept are more likely to perceive science as important and relevant to their lives, which increases their interest and motivation to learn science. They are also more likely to engage in science activities, such as reading science books or participating in science clubs, which can lead to increased knowledge and skills in science and ultimately better achievement. Second, a positive science self-concept can lead to greater confidence in one's abilities in science. Students who believe they are capable of succeeding in science are more likely to approach science tasks with a positive attitude and persevere when faced with challenges. This can lead to better problem-solving skills, improved scientific reasoning, and ultimately better performance in science. Finally, a positive science self-concept can lead to greater perseverance and resilience in the face of setbacks or failure. Students who have a positive science self-concept are more likely to view failures as opportunities to learn and grow, rather than as evidence of their incompetence. This can lead to a greater willingness to take risks, experiment, and explore, which ultimately leads to better performance in science.

However, the relationship between science self-concept and science achievement is not unidirectional, but bidirectional (Marsh & Craven, 2006; Marsh & Martin, 2011). The two factors influence and reinforce each other in a complex interplay, creating a reciprocal feedback loop. Success in science can strengthen science self-concept (Bong & Skaalvik, 2003; Marsh, 1990). When students perform well in science, they receive positive reinforcement from teachers, peers, and themselves, which further strengthens their belief in their abilities (Schunk, 1991; Zimmerman et al., 1992). In this way, science achievement serves as a source of validation and confirmation of students' self-concept and fosters a sense of competence and efficacy in science (Bandura, 1997; Pintrich & De Groot, 1990). This bidirectional relationship can create positive or negative cycles of reinforcement. For example, a positive feedback loop occurs when a strong science self-concept leads to better performance, which in turn reinforces and further strengthens the self-concept, contributing to continued success and growth in science (Marsh & Craven, 2006). On the other hand, a negative feedback loop can occur when a weak science self-concept leads to poorer performance, which in turn further undermines self-concept, leading to a decline in science achievement and continued erosion of the self-concept (Marsh & Martin, 2011). Understanding this bidirectional relationship is critical for educators and researchers because it underscores the importance of considering both science self-concept and achievement when developing interventions and educational strategies to improve student learning outcomes in science.

RQ 2. How well does science self-concept predict intrinsic and instrumental motivation to learn science in Emirati early adolescents?

Consistent with the findings of previous studies (Jansen et al., 2015), the results of the current study also suggest that there is a positive relationship between science self-concept and intrinsic motivation to learn science. In other words, students who have higher science self-concept tend to have higher intrinsic and instrumental motivation to learn science than students who have lower science self-concept. The positive relationship between science self-concept and intrinsic motivation to learn science can be explained by SDT. According to SDT, intrinsic motivation is driven by the need for autonomy, competence, and relatedness (Ryan & Deci, 2017). When students have a positive self-concept in science, they feel more competent in the subject and have a greater sense of control over their learning. This, in turn, leads to a greater sense of autonomy in learning, as they are more likely to engage in science activities for the enjoyment of the subject itself rather than for external rewards or recognition.

The results of the present study also suggest that there is a positive but weak relationship between science self-concept and instrumental motivation to learn science. One possible reason for the weak positive relationship could be that instrumental motivation is related to external factors, such as rewards and recognition rather than intrinsic factors, such as personal interest and enjoyment of the activity (Ryan & Deci, 2017, 2020). While a positive science self-concept may provide a sense of competence and belonging that motivates students to seek opportunities for recognition, these external factors may not be as strongly related to intrinsic factors, such as personal interest and enjoyment, that drive intrinsic motivation. Another possible reason for the weak positive association could be related to individual differences in motivation and goal orientation. For example, some students might be more motivated by external rewards and recognition, whereas others might be more motivated by personal interest and enjoyment. In such cases, a positive science self-concept might have a stronger relationship with intrinsic motivation than with instrumental motivation.

RQ 3. How well do intrinsic and instrumental motivation to learn science predict science achievement in Emirati early adolescents?

In line with the findings of prior studies (Areepattamannil et al., 2011), the results of the present study also provide evidence for a positive relationship between intrinsic motivation to learn science and science achievement. In other words, students who report higher levels of intrinsic motivation for learning science tend to perform better on science assessments than their peers who report lower levels of intrinsic motivation for learning science. Students who have higher levels of intrinsic motivation for learning science tend to be more curious and enthusiastic about the subject matter, which can lead to a deeper understanding of concepts and principles. This, in turn, can lead to higher scores on assessments that require the application of scientific knowledge and skills. Furthermore, students who are intrinsically motivated to learn science are more likely to engage with the subject matter and put forth the effort necessary to succeed. They may be more willing to learn, ask questions, and seek help when needed, which can lead to better performance on science assessments.

Despite the positive relationship found in the present study between science self-concept, intrinsic motivation to learn science, and science achievement, instrumental motivation to learn science was not significantly related to science achievement. Previous research has also documented similar findings (Huang et al., 2021; Lau & Ho, 2022; Lee et al., 2016). This result suggests that motivation to learn science due to extrinsic rewards or incentives, such as grades or job opportunities, may not be as influential as intrinsic motivation to learn science in achieving better outcomes in science activities or subjects. While instrumental motivation to learn science may drive some students to learn and work hard, it may not be sufficient to sustain their interest or engagement in science, especially when faced with challenges or setbacks (Covington & Müeller, 2001). Moreover, students who are motivated solely by external factors may be more likely to engage in surface-level learning strategies rather than actively seeking to understand and apply the concepts they are studying (Kwarikunda et al., 2021).

RQ 4. To what extent do intrinsic and instrumental motivation to learn science mediate the relationship between science self-concept and science achievement in Emirati early adolescents?

Finally, the present study found that intrinsic motivation to learn science, rather than instrumental motivation to learn science, mediated the relationship between science self-concept and science achievement. This implies that the positive relationship between science self-concept and science achievement can be partially explained by a student's level of intrinsic motivation to learn science, but not by the level of instrumental motivation to learn science. Students who are intrinsically motivated to learn science are more likely to engage in science activities, persevere in the face of challenges, and actively seek opportunities to learn more about science (Taylor et al., 2014). This type of motivation is closely related to a student's sense of autonomy, competence, and relatedness, which are important components of SDT (Ryan & Deci, 2017). In contrast, students motivated by instrumental factors may be less interested in science itself and more focused on achieving a desired outcome, such as a good grade or a future career. This type of motivation is less likely to lead to deep engagement and curiosity in science activities (Kwarikunda et al., 2021), and is not as strongly with a student's sense of autonomy, competence, and relatedness (Ryan & Deci, 2017). Therefore, it is not surprising that intrinsic motivation to learn science mediates the relationship between science self-concept and science achievement, whereas instrumental motivation to learn science does not.

Implications of the findings for practice and policy

The results of the present study have important implications for parents, teachers, and policymakers interested in promoting science achievement in young Emirati students. Fostering science self-concept is an important aspect of promoting science achievement in students. There are several ways that parents and teachers can help students develop a positive science self-concept. Crucially, they can give them the opportunity to succeed in science activities. Parents and teachers can create a positive learning environment by providing opportunities for students to engage in hands-on science activities that are appropriate for their age and skill level. By offering activities that are challenging but doable, students can have a sense of accomplishment and gain confidence in their ability to learn and succeed in science. It is also important to emphasize the relevance of science to students' lives. Parents and teachers can help students understand the importance of science to their daily lives and how it can be used to solve real-world problems. By showing students how science can be applied in real-world situations, they can see the value and importance of science, which in turn can foster a positive science self-concept. Finally, positive feedback that reinforces students' sense of competence and identity in science is critical. Parents and teachers can praise and encourage students when they understand science concepts well, perform well in science activities, or show interest in science. This positive feedback can strengthen students' sense of competence and identity in science, which can lead to increased motivation and engagement in science activities.

Fostering intrinsic motivation to learn science is also an important aspect of promoting student science achievement. There are several ways that parents and teachers can help students develop and maintain their intrinsic motivation to learn science. First, it is important to provide choice and autonomy. Parents and teachers can give students the freedom to choose what they want to learn and how they want to learn it. This approach can help students feel responsible for their learning, which can foster their intrinsic motivation to learn science. Second, it is important to emphasize curiosity and enjoyment of science content. Parents and teachers can emphasize the fun and interesting aspects of science content and activities, which can stimulate students' natural curiosity and lead to greater intrinsic motivation to learn. When science learning is fun, students are more likely to be engaged and motivated to learn more. Third, it is important to provide opportunities for active engagement in science activities. Parents and teachers can provide opportunities for students to explore science content through hands-on, active activities. This approach can help students develop a deeper understanding of scientific concepts and processes and can lead to greater intrinsic motivation to learn science.

Furthermore, favoring intrinsic motivation over instrumental motivation is a critical aspect of promoting long-term engagement and success in science learning. Parents and teachers can play an important role in encouraging students to focus on intrinsic motivation for learning science. If they emphasize the importance and relevance of science to students' lives, this can help students develop an enduring interest and commitment to science. Parents and teachers can use examples to show how science relates to real-world issues and problems and how science knowledge and skills can be applied in students' lives. This approach can help students appreciate the value of science more and develop stronger intrinsic motivation to learn. In addition, focusing on the fun and satisfaction that science learning provides, rather than just grades or external rewards, can help students develop stronger intrinsic motivation for science learning. Parents and teachers can praise students for their efforts and progress and encourage them to take risks and explore scientific concepts and ideas. This approach can help students develop a love of science learning that is not motivated solely by external rewards or pressure. Allowing students to pursue their own interests and passions in science can foster intrinsic motivation to learn. Parents and teachers can give students the opportunity to choose research or inquiry topics that match their interests and passions and encourage them to investigate these topics in depth. This approach can help students develop a sense of autonomy and ownership over their learning, which can foster stronger intrinsic motivation to learn science.

Opportunities for active engagement with science can also improve students' motivation to learn science and their achievement in science. Parents and teachers can encourage students to engage with science by providing access to resources such as science books, documentaries, and podcasts that capture students' attention and spark their interest in science. Moreover, extracurricular science activities, such as science clubs or science fairs, can provide opportunities for students to engage in collaborative and hands-on science experiences that help them develop a deeper understanding of scientific concepts and applications. Parents and teachers can also encourage students to design and conduct their own experiments or investigations that allow them to develop problem-solving skills, scientific reasoning, and critical thinking. By providing students with opportunities to actively engage in science, parents and teachers can help them develop a lifelong interest in science and enter science-related careers.

The results of this study also have important implications for science education policy. Policymakers can consider strategies that promote positive science self-concept in students, such as providing resources and opportunities for success in science activities. Policymakers can also support initiatives to increase the number of qualified science teachers in schools, as teachers play a critical role in promoting students' science self-concept and motivation. In addition, policy can prioritize intrinsic motivation to learn science over instrumental motivation. This can include developing science curricula that encourage curiosity and enjoyment of science content rather than focusing solely on grades or external rewards. Further, policymakers can encourage the use of teaching methods that promote active engagement with science, such as inquiry-based learning and project-based learning, which can increase students' intrinsic motivation to learn science. Policymakers can consider providing resources and support for science-related extracurricular activities, such as science clubs or science fairs, that provide opportunities for students to engage in collaborative and hands-on science experiences that enhance their science self-concept and motivation. Policymakers can also prioritize the development of science education programs that are accessible to all students, regardless of socioeconomic background, to ensure that all students have an equal opportunity to develop their science self-concept and succeed in science.

Limitations of the study and directions for future research

It is important to consider the following limitations when interpreting the results of the study. First, the TIMSS context questionnaire data are based on student self-reports. Self-reported data may be subject to various biases, including social desirability bias, recall bias, and response bias, which may affect the accuracy and reliability of the data (Gonyea, 2005). Participants may not always accurately reflect their experiences or may not fully understand the questions, leading to misinterpretation or inaccurate responses. Therefore, the validity and reliability of the results may be limited by the self-report nature of the data. To minimize these limitations, future research could use multiple methods to collect data, including direct observations or objective measures in addition to self-reports. Second, this study used a cross-sectional design, which limits the ability to demonstrate causality. Future research could use longitudinal designs to examine the directionality of the relationship between science self-concept, motivation, and achievement and the potential mechanisms underlying these relationships over time. Third, the study focused only on two types of motivation for learning science (intrinsic and instrumental motivation) and did not consider other factors that may influence science achievement, such as interest, curiosity, or parental involvement. Future research could examine the role of these factors in the relationship between science self-concept and science achievement. Fourth, the TIMSS samples are selected using a rigorous and complex sampling design designed to ensure representativeness of the population of interest within a given country or region. Although the rigorous sampling procedures and adjudication process aim to minimize potential bias, it is important to interpret the results with caution because no sampling method is completely immune to limitations. For example, some schools or students may choose not to participate in the study, which could lead to nonresponse bias, or there may be cultural differences in how survey items are interpreted. Despite these potential biases, the robustness of the TIMSS methodology provides a high degree of confidence in the overall representativeness and quality of the samples. Finally, the TIMSS assessments measure a significant portion of the skills and knowledge students acquire in science. The TIMSS science assessment evaluates knowledge in four main areas: biology, chemistry, physics, and Earth science, which are the core content areas of interest to TIMSS populations. Although these areas cover important aspects of science education, it is important to recognize that there may be additional, relevant areas that are not directly covered by the TIMSS. This consideration underscores the importance of using multiple measurement tools to provide a more comprehensive view of student science learning and to ensure that the full range of science knowledge and skills students need is assessed and addressed.

In conclusion, the present study highlights the importance of science self-concept and motivation in science education, especially for early adolescents in the UAE. The results indicate that students who have a positive science self-concept and intrinsic motivation to learn science tend to perform better on science assessments. Furthermore, the study demonstrates that intrinsic motivation to learn science plays a mediating role in the relationship between science self-concept and science achievement. These findings have important implications for parents, teachers, and policymakers. They underscore the need to foster students' science self-concept, to support intrinsic motivation to learn science, and to prioritize intrinsic over instrumental motivation in science education. Although this study provides valuable insights into the relationship between science self-concept, motivation, and achievement, there are limitations that need to be considered, such as the cross-sectional nature of the data and the self-reported measures that were used. Future research can build on these findings by conducting longitudinal studies, using multiple measures of motivation, and examining the role of contextual factors in shaping science self-concept and motivation. In summary, this study contributes to a growing body of research that highlights the importance of science self-concept and motivation in science education and underscores the need for further efforts to promote student engagement and achievement in science.

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SA conceptualized and conducted the statistical analyses, and drafted the manuscript. OAK, NA, RAH, and HK provided critical feedback and comments on the analysis and manuscript at various stages. All authors read and approved the final manuscript.

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Data availability
The datasets supporting the conclusions of this article are openly accessible and can be downloaded as public use files from the IEA's website: https://www.iea.nl/data-tools/repository/reds.

Declarations

Competing interests
The authors declare that they have no competing interests.

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