

Motivational pathways from autonomy-supportive learning climates to science-learning self-efficacy among Cambodian high school students

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Article info

Article history

Received: November 06, 2024

Revised: March 11, 2026

Accepted: May 29, 2026

Keywords

Autonomy

Cambodia

Learning climate

Motivational factor

Science-learning self-efficacy

Article type

Research article

Abstract

The purpose of this study was to examine the relationships among motivational factors, science self-efficacy, and autonomy-supportive climates in science education among Cambodian high school students. A correlational research design was employed to investigate the associations among these variables. The study involved 685 high school students, with the sample size determined using a rule-of-thumb approach for quantitative research. The findings revealed that autonomy-supportive climates significantly predicted both motivational factors and science self-efficacy in science education. Specifically, the self-decision provision predicted self-efficacy in conceptual understanding, whereas the acceptance provision significantly predicted self-efficacy in practical work. Furthermore, among the motivational factors, attainment value emerged as a strong predictor of science achievement, mediated by its association with science self-efficacy. Based on these findings, the study suggests that science teachers should create supportive learning environments that encourage students' autonomy, acceptance, and participation in science-related tasks in order to strengthen their self-efficacy, curiosity, perceived value, and sense of belonging in science education. In addition, educational stakeholders should promote inquiry-based and project-centered learning approaches within the curriculum. Future research should further explore these relationships across different educational contexts and learner populations.

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1. Introduction

With modern education, the scientific curriculum is considered the most effective and promotive sector. Science education becomes a backbone in reshaping how people address their misperceptions of global changes, rather than confusingly understanding the natural world, fostering critical thinking and problem-solving competencies, and informing decision-making through logical reasoning in the science world (Bybee, 2013). Significantly, the scientific implementation has assisted in managing the ongoing situation, allowing us to understand the relationship between human needs and natural processes (Cheng & Li, 2024). To enhance the effectiveness of science education, inquiry, experimentation, and evidence-based reasoning are essential for preparing students for both academic and real-life contexts

(Lederman & Lederman, 2019). In this case, students who were allowed to study science were expected to perceive scientific concepts that linked to well-practiced real-world situations.

Furthermore, the decline in interest in science-related skills has affected a greater number of learners (OECD, 2018). It is alarming that an increasing number of students aged 15 to 22 are switching from science to non-science fields (Freeman et al., 2019). Among Cambodian students in upper secondary school who were required to choose between the social science and science tracks, 62% opted for the social science track in 2020, an increase from 2014. The choice of the science track, on the other hand, fell sharply from 96% in 2014 to 34% in 2020. These trends contradict the government's efforts to enhance the workforce, which align with global trends (Pov et al., 2024).

As revealed above, adult learners' beliefs about choosing science-related skills pose a major barrier to scientific progress. Nevertheless, the most intriguing belief identified in the science-track-related course is science-learning self-efficacy (Britner & Pajares, 2006; Uzuntiryaki & Çapa Aydın, 2009). As Britner and Pajares (2006) and Uzuntiryaki and Çapa Aydın (2009) noted, science-learning self-efficacy is the most powerful driver of decision-making through self-confidence when learners' interests align with their intentions, thereby enhancing science content knowledge. In addition, these are related to Asian curricula that admit students to study science-related skills.

Not only this, academic motivations such as sense of belonging (Aelenei et al., 2020), attainment value (Eccles & Wigfield, 2002), and science-learning curiosity (Litman, 2005) also primarily contribute to a human's belief. To deepen self-beliefs that depend on human psychological states, such as those academic motivations (Aelenei et al., 2020; Bandura et al., 1996; Goodenow, 1993). In this notice, scientific belief is more likely to be fostered through a sense of belonging, attainment value, and curiosity about science learning.

Moreover, as argued by Banilower et al. (2010), effective science instruction is essential for accelerating scientific understanding in real-world practice, as societies become increasingly reliant on scientific advancement. Through the study of biology, chemistry, physics, and earth sciences, learners not only acquired content knowledge but also developed scientific literacy, a key competency for promoting active citizenship in the 21st century (Ward, 2018). In this sense, teacher instruction behind learning climates plays a vital role in predicting academic outcomes.

Therefore, science education is significant in contemporary education because it helps individuals deepen their knowledge of the natural world, develop critical thinking and problem-solving competencies, and improve decision-making. It manages ongoing situations to understand the relationship between human needs and natural products. Effective science learning climates accelerate science understanding and promote scientific literacy, which is essential for active citizenship in the 21st century. Inquiry, experimentation, and evidence-based reasoning are essential for preparing students for real-life contexts. Academic motivations such as a sense of belonging, attainment value, and curiosity about science contribute to people's belief in science.

2. Literature reviews

2.1 Science-learning self-efficacy in science education

Science-learning self-efficacy refers to students' beliefs in their ability to complete their academic tasks (Bandura et al., 1999). In the context of science education, science-learning self-efficacy refers to the degree to which learners believe they can understand scientific concepts, ranging from low to high cognitive processes, after adapting these concepts for experimental use, everyday problem-solving related to their livelihoods, and developing scientific communication skills (Lin & Tsai, 2013; Tsai et al., 2011; Wang et al., 2018). In this way, science-learning self-efficacy is divided into two types: cognitive and practical (Wang et al., 2018). As mentioned above, cognitive science-learning self-efficacy pertains to the degree to which science learners are aware of their confidence in perceiving science concepts to understand definitions, laws, and theories (conceptual understanding) and in applying complex cognitive skills (higher-order understanding). In contrast, practical science-learning self-efficacy pertains to the degree to which science learners can use those concepts in laboratory practice (practical work), adapt them in everyday problem-solving (everyday application), and argue with peers in science class (social communication). What is particularly noteworthy is that Wang et al. (2018) found that cognitive science-learning self-efficacy can influence practical science-learning self-efficacy, but the effects differ across contexts. Essentially, there is limited knowledge about how cognitive science-learning self-efficacy predicts practical science-learning self-efficacy in developing countries.

2.2 Motivational factors

To ensure one's belief is interpreted in a positive light, reducing negative moods rather than increasing positive aspects is crucial for internal attitudes, such as an individual's motivational aspects (Bandura & Wessels, 1994). Hence, science-learning self-efficacy does not solely exist to enhance choices related to science skills. As proposed, this study included four contributors: sense of belonging, attainment value, and science-learning curiosity, which were considered motivators in expanding the science interest for general education students.

In the context of science education, a sense of belonging refers to how emotionally secure, valued, and supported students feel (Freeman et al., 2007; Strayhorn, 2018). This includes feeling respected, cared for, and connected to others; trusting their teachers; and feeling motivated to actively engage in science classes as a result of these positive social-emotional conditions (Goodenow, 1993; Lewis et al., 2016). In this scenario, scientific learners consider external motivators to enhance their satisfaction with learning science. Essentially, Aelenei et al. (2020) depicted students with a weak sense of belonging; they reported reduced science-learning self-efficacy when pursuing a given academic choice in STEM and non-STEM fields. Moreover, based on expectancy-value theory, instructional climates promote a sense of belonging; students perceive learning tasks as important (Eccles & Wigfield, 2002). Regarding science-learning curiosity, students' sense of belonging nurtures the development of insightful curiosity in science learning (Amponsah, 2023). However, clear evidence linking a sense of belonging to task value, curiosity, and self-efficacy in science conditions remains limited in simultaneous models (Bandura, 1997).

In terms of attainment value, which is grounded in Expectancy-Value Theory (EVT), it refers to how much students perceive the importance of understanding scientific content, mastering proficiency in science subjects, solving problems rationally, and performing better in scientific academics (Eccles et al., 2005; Eccles & Wigfield, 2002). In this case, scientific learners reflect the internal value they place on learning, thinking, and excelling at science tasks. According to Britner and Pajares (2006), attainment value, a positive emotional state, influences an individual's beliefs by enhancing self-efficacy for performing and learning tasks. As found by Chan et al. (2023), self-efficacy in doing a task was associated with subjective task value.

Moreover, Di Leo et al. (2019) and Rossing and Long (1981) found that science-learning curiosity is linked to perceived value in learning tasks. According to Fraschini and Tao (2023), students become more curious and less nervous as they perceive a higher value. However, little is known about science perspectives and developing citizens.

As defined by Lindholm (2018) and Loewenstein (1994), science-learning curiosity refers to learners' sense of wonder and intrinsic passion for exploring the diverse information available in the world. Kashdan et al. (2009) identified two components of science-learning curiosity: predictable curiosity, which encompasses students' internal willingness to engage in independent learning, to overcome scientific challenges, to reflect on prior experiences, and to seek opportunities to enhance their scientific competencies proactively. In this case, science learners activated personal initiative, a desire to seek new information, and a confident attitude toward lifelong learning (Engel, 2011). Instead, unpredictable curiosity pertains to students' optimistic mindset when facing challenges, their eagerness to explore new experiences, and their intrinsic interest in tackling difficult tasks (Kashdan et al., 2009; Ryan & Deci, 2020). From this approach, science learners define their willingness to learn, their tendency toward risk-taking in knowledge pursuits, and a deeper quest to uncover scientific theories or concepts that emerge from real-world circumstances (Jirout & Klahr, 2012). Previous studies found that risk-taking behaviors, such as curiosity, predicted learning creative self-efficacy in science (Beghetto, 2009). However, little is known empirically about how curiosity predicts self-efficacy in science contexts.

2.3 Autonomy-supportive learning climates

Learning climates refer to the overall supportive offers that facilitate learning by incorporating emotional, social, psychological, and physical factors, which in turn affect students' academic performance (e.g., Deci & Ryan, 2000; Fouts & Myers, 1992; Gabel, 1994; Reyes et al., 2012). Various studies assert that autonomy-supportive learning climates are the most powerful determinants of psychological states (Deci & Ryan, 1985; Ruos et al., 2025; Ryan & Deci, 2000, 2017). In scientific contexts, autonomy-supportive learning climates refer to the extent to which teachers provide students with opportunities to deepen their engagement in decision-making about their learning processes and task choices (Reeve, 2006). Even though students' concepts differ from teachers' perspectives, teachers remain engaged in valuing them (Stefanou et al., 2004).

In addition, teachers encourage students to take ownership of their learning by engaging in activities such as setting goals, engaging in tasks, consulting various information sources, participating in structured educational groups, defining problem-solving strategies, and conducting peer evaluations (Deci & Ryan, 2000). An autonomous climate that promotes acceptance and appreciation of diverse viewpoints enhances learners' innovation in developing new concepts to meet their comprehensive requirements and processes (Beghetto, 2009; Hattie, 2008). By pursuing their expectations, they become active and reflective participants in their educational journey (Hattie, 2008; Niemiec & Ryan, 2009). Consequently, learners value their science-related learning tasks through their engagement, thereby fostering lifelong passions throughout their educational experiences (Ryan & Deci, 2020).

Therefore, autonomy-supportive learning climates such as self-decision and acceptance provisions seem to affect students' sense of belonging, attainment value, curiosity, and self-efficacy by enhancing accelerant agency, appreciating various perspectives, and exploratory characteristics along science circumstances (Patall et al., 2018; Patall & Zambrano, 2019;

Reeve & Cheon, 2021). However, little is known about empirical studies that specifically examine science learning climates, as this design focused solely on those settings.

2.4 The rationales and purposes of the research study

The purpose of this study was to examine the association between motivational factors, science-learning self-efficacy, and autonomy-supportive learning climates in science education. It was designed to address the decline in science-related skills, course engagement, and achievement; reconcile gaps in motivation theories; promote equity in science education; and elucidate the role of sense of belonging, attainment value, and curiosity in self-efficacy-related science conditions. The research confirmed the correlation between autonomy-supportive learning climates and the sense of belonging, attainment value, curiosity, and self-efficacy, thereby establishing a unified model of motivational pathways in scientific research. It also elucidated the practical implications for teacher training, emphasizing the impact of teachers' instructions on learners' psychological well-being and motivation. Most importantly, to equip students with the necessity of science competitions that navigate a rapidly evolving world. By identifying an influence strategy to engage science classrooms, investing in teacher training, and shaping the scalable interventions, the study has the potential to advance theory, practice, and policy. Hence, the researchers proposed the following research questions:

1. What is the relationship between motivational factors, science-learning self-efficacy, and autonomy-supportive learning climates in science education?
2. How is science-learning self-efficacy associated with motivational factors and autonomy-supportive learning climates in science education?

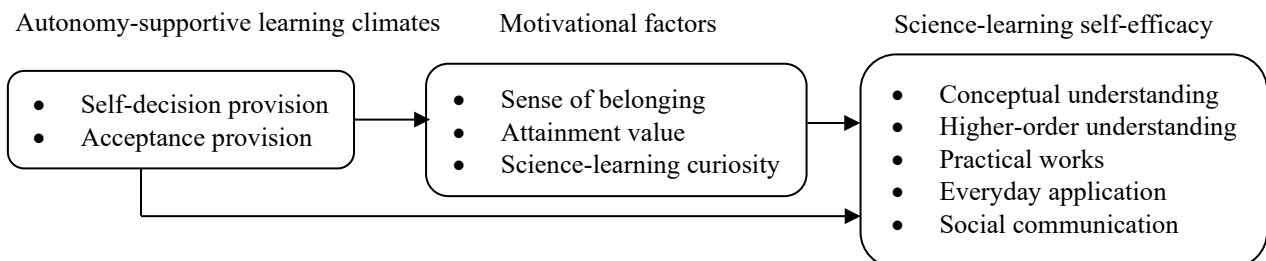


Figure 1. Conceptual framework of the relationship between science-learning self-efficacy, motivational contributors, and autonomy- supportive learning climates in science education

3. Methodology

A correlational research design using convenience sampling was employed in this study. To ensure the validity and reliability of the measurement model, the sample size was set to at least 5 times the number of indicators. Of the 685 high school students who voluntarily participated in this survey, 67.4% were female, and the typical student was a high school senior (78.1%). Of all academic foci, 43.5% were in the social sciences, while 56.1% were in pure science. Schools joined through Non-Project Support (NPS), GEIP, and New Generation School (NGS) fabricated the prevalent informants. Of all applicants, 442 (64.5%) were from Kampong Cham. There was a narrow age range in the sample, with a mean age of 17.55 years (SD = 0.978), ranging from 16 to 20 years (see Table 1).

Table 1. Description of samples within research study (N = 685)

Categories		Frequency	Percent
Gender	Female	462	67.4%
	Male	223	32.6%
Grade	Grade 12 th	535	78.1%
	Grade 11 th	150	21.9%
Skill choice	Social science	298	43.5%
	Pure science	384	56.1%
School types	Non-project support school (NPS)	406	59.3%
	General Education Improvement Project school (GEIP)	163	23.8%
	New Generation School (NGS)	116	16.9%
Provinces	Kampong Cham	442	64.5%
	Prey Veng	126	18.4%
	Svay Rieng	114	16.6%
Age	Mean	17.55	
	SD	0.978	

3.1 Research instrument

In this study, we employed the back-translation technique outlined by Behling and Law (2000). First, we adjusted the original English version. Then, we translated these items into Khmer. To enhance validity and reliability, we back-translated the Khmer version into English twice. To ensure the accuracy of the measurement tools, we consulted two bilingual teachers and two experts to evaluate the content validity of the operationalized definitions and items. Additionally, we gathered ratings from 60 high school students to assess face validity before utilizing the instrument with the overall research sample, employing a five-point Likert scale to measure responses (1 = rarely/not at all true, 5 = almost always/very true) within the model.

Science-learning self-efficacy was adapted from Chang et al. (2011) and Lin and Tsai (2013). As previously mentioned, self-efficacy in conceptual understanding measures students' ability to navigate learning tasks, formulate and utilize scientific knowledge, engage in logical reasoning, generate multiple types of problem-solving, determine conclusions, and expand their understanding of reflective and evidence-based reasoning in academic performance and problem-solving (10 items, e.g., "I can describe the information that I have made observations out of my studies," $\alpha = 0.88$). For self-efficacy in higher-order understanding, it measures

students' ability to use their knowledge to link scientific theories or concepts for prediction, elucidation, and estimation of scientific phenomena, such as formulating scientific hypotheses, originating conclusions, identifying impact factors, organizing the systematic inquiry, and deriving next-order questions based on scientific observations (5 items, e.g., "I can study or research phenomena based on specific theories or clear pre-planning," $\alpha = 0.84$). In terms of self-efficacy in practical works, it measures how well students are perceived to plan, conduct, solve problems, and evaluate scientific experiments, including selecting and using materials, designing procedures, accurately recording experimental data, relating results to theory, and adjusting for experimental errors during hypothesis testing (7 items, e.g., "I can associate theory and data to conclude the experimental results," $\alpha = 0.87$). In the matter of self-efficacy in everyday applications, it measures the extent to which students can understand and apply theoretical knowledge to real-world applications, such as interpreting social challenges, solving personal or practical problems, repairing or improving everyday equipment, and making informed career or life decisions based on scientific understanding (7 items, e.g., "I can interpret the social problems associated with the theory," $\alpha = 0.93$). As regards self-efficacy in social communication, it measures students' ability to interact meaningfully in academic engagements with peers, such as sharing personal ideas or feedback, clarifying multiple concepts, discussing scientific content knowledge, and correcting misconceptions by social dialogue and peer support (9 items, e.g., "I can use what I have learned to discuss with peers," $\alpha = 0.93$).

Regarding motivational factors, the sense of belonging in science studies was adapted from Trujillo and Tanner (2014). It measures how much learners feel valued and respected by others (5 items, e.g., "I feel respected by others," $\alpha = 0.81$). For attainment value in the science study, it was adapted from Trautwein et al. (2012) and Wigfield and Eccles (2000) and measures how important learners consider a science learning task and procedure by aligning it with their self-developed competencies and the rewards they receive from others (6 items, e.g., "I think it is important for me to identify a solution to the problem rationally," $\alpha = 0.91$). With science-learning curiosity, it was adapted from Kashdan et al. (2009). Predictable curiosity assesses the extent to which learners are eager to acquire new knowledge through challenging situations, aiming to enhance their self-competence through adequate self-preparation (6 items, e.g., "I consider difficult situations to be awkward or doing tasks as an opportunity to learn or build my abilities," $\alpha = 0.91$). Unpredictable curiosity measures the desire of learners to discover new information in unfamiliar situations during science learning tasks (6 items, e.g., "I like to try learning or doing something," $\alpha = 0.88$).

The concept of autonomy-supportive learning climates is adapted from Chan et al. (2023) and Niemi (2002). The self-decision provision assesses the extent to which learners perceive they have the freedom to make decisions about their learning, both in terms of tasks and interactions with peers (5 items, e.g., "My teacher accepts my suggestions when he arranges tasks for me to do," $\alpha = 0.86$). Acceptance provisions evaluate how accepted learners feel during activities such as learning inquiry, self-directed exploration, cooperative problem-solving, reflective evaluation, and adherence to student-centered principles (6 items, e.g., "My teacher allows me to provide a detailed explanation of the new solution related to the task," $\alpha = 0.89$).

3.2 Data collection

Between the 1st and 28th of February in 2023, data collection was adapted by using the self-survey questionnaire. Students' perception was affected by their understanding of science-linked courses. Entry allowance was officially supported by the Royal University of Phnom Penh's ethics board under protocol number 136/2023 RUPPKS. Various high school principals

supported our initiative. Additionally, informants felt secure in offering their honest understanding because they were allowed to opt out of sharing their personal information. All participants were encouraged to share their perspectives voluntarily. All their privacy was ensured from others, but not the researchers' board.

3.3. Data analysis

The purpose of this study was to examine the association between sense of belonging, attainment value, curiosity, self-efficacy, and autonomy-supportive learning climates in science-related education. Partial least squares structural equation modeling (PLS-SEM) was conducted using SmartPLS 3.2.9. Measurement and structural models were identified simultaneously.

Table 2. Descriptive statistics and data normality

Var.s	Items	Statements	$\bar{X}$	SD	γ_1	γ_2	λ_i	VIF
Most of the time I studied science courses for a long time....								
Conceptual understanding	CU1	I can choose a method for dealing with the tasks the teacher assigns.	3.749	1.051	-0.596	-0.382	0.682	1.650
	CU2	I can relate the content of each lesson to create new knowledge.	3.533	1.188	-0.372	-0.854	0.680	1.601
	CU3	I can understand the basics of studying a subject or theory.	3.461	1.073	-0.372	-0.512	0.714	1.709
	CU4	I can relate what I have thought to my practice.	3.526	1.125	-0.446	-0.611	0.699	1.764
	CU5	I can agree with the theory, based on practical evidence.	3.628	1.185	-0.551	-0.638	0.665	1.563
	CU6	I can describe the information I have observed from my studies.	3.460	1.194	-0.279	-0.890	0.730	1.783
	CU7	I can find many solutions when I have a problem.	3.461	1.062	-0.379	-0.564	0.687	1.587
	CU8	I can find a reasonable answer to the question.	3.434	1.189	-0.422	-0.687	0.703	1.790
	CU9	I can clarify the reasonableness of my solution or conclusion.	3.109	1.162	-0.169	-0.836	0.719	1.832
	CU10	I can find more relevant information to deepen the understanding.	3.365	1.193	-0.433	-0.730	0.678	1.604
Higher-order understanding	HU1	I can make predictions of phenomena based on specific theories.	2.759	1.173	0.150	-0.727	0.716	1.597
	HU2	I can study or research phenomena based on specific theories or clear pre-planning.	2.912	1.200	-0.009	-0.874	0.818	1.965
	HU3	I can use theory to deduce how the phenomenon varies.	3.007	1.187	-0.040	-0.759	0.794	1.840

	HU4	I can conclude from various factors influencing the phenomenon.	2.838	1.191	0.050	-0.855	0.799	1.864
	HU5	I can form questions through observing phenomena.	3.133	1.241	-0.217	-0.944	0.759	1.614
Practical work	PW1	I can choose materials for the experimental process.	2.491	1.277	0.314	-1.089	0.826	2.618
	PW2	I can figure out how to use the lab materials.	2.480	1.256	0.321	-1.045	0.857	3.245
	PW3	I can figure out how to sample the experimental data.	2.311	1.183	0.520	-0.666	0.830	2.773
	PW4	I can choose the experimental method by pre-setting the experimental results.	2.460	1.218	0.397	-0.787	0.854	2.787
	PW5	I can associate theory and data to conclude the experimental results.	2.473	1.190	0.392	-0.799	0.859	2.820
	PW6	I can try to find a solution if the experimental process is problematic.	2.661	1.307	0.188	-1.145	0.823	2.606
	PW7	I can carefully observe or record the results of the experiment.	2.902	1.364	-0.003	-1.277	0.821	2.511
Everyday application	EA1	I can use theory to interpret phenomena in everyday life.	2.987	1.167	-0.046	-0.878	0.745	1.699
	EA2	I can understand the documents or information I view or read.	3.721	1.101	-0.597	-0.422	0.728	1.729
	EA3	I can interpret the social problems associated with the theory.	3.136	1.214	-0.026	-0.893	0.805	2.055
	EA4	I can repair the items in my life using theories.	2.739	1.318	0.336	-0.979	0.747	2.070
	EA5	I can use theory to solve problems in my life.	3.117	1.266	-0.022	-1.038	0.790	2.262
	EA6	I can learn about any occupation or career that involves scientific skills.	3.534	1.273	-0.566	-0.691	0.673	1.503
	EA7	I can take what I learned from school and put it into practice in my life.	3.632	1.208	-0.461	-0.822	0.741	1.743
Social communication	SC1	I can participate in discussions with others in the class.	3.928	1.119	-0.836	-0.283	0.778	2.211
	SC2	I can help suggest presentations based on what I have learned.	3.486	1.200	-0.307	-0.907	0.789	2.334
	SC3	I can evaluate my peers' work based on what I have learned.	3.369	1.209	-0.236	-0.917	0.791	2.383
	SC4	I can use what I have learned to discuss with peers.	3.801	1.116	-0.645	-0.522	0.841	2.766
	SC5	I can explain my perception to friends in various ways.	3.577	1.178	-0.393	-0.860	0.808	2.594

	SC6	I can share my thoughts with peers.	3.724	1.139	-0.573	-0.571	0.814	2.593
	SC7	I can ask my peers to help explain it again when I am not yet clear about the interpretation.	3.797	1.113	-0.612	-0.571	0.738	2.048
	SC8	I can check my thoughts to understand the opposite of what my peers think, relying on their suggestions.	3.564	1.141	-0.328	-0.830	0.803	2.344
	SC9	I was able to correct my misunderstandings through suggestions from peers.	3.727	1.135	-0.604	-0.504	0.767	2.223
Sense of belonging	SB1	I feel like I have a good relationship with others.	3.933	1.173	-0.880	-0.229	0.761	1.718
	SB2	I feel respected by others.	3.815	1.131	-0.676	-0.436	0.852	2.392
	SB3	I feel cared for by others.	3.492	1.214	-0.367	-0.811	0.800	1.935
	SB4	I feel confident in my teachers.	4.229	1.016	-1.274	0.846	0.679	1.428
	SB5	I feel like being an active student in class.	3.375	1.190	-0.163	-0.878	0.692	1.323
Attainment value	AV1	I think it is important for me to learn the content of each lesson.	3.950	1.055	-0.776	-0.286	0.793	2.020
	AV2	I think it's important for me to be an outstanding student.	3.648	1.199	-0.510	-0.715	0.824	2.327
	AV3	I think it is important for me to learn to be proficient in the subject.	3.904	1.116	-0.838	-0.137	0.857	2.739
	AV4	I think it is important for me to understand the content of each lesson.	3.864	1.096	-0.670	-0.421	0.859	2.850
	AV5	I think it is important for me to identify a solution to the problem rationally.	3.755	1.109	-0.598	-0.466	0.862	2.790
	AV6	I think it is important for me to be a problem-solver.	3.561	1.187	-0.370	-0.876	0.824	2.287
Predisable curiosity	PC1	I have been actively researching information to the best of my ability.	3.542	1.159	-0.442	-0.709	0.792	1.993
	PC2	I tried my best to do the difficult and complicated tasks.	3.766	1.068	-0.592	-0.426	0.819	2.247
	PC3	I consider difficult situations to be awkward or doing tasks as an opportunity to learn or build my abilities.	3.816	1.040	-0.649	-0.275	0.850	2.510
	PC4	I have been looking forward to the experiences I've encountered before in learning or doing tasks to explore myself or things around me.	3.698	1.088	-0.497	-0.552	0.833	2.260
	PC5	I have been looking for opportunities or time to motivate myself to learn more.	3.924	1.035	-0.805	0.013	0.824	2.513

	PC6	I was looking for opportunities or time to strengthen my abilities.	3.904	1.035	-0.773	-0.099	0.834	2.557
Unpredictable curiosity	UC1	I thought positively about the problems I encountered.	3.701	1.094	-0.533	-0.552	0.808	1.974
	UC2	I have explored new things everywhere I've been.	3.692	1.070	-0.510	-0.464	0.844	2.254
	UC3	I like to do things that are likely to be difficult for me.	3.562	1.097	-0.364	-0.658	0.825	2.076
	UC4	I like to try learning or doing something.	3.728	1.054	-0.527	-0.499	0.855	2.420
	UC5	I love to explore unique things.	3.733	1.128	-0.592	-0.503	0.797	2.029
Self-decision provision	SP1	My teacher decides to pair me with someone to learn or work in a team with.	3.404	1.204	-0.388	-0.756	0.759	1.651
	SP2	My teacher allows me to choose assignments according to my passion.	3.209	1.363	-0.122	-1.193	0.824	2.170
	SP3	My teacher puts in a lot of assignments and lets me pick any one.	3.055	1.385	-0.047	-1.223	0.828	2.272
	SP4	My teacher accepts my suggestions when he arranges tasks for me to do.	3.372	1.235	-0.237	-0.960	0.835	2.133
	SP5	My teacher accepts my ideas even if they don't align with his.	3.255	1.211	-0.272	-0.809	0.760	1.698
Acceptance provision	AP1	My teacher allows me to set lesson objectives for learning.	3.423	1.241	-0.403	-0.827	0.781	1.887
	AP2	My teacher allows me to do projects or make presentations about the lessons.	3.429	1.215	-0.314	-0.831	0.824	2.210
	AP3	My teachers allow me to explore various knowledge from various news sources.	3.747	1.107	-0.628	-0.409	0.785	2.014
	AP4	My teacher allows me to work as a team to find solutions to tasks.	3.730	1.122	-0.633	-0.399	0.824	2.326
	AP5	My teacher allows me to do a detailed explanation of the new solution related to the task.	3.428	1.202	-0.317	-0.856	0.857	2.572
	AP6	My teacher allows me to evaluate the results of other peers' tasks or my own.	3.060	1.277	-0.070	-1.026	0.746	1.852

Notes: $\bar{X}$; Mean, SD; Standard deviation, γ_1 ; Skewness, γ_2 ; Excess kurtosis, λ_i ; Outer loading, VIF; Variance inflation factor.

4. Findings

Before assessing the measurement model, data normality was assessed by skewness between +1 and -1 and excess kurtosis close to zero (Hair et al., 2022). As shown in Table 2, the skewness value exceeded the acceptable range, while the excess kurtosis value differed,

confirming that the data is non-normally distributed. In terms of reflective constructs, they were measured by identifying outer loadings greater than 0.70, indicating that each construct explained more than 50% of its variance (Kline, 2016, 2023). In this way, most of the outer loadings are higher than 0.70 to 0.86. This affirms that the observed indicators are well-reflective of the constructs' variance (Table 2). Moreover, convergent validity is assumed when the average variance extracted (AVE) exceeds 0.50, outer loadings exceed 0.50 or 0.70, and construct/composite reliability (CR) exceeds 0.70. As can be seen in Tables 2 and 3, convergent validity is acceptable, respectively. Discriminant validity is confirmed when the heterotrait-monotrait (HTMT) ratio is lower than 0.90, or the threshold of 0.85 (Henseler et al., 2009, 2016), whereas Fornell and Larcker (1981) noted the square roots of AVE are higher than each bivariate correlation. As expressed in Table 3, the HTMT correlation ranged between 0.39 and 0.78, and most of the bivariate correlations were lower than the square roots of AVE, assuming acceptable discriminant validity. Furthermore, to ensure internal consistency, the values for composite reliability, rho_a reliability, and Cronbach's alpha reliability are all greater than 0.70, respectively (Hair et al., 2017). In the same case, all internal consistency reliability was revealed to be more reliable, respectively (Table 3). In summary, model fit is indicated by the Standardized Root Mean Square Residual (SRMR) being close to zero and the Normed Fit Index (NFI) being close to one, which confirms an acceptable fit (Schuberth et al., 2018, 2023). Table 4 shows that the estimated model has an SRMR of 0.06 and an NFI of 0.81, indicating an acceptable fit in the Cambodian high school context.

Table 3. Internal consistency reliability, discriminant, and convergent validity

Constructs	AP	AV	CU	EA	HU	PW	PC	SP	SB	SC	UC
AP	0.80	0.68	0.61	0.62	0.53	0.57	0.71	0.82	0.63	0.64	0.73
AV	0.62	0.84	0.72	0.68	0.55	0.50	0.73	0.59	0.68	0.72	0.72
CU	0.54	0.65	0.70	0.81	0.77	0.63	0.70	0.53	0.69	0.74	0.70
EA	0.54	0.60	0.71	0.75	0.78	0.75	0.67	0.58	0.62	0.78	0.65
HU	0.46	0.48	0.66	0.67	0.78	0.68	0.52	0.50	0.50	0.57	0.56
PW	0.52	0.46	0.58	0.67	0.60	0.84	0.49	0.53	0.43	0.54	0.50
PC	0.64	0.67	0.63	0.60	0.46	0.45	0.83	0.56	0.69	0.70	0.87
SP	0.71	0.53	0.47	0.50	0.43	0.48	0.49	0.80	0.57	0.54	0.61
SB	0.54	0.59	0.59	0.52	0.42	0.39	0.59	0.48	0.76	0.75	0.67
SC	0.58	0.67	0.68	0.70	0.50	0.50	0.64	0.48	0.66	0.79	0.68
UC	0.65	0.65	0.62	0.57	0.49	0.45	0.78	0.53	0.57	0.61	0.83
α	0.89	0.91	0.88	0.87	0.84	0.93	0.91	0.86	0.81	0.93	0.88
ρ_A	0.89	0.92	0.88	0.87	0.84	0.93	0.91	0.86	0.82	0.93	0.89
CR	0.92	0.93	0.90	0.90	0.88	0.94	0.93	0.90	0.87	0.94	0.91
AVE	0.65	0.70	0.48	0.56	0.61	0.70	0.68	0.64	0.58	0.63	0.68

Notes: AP; Acceptance provision, AV; Attainment value, CU; Conceptual understanding, EA; Everyday application, HU; Higher-order understanding, PW; Practical work, PC; Predictable curiosity, SP; Self-decision provision, SB; Sense of belonging, SC; Social communication, UC; Unpredictable curiosity, α ; Cronbach's alpha internal consistency reliability, ρ_A ; rho_A composite reliability, CR; composite/construct reliability, AVE; Average variance extracted. The bold bivariate correlations refer to the Heterotrait-Monotrait ratio (HTMT) of correlations, while the unbolt bivariate correlations refer to the Fornell-Larcker criterion, and the *Italic* values in the center line refer to the square root of AVE.

Table 4. The model fits within the entire model of science education

Model fit	Saturated model	Estimated model
SRMR	.05	0.06
d_ ULS	5.85	9.57
d_ G	1.6	1.79
Chi-Square	6223.37	6593.19
NFI	.82	0.81

In terms of the structural model, variance inflation factors (VIFs) were assessed to reduce multicollinearity, with VIFs kept below 5 or a threshold of 3 (Hair, 2010; Hair et al., 2019). As revealed in Table 2, the VIF values of 1.563 and 3.245 indicate no multicollinearity. The coefficient of determination (R^2) was identified relying on Hair (2014); R^2 values are 0.25 (low), 0.50 (moderate), and 0.75 (excellent). Furthermore, the predictive relevance (Q^2) values are 0.02 (low), 0.15 (medium), and 0.35 (high), indicating that the model demonstrates acceptable out-of-sample performance as assessed by the blindfolding method (Chin, 1998; Geisser, 1974; Henseler et al., 2009; Stone, 1974). Lastly, the path coefficient with bootstrapping over 5000 samples was used, defining 0.10 (low), 0.20 (moderate), and 0.30 (high), following Cohen (2013).

Figure 2 below depicts all significant direct paths in the model. Autonomy-supportive climate dimensions were positively linked to students' motivational attitudes and science-learning self-efficacy. In particular, self-decision and acceptance provision both had significant positive effects on motivational factors (e.g., sense of belonging, attainment value, and curiosity) and on science-learning outcomes (e.g., conceptual understanding, higher-order understanding, everyday application, practical work, and social communication). All significant paths were positive, indicating that higher perceived autonomy-supportive learning climates predict higher motivational factors and science-learning self-efficacy. The strengths of these effects varied: for example, the model explained about 31% of the variance in the sense of belonging ($R^2 = 0.31$), 48% of the attainment value construct ($R^2 = 0.48$), 56% of predictable curiosity ($R^2 = 0.56$), and 54% of unpredictable curiosity ($R^2 = 0.54$). Among the science-learning self-efficacy measures, the explained variance was also substantial (e.g., $R^2 = 0.54$ for conceptual understanding, $R^2 = 0.31$ for higher-order understanding, $R^2 = 0.62$ for social communication and everyday application, and $R^2 = 0.47$ for practical work). These R^2 values indicate that the autonomy climate and motivation variables together explain a large portion of differences in students' self-efficacy in science education. The pattern of results is consistent with motivation theory: autonomy support from teachers enhances students' belonging and perceived value of science, which in turn boosts their confidence in science tasks.

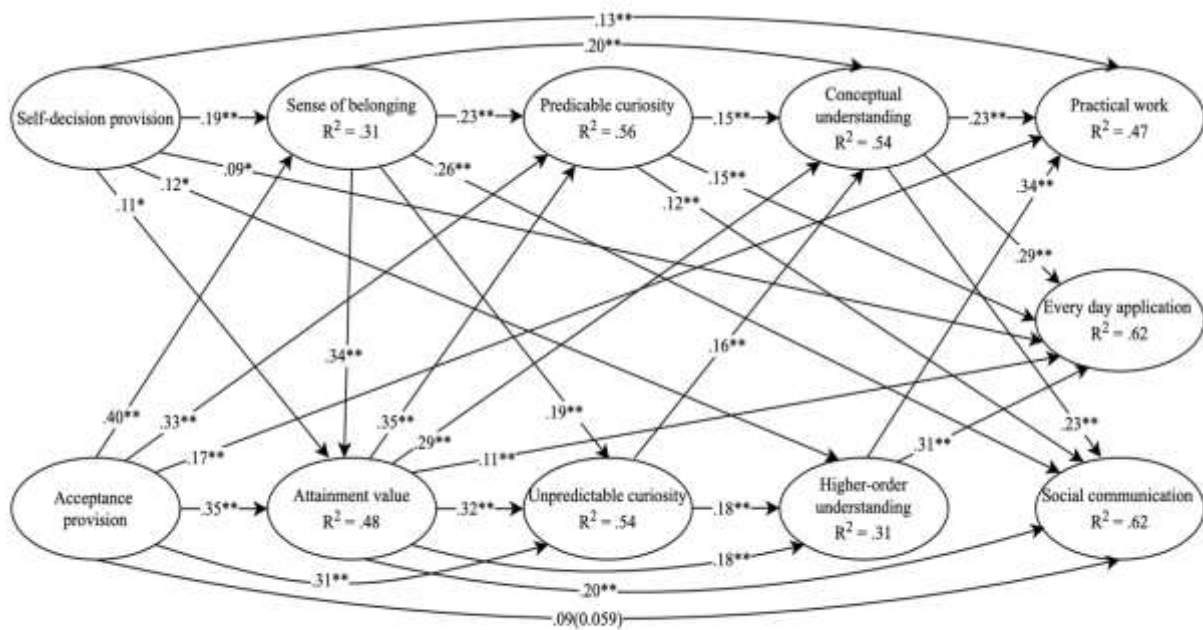


Figure 2. path coefficient of direct effects between autonomy climates, academic motivation and self-efficacy in science education
Note: *p < .05, **p < .01, R²: coefficient of determination, N = 685

Figure 3 below shows the mediated (indirect) pathways through the motivational constructs. Here, each path coefficient represents the product of two links. The direction of all significant indirect effects remained positive, underscoring that autonomy-supportive climates increased science-learning self-efficacy via enhanced motivational factors. For example, the indirect effect of acceptance provisions on conceptual understanding is strongly positive when sense of belonging, attainment value, and science-learning curiosity are enhanced first, indicating that choice and acceptance climates lead to a better conceptual grasp through increased motivation. Moreover, the predictive relevance (Q^2) values for the key mediators are also exposed: sense of belonging ($Q^2 = 0.17$), attainment value ($Q^2 = 0.33$), predictable curiosity ($Q^2 = 0.38$), and unpredictable curiosity ($Q^2 = 0.37$). These exceed zero, confirming that the model has meaningful predictive relevance for these constructs. Similarly, science-learning self-efficacy (e.g., everyday application, higher-order understanding) shows positive indirect paths with non-zero Q^2 values. In sum, the indirect paths reinforce the direct findings: autonomy-supportive climates translate into higher self-efficacy in science largely by first increasing students' sense of belonging, the attainment value, and the curiosity they attach to science. This mediating pattern aligns with prior research showing that a deeper understanding and greater valuing of science drive confidence in science education.

Across the two models, the significant relationships were consistent in sign and generally similar in magnitude. Notably, many associations visible in Figure 2 also appeared (as mediated effects) in Figure 3. For instance, the positive influence of acceptance-provision climates on conceptual understanding was evident in both the direct and mediated models (via sense of belonging, attainment value, and science-learning curiosity), with the indirect coefficient ($\beta = 0.40$) comparable to the direct effect. In general, indirect (mediated) coefficients tended to be similar in size to, or slightly larger than, the direct links alone, reflecting the combined contribution of motivation. For example, while direct paths from climate to some outcomes were modest, the corresponding indirect path (through motivation) was stronger. This comparison suggests that motivation constructs act as key conduits: autonomy-supportive climates affect outcomes both on their own and more substantially by shaping students' sense of belonging and value.

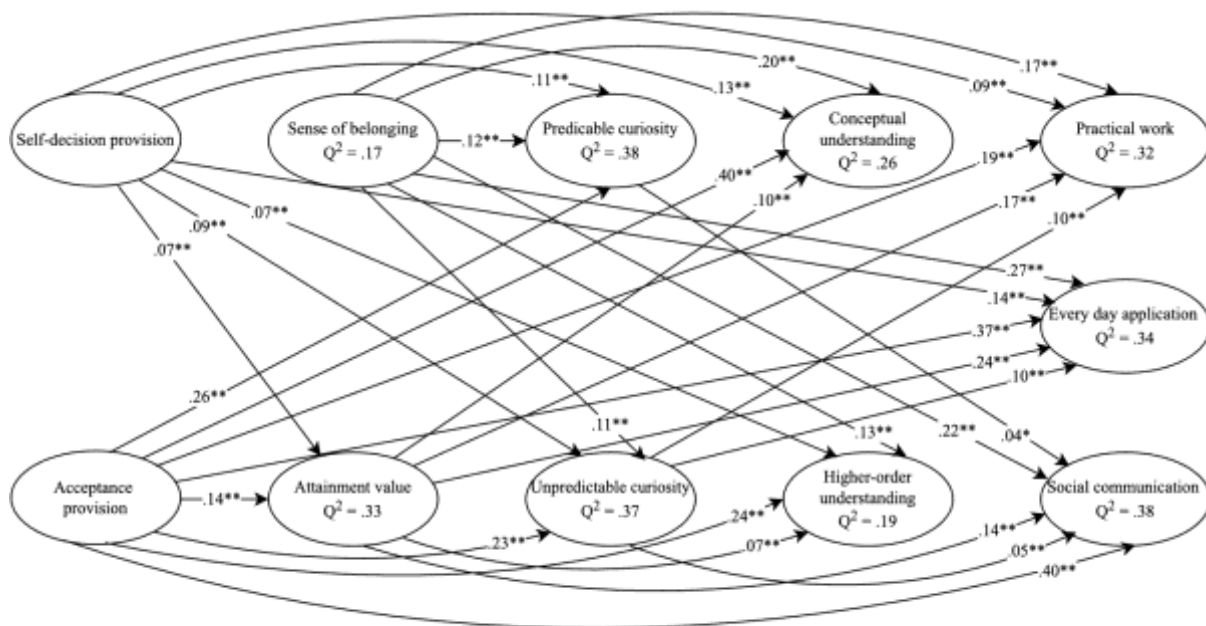


Figure 3. path coefficient of indirect effects between autonomy climates, academic motivation and self-efficacy in science education
Note: * $p < .05$; ** $p < .01$, Q²: predictive relevance for path model with blindfolding method, $N = 685$

5. Discussion

Consistent with self-determination theory, our findings show that autonomy-supportive climates significantly enhanced intrinsic motivational resources (e.g., sense of belonging, attainment value, and science-learning curiosity): when teachers offer choice and acknowledge students' perspectives, students reported a higher sense of belonging and curiosity about science (Baumeister & Leary, 1995; Reeve, 2006). Self-decision provision notably predicted a heightened sense of belonging and a more predictable curiosity. In contrast, the acceptance provision significantly predicted higher attainment value (the value students attribute to excelling in science) and unpredictable curiosity (risk-taking). These findings support SDT's assertion that fulfilling students' needs for autonomy promotes intrinsic motivation (e.g., Deci & Ryan, 2000; Ryan & Deci, 2017). Specifically, our model reflects the findings of Patall et al. (2018) and Patall and Zambrano (2019). Likewise, choices and rationales provided by teachers (self-decision support) invite students to seek out novelty and challenges and to feel ownership of their learning, as reflected in the elevated curiosity they observed.

From an expectancy value theory perspective, autonomy-supportive climates also bolstered students' subjective task values. The acceptance provision's perceptions of students link to attainment value, as the personal importance of success in science is consistent with their concepts. When students feel valued and a sense of belonging, they are more likely to value the subject themselves. Eccles and Wigfield (2002) define attainment value as the importance of a task to one's identity, and our findings suggest that autonomy-supportive interactions help cultivate this value. Moreover, autonomy-supportive learning climates (e.g., offering choices and encouraging student voice) create a positive learning environment, which meta-analyses have shown can increase students' expectancy beliefs and task values (Reeve & Cheon, 2021).

In terms of social cognitive theory, prior work has shown that students who approach science with a mastery-oriented attitude by understanding and seeing in a new way or applying concepts exhibit higher self-efficacy for learning science (Bandura, 1982; Pintrich, 2000). The present findings extend this: autonomy-supportive climates foster precisely these positive motivational states, and the resulting boost in self-efficacy translates into better science-learning outcomes, as previous studies have shown (e.g., Black & Deci, 2000; Deci & Ryan,

1985). In line with social-cognitive theory, self-efficacy itself is a strong predictor of achievement, so these links are of practical significance as proposed by Multon et al. (1991) and Zimmerman (2000).

A sense of belonging effectively accelerates attainment value, curiosity, and self-efficacy in conceptual understanding and social communication. In this context, students are more likely to feel a sense of relatedness when in a supportive environment. Previous studies have shown that low science-learning self-efficacy can discourage some students from engaging in the challenging journey of learning science (Aelenei et al., 2020). Additionally, a sense of belonging, through attainment value, is likely to increase students' self-esteem (Eccles & Wigfield, 2002). Furthermore, the link between students' abilities and their curiosity fosters insightful engagement in learning (Amponsah, 2023).

Regarding motivational factors, the model indicated that promoting robust science-learning self-efficacy depends on the personal value a student assigns to science courses. When students perceive science class as integral to their identity and self-worth, they seem to develop the self-confidence to engage and overcome the challenging cases (Bandura, 1982; Breetzke & Bohndick, 2024; Wigfield, 1994). This aligns with SCT and EVT; learners' self-confidence might emerge from valuing a task as necessary (Bandura et al., 1996; Eccles & Wigfield, 2002). As Chan et al. (2023) claimed, a person's belief may grow when the task's value aligns with self-value.

In science learning, curiosity predicts most of the variance in cognitive science self-efficacy, not in science practice self-efficacy. In this sense, students who are curious to seek adequate knowledge seem to increase their cognitive competency rather than apply those concepts in practice. As previous research shows, learners' willingness and tendency to take risks and build knowledge stem from real-world views, moving from concrete to abstract concepts (Beghetto, 2009; Jirout & Klahr, 2012).

Importantly, the enhanced motivation mediated the effect of autonomy-supportive climates on science learning outcomes (e.g., Deci & Ryan, 2000; Niemiec & Ryan, 2009). Both self-decision and acceptance provision were indirectly associated with better outcomes in conceptual understanding, practical work, higher-order understanding, everyday application, and social communication. For instance, the self-decision provision had positive paths to practical and conceptual outcomes, largely through increased belonging and curiosity, whereas the acceptance provision's strongest indirect effects on everyday application and social communication were mediated by higher attainment value and curiosity. In this sense, students who are increasing their curiosity and investing in science promotions are more likely to obtain autonomous provision and supported input (Niemiec & Ryan, 2009; Núñez & León, 2015; Singh & Manjaly, 2022). Furthermore, they strengthen each motivational evaluation by boosting their confidence and becoming more familiar with science tasks, such as applying concepts to everyday problems and communicating ideas (Girelli et al., 2018; Guay et al., 2001).

Overall, the importance of both direct and indirect effects in promoting autonomy-supportive provision and a positive science climate lies in their ability to enhance students' self-motivation and self-confidence, thereby deepening their understanding and emotional engagement with science education.

6. Practical implications for science educators and policy

Our findings indicate specific implications for the science training practicum. At the beginning, science educators should attempt to cultivate autonomous-support classroom climates. Suppositionally, teachers should provide engaging learning activities and tasks, enhance students' goals for science practicum by allowing them to set their own, and actively solicit and appreciate students' perspectives and emotional states. For instance, a teacher might allow them to choose their science project topics and suggest they seek alternative ways to complete the task to demonstrate their understanding. By providing meaningful rationale for learning tasks and acknowledging students' points of view, teachers can help students perceive the science training course as personally relevant and worth mastering. Such practices not only support students' need for autonomy but also increase their valuation of science content (attainment value) and spark curiosity—all of which our model links to better learning. Professional development should train teachers in autonomy-supportive techniques (e.g., adaptive scaffolding, empathetic communication) since research shows these skills can be learned and lead to greater student motivation.

Moreover, this finding also suggests actions for policymakers and curriculum designers. They should prepare student-centered and mastery-oriented learning climates. Science curricula should include inquiry- and project-based learning modules. This provision naturally affords autonomy and relatedness. Policies should limit overly controlling support (e.g., inflexible testing, punitive grading), as it can undermine freedom of decision-making, and instead promote flexible options (e.g., optional assignments, alternative assessment modes), which have been shown to increase engagement. At the system level, autonomous activities in group work might strengthen a sense of belonging, value, curiosity, and self-efficacy, which our findings and motivation theories link to motivational factors.

In sum, educational reforms that endorse autonomy-supportive pedagogy are likely to yield dividends in science learning. By enabling students' self-directed decision-making and validating their perspectives, we help them feel ownership of and interest in science, which translates into deeper understanding and practical skill development.

7. Limitation

This study has several limitations that should be acknowledged. First, the study employed a cross-sectional correlational design, which limits the ability to establish causal relationships among the variables. Therefore, the findings should be interpreted as associations rather than evidence of causation. Future studies employing experimental, causal-comparative, or longitudinal designs are needed to verify the causal pathways proposed in this study. Second, the sample was drawn from a specific geographical and educational context, which may limit the generalizability of the findings to other student populations, regions, or cultural settings. Third, the data were collected through self-report questionnaires, which may be subject to common method bias, social desirability effects, and respondents' subjective perceptions. In addition, self-reported measures may not fully reflect actual academic outcomes, such as students' objective academic performance or standardized test scores. Finally, although the study focused on autonomy-supportive instructional behaviors and related motivational factors, other variables not included in the model, such as teacher characteristics, peer relationships, family support, and school resources, may also influence students' motivation and academic outcomes. Future research should incorporate these factors to provide a more comprehensive understanding of student learning and achievement.

8. Future direction

Building on our findings, the next research should employ longitudinal and experimental designs to test the causal effects of autonomy-supportive practices. Students might be tracked through a longitudinal study to see if sustained autonomy support predicts growth in academic achievement. Furthermore, intervention studies and randomized control policy experiments could manipulate aspects of the autonomy-supportive climates (e.g., teacher training in autonomy support and choice-based curricula). By addressing these questions, future research can more definitively map how autonomy-supportive science classrooms enhance students' motivation, confidence, and ultimately their science learning.

Acknowledgments

The authors wish to convey their profound appreciation to the reviewers and the editing team of CJESS for their evaluation and proofreading of the manuscript. This piece would not have emerged in academic circles without their assistance. Consequently, their contributions are seen as indispensable and beneficial to society at large, particularly within the academic community of research and publication.

Conflict of interest

No potential conflict of interest was reported by the authors.

Funding

The authors received no financial support for the study, authorship, and/or publication of this study.

Declaration of AI usage

The authors used Grammarly to polish the language in some parts of the article. However, they declared that the article's content is entirely theirs and not generated by any means.

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