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THE INFLUENCE OF STEM ATTITUDE, 21ST CENTURY SKILLS, AND TECHNOLOGY USE ON STUDENT OUTCOMES: A MEDIATION MODEL ANALYSIS

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ABSTRACT

Aim/Purpose	This study aims to investigate the relationships between students' attitudes toward STEM subjects, 21st-century skills, and technology use, and how these factors influence STEM career interest and subjective well-being among adolescents in the 21st-century classroom.
Background	While positive attitudes, skill acquisition, and digital learning have been individually studied, their combined effect on students' career aspirations and subjective well-being remains underexplored. Addressing this gap can show how these factors work together to support adolescent development.
Methodology	This study was grounded in established theories of learning and motivation. It employed a statistical method, Structural Equation Modeling (SEM), to test a conceptual model. Data were collected from 1,302 students (grade levels VIII-XII) across 30 schools in Kerala, India. Also analysed were the mediating effects of mathematics and science engagement, teacher efficacy, and teacher leadership.
Contribution	This research offers a combined model that reveals how students' attitudes, skills, technology use, and classroom teaching practices are connected. These factors are shown to influence both career motivation and well-being. Together, the findings provide a broader and clearer picture of modern education.
Findings	Students with positive attitudes toward STEM showed more engagement in learning. Effective and supportive teachers also influenced them. This influence

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	shaped their career interest. Their well-being was improved indirectly through this engagement and career motivation, but their direct impact on well-being was limited. The model demonstrated good fit indices, supporting its structural validity. By addressing the gap in integrative models that link learner attitudes, competencies, technology use, and instructional mediators to both career and well-being outcomes, this study contributes a holistic framework for understanding adolescent development in modern classrooms.
Recommendations for Practitioners	Teachers should focus on fostering STEM-positive attitudes. They can enhance engagement through inquiry-based methods. They should also integrate 21st-century skills into everyday classroom activities. Teacher professional development should include leadership training and technology-enhanced pedagogy. Purposeful and regulated technology integration should be prioritized to avoid negative impacts on student focus and well-being.
Recommendations for Researchers	Future research should explore the longitudinal effects of these variables across diverse educational contexts and age groups. Alternative indicators of academic success beyond grades should be considered. These indicators could examine how digital and thinking skills apply across different subjects.
Impact on Society	By identifying pathways to both academic and emotional development, the study supports policy and curriculum reforms. These reforms aimed at preparing future-ready learners capable of contributing to innovation-driven economies while maintaining adaptability.
Future Research	Investigations should extend to virtual or immersive environments, examine differential impacts across demographic groups, and develop standardised tools for measuring digital literacy and well-being in diverse settings.

Keywords	STEM career interest, subjective well-being, 21st century skills, teacher leadership, teacher efficacy, student engagement, technology use, structural equation modeling, Indian adolescents

INTRODUCTION

In the rapidly evolving educational landscape of the current century, there is an increasing emphasis on equipping students with the skills and mindset necessary for success in science, technology, engineering, and mathematics (STEM) careers (Blotnicky et al., 2018). Amalina et al. (2025) describe that global economies are becoming increasingly based on innovation and technology, developing positive attitudes toward STEM, enhancing engagement in mathematics and science, and promoting technology use have become central to education policy and research. Equally important is understanding how these factors influence students' subjective well-being (Iqbal & Dar, 2021), a critical indicator of overall development.

In India, recent education policies, such as the National Education Policy (Ministry of Human Resource Development, 2020), have underscored the integration of STEM education, 21st-century skills, and technology-enabled learning to prepare students for future challenges. These reforms aim to balance academic achievement with holistic well-being, ensuring that students are not only career-ready but also equipped with the resilience and adaptability needed in a rapidly changing society (Bhowmik et al., 2024).

Within this national context, Kerala presents a distinctive setting for studying STEM-related attitudes and well-being. The state is known for its high literacy rate and robust public examination system. The state has also been an early adopter of ICT-enabled initiatives such as the Kerala Infrastructure and Technology for Education (2025) (KITE) project. These features make Kerala a fertile ground

for examining how students' dispositions, skills, and technology use interact with teaching practices. At the same time, disparities across public and private schools, between rural and urban regions, make Kerala a relevant model for exploring broader challenges in implementing STEM and 21st-century skill development.

Attitude towards STEM plays a pivotal role in fostering persistence and interest in STEM-related fields (Kırkıç & Uludağ, 2021). These attitudes are often shaped by early learning experiences and societal perceptions. When students perceive STEM subjects as relevant and attainable, they are more likely to invest cognitively and emotionally. This investment, in turn, enhances their engagement levels and future career intentions (Xu & Lastrapes, 2021).

Current educational frameworks, such as the Partnership for 21st Century Learning [P21] and OECD standards, highlight the importance of integrating critical thinking, collaboration, digital literacy, problem solving, creativity, and adaptability. These 21st-century skills prepare students for the challenges of the future (Ananiadou & Claro, 2009; D. Chen, 2021; Fajrina et al., 2020; Han et al., 2024; Thornhill-Miller et al., 2023). In this study, we conceptualize 21st-century skills as a multidimensional construct encompassing these subskills. Tight (2020) observed that these competencies not only enhance students' academic capabilities but also contribute to their capacity to navigate complex social and technological environments with confidence. While it is possible to argue that engagement may foster the development of such skills, existing theoretical and empirical perspectives suggest that possessing these skills enables students to engage more meaningfully in the learning process. Therefore, we view 21st-century skills as abilities that come first and help students stay engaged in learning.

Technology use has become an inseparable component of modern classrooms. While access to digital tools can foster autonomy and engagement, the quality and purpose of technology integration are critical determinants of its impact (Kareem et al., 2022). When guided by effective teaching practices, purposeful technology use enhances students' sense of agency and supports differentiated instruction (Akkoyunlu & Erkan, 2013). In contrast, unstructured or excessive use may lead to distractions or dependency, ultimately affecting both teaching efficacy and student well-being (Bakshi, 2022; Kareem et al., 2022). Thus, understanding the inevitable role of technology, mediated by teacher leadership and pedagogical design, is central to optimizing its benefits in educational settings (Ainley, 2012; Bundick et al., 2014; Cents-Boonstra et al., 2020).

Despite global, national, and regional emphasis on STEM and 21st-century skills, there remains a gap in understanding the pathways through which students' attitudes toward STEM, 21st-century skills, and technology use translate into academic engagement, career interest, and subjective well-being. Against this backdrop, the present study tests a conceptual model that examines the relationship among Attitude towards STEM, 21st Century Skills, and Student Technology Use, and their influence on Mathematics and Science Engagement, Teacher Efficacy, Teacher Leadership, STEM Career Interest, and Subjective Well-being. Using Structural Equation Modeling (SEM) (Stein et al., 2012), this study explores both direct and mediated effects. Doing so contributes to a deeper understanding of how cognitive and behavioural aspects interact to affect both academic aspirations and personal development among students.

In light of these complex interdependencies, the conceptual model proposed in this study establishes the importance of examining mediating variables that bridge the gap between student dispositions and outcomes. Mathematics and science engagement serve as proximal indicators of students' sustained interest and participation in core STEM disciplines, while teacher efficacy and teacher leadership function as pivotal influences on learning environments and motivational climates (Ainley, 2012; Al Mamun & Lawrie, 2023). By modeling these mediating effects, this study aims to explain the pathways through which students' attitudes, skills, and technology use translate into tangible academic and well-being outcomes. The findings are expected to inform policy decisions, curriculum design,

and teacher training programs that seek to cultivate holistic, future-ready learners in an increasingly digital and innovation-driven world.

Research Questions

1. To what extent do mathematics and science teaching efficacy, student engagement, and teacher leadership mediate the relationship between students' attitudes towards STEM career interest as well as subjective well-being?
2. How do 21st-century skills influence STEM career interest and subjective well-being, and what mediating roles do teaching efficacy, student engagement, and teacher leadership play in this process?
3. In what ways do students' technology use contribute to their STEM career interest and subjective well-being, and how are these relationships mediated by teaching efficacy, engagement, and teacher leadership?

Literature Review

In the emerging field of 21st-century education, fostering students' interest in STEM careers while supporting their subjective well-being is a dual priority. As envisioned by Xia and Qi (2024) the classroom has become a dynamic environment where technology, pedagogy, and student-centred practices converge to influence both academic and psychological outcomes. The present study proposes a structural equation model that integrates learner-centred, instructional, and technological variables to understand how these factors shape STEM career interest and well-being. This literature review explores these constructs under four key sections to better understand what past research and theories say about them.

Learner-Centred Factors

STEM attitude

Students' attitude toward STEM disciplines – including interest, value, and perceived competence – is critical to their sustained engagement and future career decisions (Baran et al., 2019; Erol & Canbeldek Erol, 2023). Berger et al. (2020) observed that students with a positive attitude towards mathematics and science showed higher achievement in each, highlighting a mutually reinforcing effect. The study also established that males were more likely to exhibit these positive attitudes, leading to greater academic benefit compared to females. According to the expectancy-value theory (Wigfield & Eccles, 2000), students are more likely to pursue academic tasks when they find them valuable and believe they can succeed. Gok (2021) observed that positive STEM attitudes are cultivated through exposure, meaningful learning experiences, and encouragement from teachers and parents. These attitudes have been linked to both academic motivation and long-term interest in STEM careers (Abdi et al., 2024).

Mathematics and science engagement

Engagement is a multifaceted construct involving behavioural, emotional, and cognitive components (Ainley, 2012). Bundick et al. (2014), Cents-Boonstra et al. (2020), Erdoğdu (2019), and Gladstone et al. (2022) all agree that engagement involves active participation and emotional investment in learning activities. In STEM education, engaged students are more likely to persevere through complex problem-solving tasks and report higher levels of intrinsic motivation (Kareem et al., 2022). Engagement also mediates the relationship between instructional inputs and student outcomes, making it a pivotal factor in both academic success and student well-being (Flores et al., 2021).

Classroom and Instructional Factors

Teaching efficacy

Teaching efficacy, or a teacher's belief in their capacity to influence student learning, has been linked to the implementation of innovative instructional practices and student achievement (Barni et al.,

2019; Gümüş et al., 2022). In STEM contexts, highly efficacious teachers are more likely to adopt active learning strategies and integrate real-world applications that promote both interest and understanding (Jerrim et al., 2023). Their confidence often translates to increased student motivation and fosters a classroom environment conducive to learning and personal growth.

Teacher leadership

Teacher leadership extends beyond formal roles to include influence over instructional quality, classroom culture, and peer mentoring (Bakshi, 2022). Fernández Espinosa and López González (2023) noted that effective teacher leaders serve as role models and create supportive learning environments that nurture student autonomy and engagement. In the context of STEM learning, teacher leadership is especially critical in guiding students through inquiry-based learning and managing complex, technology-rich environments (X. Luo et al., 2024; Schott et al., 2020; Tyaningsih et al., 2021). Leadership that emphasizes inclusivity and student voice also contributes positively to students' emotional and academic outcomes (Shen et al., 2020).

21st Century Learning Environment

21st-century skills

21st-century skills, comprising critical thinking, communication, collaboration, creativity, problem-solving, and digital literacy, are essential for success in a knowledge-based economy (Patel et al., 2024). These skills also align with the competencies needed for STEM careers and global citizenship (Han et al., 2024; Küçükaydın et al., 2024). O'Lawrence (2017) observed that integrating these skills into the curriculum enhances students' ability to solve real-world problems, work in teams, and adapt to technological changes. Developing these skills contributes not only to academic achievement but also to student confidence and satisfaction, reinforcing well-being (Perdana et al., 2021; Stehle & Peters-Burton, 2019; Tight, 2020).

Student technology use

Technology is a defining feature of 21st-century classrooms. When used purposefully, it supports personalized learning, facilitates collaboration, and enhances student engagement (Akkoyunlu & Erkan, 2013; Berges Puyo, 2024; Haddock et al., 2022). Haleem et al. (2022), Kareem et al. (2022), and Koval-Mazyuta et al. (2023) observed that educational technology, including simulations, virtual labs, and coding platforms, has been shown to improve STEM learning outcomes. Furthermore, students proficient in using technology often exhibit higher levels of self-efficacy and autonomy, which are key predictors of academic performance and subjective well-being.

STEM career interest

Blotnicky et al. (2018) defined STEM career interest as a student's aspiration toward pursuing education and employment in science, technology, engineering, and mathematics fields. This interest is influenced by multiple factors, including self-efficacy, attitude, role models, and exposure to STEM experiences (Ardianto et al., 2023; Y. Chen et al., 2024; T. Luo et al., 2021). Social Cognitive Career Theory (D. Wang et al., 2022) posits that career choices are shaped by the interaction of personal beliefs, contextual supports, and learning experiences. Early engagement in STEM and positive perceptions of relevance significantly increase the likelihood of pursuing a STEM career (Abdi et al., 2024; Dönmez & İdin, 2020; Sadler et al., 2012).

Subjective well-being

Subjective well-being refers to individuals' evaluations of their lives, encompassing both emotional responses and cognitive judgments such as life satisfaction (Diener, 1984). As observed by Abele-Brehm (2014), in school settings, subjective well-being is influenced by relationships, academic success, and self-concept. High levels of well-being in students are associated with greater resilience, aca-

demic performance, and positive school experiences (Asanjarani et al., 2022; Bharti et al., 2023). Educational environments that support autonomy, competence, and relatedness – as outlined in self-determination theory (Deci & Ryan, 1985) – are essential for nurturing student subjective well-being.

Research Gap

In summary, the reviewed literature affirms the interconnectedness of subjective, pedagogical, and technological factors in shaping both career-related and well-being outcomes for students. However, prior research has largely examined these variables in isolation, focusing on direct effects rather than the complex mechanisms that connect them. Few studies have tested an integrative framework that simultaneously considers STEM attitudes, 21st-century skills, and technology use alongside mediating processes such as engagement, teacher efficacy, and teacher leadership. This gap limits understanding how student dispositions interact with contextual influences to produce holistic developmental outcomes. The present study addresses this gap by categorizing these variables into learner-centred, instructional, and environmental domains. The proposed structural equation model reflects a holistic view of the modern classroom. This integrated framework offers a comprehensive foundation for exploring how various elements of the learning experience influence adolescents' STEM aspirations and subjective wellness.

Theoretical Background

This study is grounded in an integrated theoretical framework that combines Social Cognitive Theory (SCT) (Bandura, 1986), the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), and Self-Determination Theory (SDT) (Deci & Ryan, 1985). SCT provides a foundational lens to examine how personal factors, such as attitude towards STEM and 21st century skills, integrate with behavioural patterns like engagement and technology use, within the context of environmental influences such as teaching efficacy and teacher leadership. This perspective supports the study's focus on reciprocal interaction among cognitive, behavioural, and contextual variables in shaping student outcomes. The TPACK framework further informs the study by emphasising the importance of integrating technology with pedagogical and content knowledge, thereby illuminating the role of student technology use in enhancing or hindering learning efficacy and instructional leadership. Finally, SDT enriches the framework by addressing students' psychological needs-autonomy, competence, and relatedness, which are central to their subjective well-being and intrinsic motivation.

By integrating these theoretical perspectives, the study highlights the complex and dynamic nature of learning in the 21st-century educational context. In SCT, Albert Bandura (1991) explained that the interaction of cognitive, behavioural, and environmental elements influences learning. This explains how students' beliefs about their capabilities (e.g., STEM self-efficacy) influence their engagement in mathematics and science, and how these beliefs are shaped through interactions with teachers and the learning environment. TPACK supports the analysis of how technology use is not only a tool for learning but also a contextual factor that interacts with instructional strategies and subject matter to impact teaching efficacy and student engagement (Akkoyunlu & Erkan, 2013; Berges Puyo, 2024; Bundick et al., 2014). Meanwhile, SDT provides meaningful support to explore students' subjective well-being, highlighting how experiences that support autonomy, competence, and relatedness can foster greater motivation and interest in STEM careers (Donald & Jackson, 2022; Van Petegem et al., 2007). This theoretical integration is particularly valuable for the present study's use of Structural Equation Modeling (SEM), which enables the simultaneous examination of direct and mediated relationships among constructs. The framework thus ensures a comprehensive understanding of the pathways through which student attitudes, skills, and technology use influence both academic and personal developmental outcomes. Table 1 presents a mapping of the constructs in this study to their underlying theoretical frameworks, thereby clarifying how SCT, TPACK, and SDT informed the conceptual model.

Table 1. Mapping of constructs with theoretical frameworks

Construct	Theoretical framework	Justification
Attitude toward STEM	Social Cognitive Theory (SCT)	Attitudes influence self-efficacy, interest, and persistence in learning.
21st-Century Skills	Self-Determination Theory (SDT) & Key Skills Framework (P21/OECD)	Competencies such as critical thinking, collaboration, and adaptability foster autonomy, competence, and relatedness.
Student Technology Use	TPACK (Technological Pedagogical Content Knowledge)	Effective integration of technology in learning is explained through TPACK.
Mathematics & Science Engagement	Social Cognitive Theory (SCT)	Engagement reflects behavioural, emotional, and cognitive investment in learning.
Teacher Leadership & Teacher Efficacy	Social Cognitive Theory (SCT) & TPACK	Teachers' beliefs about their instructional abilities and leadership roles influence student learning.
STEM Career Interest	Social Cognitive Career Theory (SCCT, branch of SCT)	Career interest develops through self-efficacy, outcome expectations, and goals.
Subjective Well-being	Self-Determination Theory (SDT)	Well-being emerges when students' needs for autonomy, competence, and relatedness are met.

RESEARCH MODEL

The literature review revealed that a positive STEM attitude – shaped by interest in mathematics and science, engineering, and technology – serves as a foundation for fostering engagement and career aspirations. As students engage more deeply in mathematics and science through behavioural, emotional, and social dimensions, they develop greater confidence in handling complex tasks and regulating their learning process (Al Mamun & Lawrie, 2023). Although existing research highlights various factors influencing STEM engagement, career interest, and subjective well-being, significant gaps remain. Few studies integrate these variables into a single model to explore their combined mediating effects. The role of emotional and social engagement, the impact of technology use on well-being, and the influence of 21st-century skills on long-term outcomes are unexplored. Considering these, the proposed research model is presented in Figure 1.

The model illustrates the dynamic interplay between students' STEM attitudes, teacher-related factors, engagement in mathematics and science, and subjective well-being. At the foundation, students' attitude towards mathematics and science, and engineering and technology, collectively shape their overall STEM attitude, which in turn significantly influences their interest in pursuing STEM careers (Y. Chen et al., 2024; Fitzgerald et al., 2024; Zhou & Shirazi, 2025). Voelkel (2022) and Bakshi (2022) acknowledged that this attitude also impacts teacher efficacy and teacher leadership, highlighting the role of educators in fostering a supportive learning environment. Furthermore, 21st-century skills and student technology use are shown to contribute to both teacher efficacy and leadership, thereby indirectly supporting students' academic engagement and well-being. Based on this model, the following hypotheses are proposed:

H1: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between STEM Attitude and STEM Career Interest.

H2: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between STEM Attitude and Subjective Well-being.

H3: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between 21st Century Skills and STEM Career Interest.

H4: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between 21st-century Skills and Subjective Well-being.

H5: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between Student Technology Use and STEM Career Interest.

H6: Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership significantly mediate the relationship between Student Technology Use and Subjective Well-being.

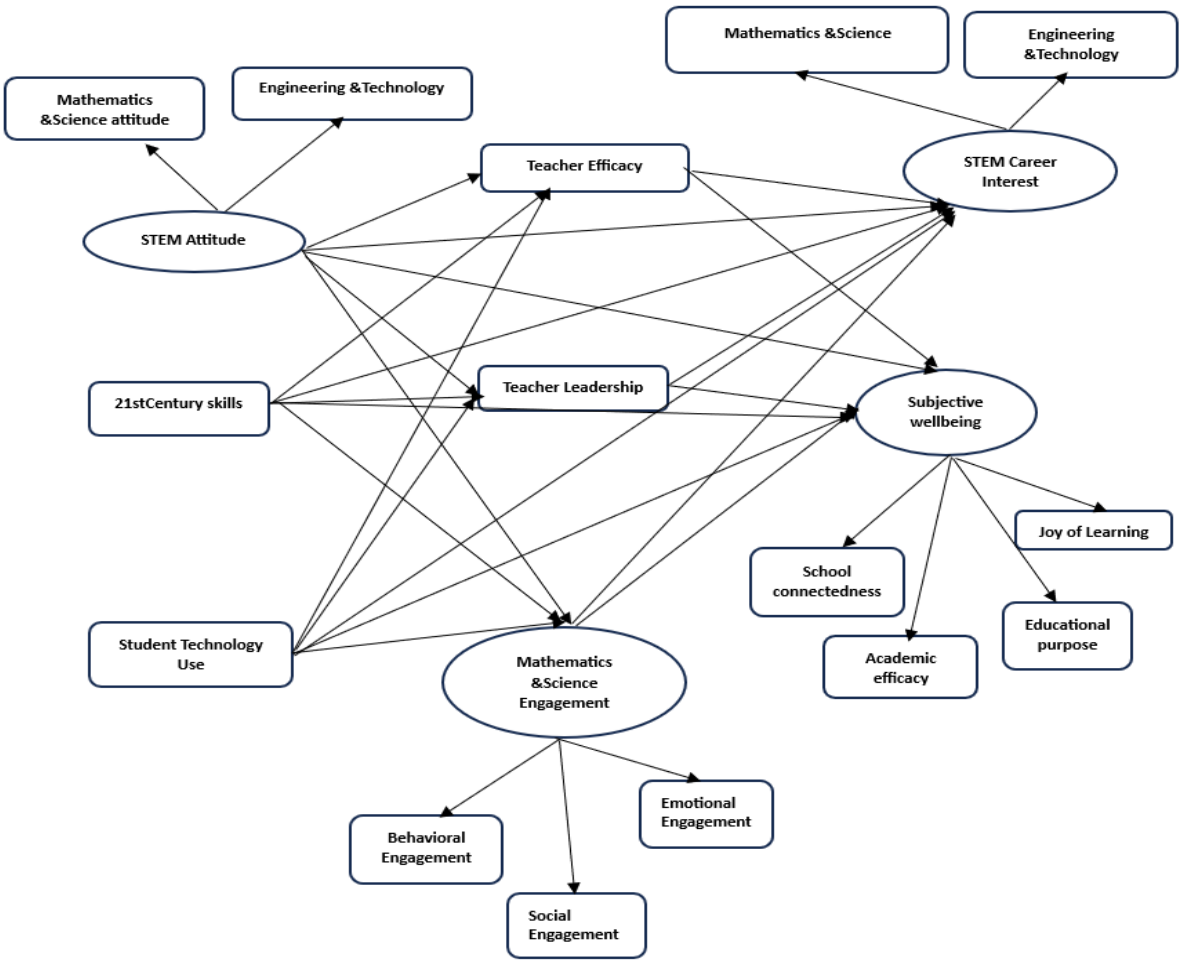

Figure 1. Proposed conceptual model

METHOD

Participants

The participants in the present study were 1,302 students from classes VIII to XII in Kerala, India. In the Indian education system, classes VIII to XII correspond to secondary and higher secondary education. Class VIII (Grade 8, 14 years) and Class IX (Grade 9, 15 years) are comparable to the middle school or early high school stage in many countries. Class X (Grade 10, 16 years) marks the completion of secondary education, after which students take nationally recognized board examinations. Classes XI and XII (Grades 11 and 12, 17-18 years) correspond to higher secondary education, similar to senior high school in other systems. A second set of board examinations at the end of Class XII serves as the qualifying stage for university admissions.

Kerala provides a distinctive context for studying STEM attitudes, career interests, and student well-being. The state consistently ranks highest in India on educational indicators, with the country's highest literacy rate (96.2%) and strong performance on the School Education Quality Index (India STEM Foundation, 2023). Education policies such as the KITE project, Hi-Tech School initiatives, and the formation of student-led IT clubs have expanded opportunities for STEM exposure and digital literacy across public and private schools ("UNICEF study praises", 2024). Kerala also demonstrates small rural-urban and gender gaps in access to schooling, offering a more equitable environment to examine adolescents' educational experiences (Express News Service, 2024). In addition, a large proportion of students pursue science and mathematics at the higher secondary level, reflecting strong social and cultural orientations towards STEM-related careers. Combined with the state's emphasis on holistic and child-friendly schooling, these features make Kerala a particularly relevant and distinctive setting for investigating the interplay of STEM attitudes, career interest, and well-being.

Sampling

A convenience sampling method was adopted in this study. It is a non-probability sampling method in which participants are selected based on their ease of accessibility, proximity, and willingness to participate, rather than random selection (Ahmed, 2024). Five districts from the southern part of Kerala were selected for data collection, as they were geographically closer to the researcher. The researcher visited schools across all five districts and obtained permission for data collection. Schools with more than 500 students in the secondary and higher secondary sections were included. Both public and private schools were considered, and the number of schools was chosen proportionately. Participants were students from classes VIII to XII, aged between 14 and 18 years, who could understand English well. Only students enrolled in regular schools and studying in the same school for at least the past two years were included, as this continuity was essential for assessing engagement and subjective well-being. Students with disabilities and special needs were excluded from the study. Table 2 illustrates the student demographics by gender and educational level.

Table 2. Participants demographic details

Demographics	Categories	Count	Percent
Location	Urban	727	55.8%
	Rural	575	44.2%
District	Kollam	397	30.5%
	Pathanamthitta	216	16.6%
	Kottayam	287	22.0%
	Thiruvananthapuram	300	23.0%
	Alappuzha	102	7.8%
Gender	Male	712	54.7%
	Female	590	45.3%

Measures

All instruments used in this study were adapted from previously validated and reliable measures of the relevant constructs. Each question is a Likert scale (Jebb et al., 2021; Joshi et al., 2015) with the choices: strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), strongly agree (5). Table 3 is the summary of the tools used in the present study. The Cronbach's alpha values >.60 indicate good reliability (Bernardi, 1994)

Table 3. Details of instruments used in the study

Construct	Item	Cronbach's alpha	Source	Sample items/subdimensions
Mathematics & Science attitude	9	.725	S-STEM survey tool (William & Ida Friday Institute for Education and Innovation, 2012a)	I am sure I could do advanced work in mathematics and science.
Engineering & Technology attitude	6	.763		I am good at building and fixing things.
21st century skills	11	.836		I am confident I can lead others to accomplish a goal.
Mathematics & Science career interest	8	.800	Career Interest Survey (Kier et al., 2013)	If I do well in my mathematics and science classes, it will help me in my future career.
Engineering & Technology career interest	8	.897		If I learn a lot about engineering and technology, I will be able to do lots of different types of careers.
Mathematics & Science teaching efficacy	10	.659	T-STEM survey tool (William & Ida Friday Institute for Education and Innovation, 2012b)	My mathematics and science teachers know the steps necessary to teach mathematics and science effectively.
Teacher leadership	6	.647		I think it is important that teachers take responsibility for all students' learning.
Student technology use	8	.684		Use technology to access online resources and information as part of activities.
Behavioral engagement	8	.870	Math and Science Engagement Scale (M.-T. Wang et al., 2016)	I keep trying even if something is hard.
Social engagement	6	.834		I try to understand other people's ideas in mathematics and science
Emotional engagement	5	.864		I enjoy learning new things about mathematics and science.
Joy of learning	4	.754	Student Subjective Well-being Scale (Renshaw et al., 2015)	I get excited about learning new things in class.
School connectedness	4	.674		I feel like I belong at my school.
Educational purpose	4	.736		I feel like the things I do at school are important.
Academic efficacy	4	.727		I am a successful student.

Procedure

The study's ethical protocols were reviewed and approved by the Institutional Review Board (IRB) of the researcher's university (CU: RCEC/00566/01/24, Dtd: 23-01-2024). The researcher reached out to schools across five southern districts of Kerala and received permission to conduct data collection in 30 schools. Once school authorities granted access, parents/guardians of eligible students were informed about the study through a consent form. The form included the study's purpose, procedure, potential risks and benefits, confidentiality assurance, and contact details for queries. Written parental consent was obtained before involving students. The researcher explained the objectives of the study, clarified that participation was voluntary, emphasized that responses would remain confidential, and reassured students of their right to decline participation or withdraw at any point without consequences. Only students who returned signed parental consent forms were included in the study.

Data collection was conducted in classrooms during school hours at times convenient for the schools. School staff assisted in arranging the sessions but did not remain present during completion of questionnaires to ensure privacy. The researcher personally administered the instruments, reading aloud standardised instructions to maintain consistency. Students completed the self-report questionnaires within 30-35 minutes. Out of 1350 distributed questionnaires, 1302 were fully completed and retained for analysis. This resulted in a 97% valid response rate.

Analysis and Discussion

The primary purpose of this research is to test the proposed conceptual model on the variables that affect STEM career interest and adolescents' subjective well-being in the State of Kerala, India. Further, it aimed to explore the mediating effect of Mathematics and Science teaching, Efficacy of Teachers, Mathematics and Science engagement of students, and teacher leadership, in the influence of STEM attitude, 21st Century Skills, and student technology use on STEM career interest and subjective well-being of adolescents. Path analysis using SEM is presented to test the proposed conceptual model. SPSS software version 19 and AMOS version 21 were used to analyse the quantitative data.

T-tests and ANOVA were conducted to check the mean differences in attitude towards STEM, STEM career interest, and Subjective Well-being across demographics. It was found that there was no significant difference in Attitude towards STEM ($t=-1.491$, $p>0.05$), and STEM Career Interest ($t=-.244$, $p>0.05$) across categories of location; however, there was a significant difference found in Subjective well-being ($t=-2.345$, $p<0.05$) across categories of location. It was found that there was no significant difference in Attitude towards STEM ($F=1.999$, $p>0.05$), and STEM Career Interest ($F=2.376$, $p>0.05$) across the five districts; however, there was a significant difference found in Subjective well-being ($F=16.696$, $p<0.05$) across the five districts. It is found that there was no significant difference in Attitude towards STEM ($t=1.316$, $p>0.05$), and STEM Career Interest ($t=.395$, $p>0.05$) across categories of Gender, however, there was a significant difference found in Subjective Well-being ($t=-7.268$, $p<0.05$) across categories of Gender. This indicates that location, districts, and gender have no influence on the effect of Attitude towards STEM-on-STEM career interest, but they could have moderated the effect of Attitude towards STEM on Subjective Well-being.

Model fit analysis

The standardized regression weights are reported in Table 4. The table indicates that STEM Attitude is significantly influencing Mathematics and Science Teaching Efficacy ($\beta=.696$, $p<0.01$); STEM Attitude is significantly influencing Mathematics and Science Engagement ($\beta=.635$, $p<0.01$); STEM Attitude is significantly influencing Teacher Leadership ($\beta=.640$, $p<0.01$); STEM Attitude is significantly influencing STEM Career Interest ($\beta=.597$, $p<0.01$); STEM Attitude is not significantly influencing Subjective Well-being ($\beta=.035$, $p>0.01$); 21st Century Skills is significantly influencing Mathematics and Science Teaching Efficacy ($\beta=-.448$, $p<0.01$); 21st Century Skills is significantly influencing Mathematics and Science Engagement ($\beta=-.259$, $p<0.01$); 21st Century Skills is significantly influencing Teacher Leadership ($\beta=-.419$, $p<0.01$); 21st Century Skills is significantly influencing STEM

Career Interest (β =-.401, p<0.01); 21st Century Skills is significantly influencing Subjective Well-being (β=.107, p<0.01); Student Technology Use is significantly influencing Mathematics and Science Teaching Efficacy (β= -.201, p<0.01); Student Technology Use is significantly influencing Mathematics and Science Engagement (β = -.208, p<0.01); Student Technology Use is significantly influencing Teacher Leadership (β=-.192, p<0.01); Student Technology Use is significantly influencing STEM Career Interest (β =-.922, p<0.01); Student Technology Use is not significantly influencing Subjective Well-being (β=.032, p>0.01); Mathematics and Science Teaching Efficacy is significantly influencing STEM Career Interest (β = -.606, p<0.01); Mathematics and Science Teaching Efficacy is not significantly influencing Subjective Well-being (β = .042, p>0.01); Mathematics and Science Engagement is significantly influencing STEM Career Interest (β = -.656, p<0.01); Mathematics and Science Engagement is significantly influencing Subjective Well-being (β = .540, p<0.01); Teacher Leadership is significantly influencing STEM Career Interest (β = -.446, p<0.01); Teacher Leadership is significantly influencing Subjective Well-being (β = .025, p>0.01).

Table 4. Standardized regression weights of the conceptual model

Paths		Estimate	
Mathematics and Science Teaching Efficacy	<---	Attitude towards STEM	.696**
Mathematics and Science Engagement	<---	Attitude towards STEM	.635**
Mathematics and Science Teaching Efficacy	<---	21st Century Skills	-.448**
Mathematics and Science Engagement	<---	21st Century Skills	-.259**
Mathematics and Science Teaching Efficacy	<---	Student Technology Use	-.201**
Mathematics and Science Engagement	<---	Student Technology Use	-.208**
Teacher Leadership	<---	Student Technology Use	-.192**
Teacher Leadership	<---	21st Century Skills	-.419**
Teacher Leadership	<---	Attitude towards STEM	.640**
Subjective Well-being	<---	Attitude towards STEM	.035
STEM Career Interest	<---	Attitude towards STEM	.597**
STEM Career Interest	<---	21st Century Skills	-.401**
Subjective Well-being	<---	21st Century Skills	.107**
STEM Career Interest	<---	Student Technology Use	-.922**
Subjective Well-being	<---	Student Technology Use	.032
Subjective Well-being	<---	Mathematics and Science Engagement	.540**
STEM Career Interest	<---	Mathematics and Science Engagement	-.656**
STEM Career Interest	<---	Mathematics and Science Teaching Efficacy	-.606**

Paths		Estimate	
Subjective Well-being	<---	Mathematics and Science Teaching Efficacy	.042
STEM Career Interest	<---	Teacher Leadership	-.446**
Subjective Well-being	<---	Teacher Leadership	.025

The indirect effect of STEM Attitude-on-STEM Career Interest through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β =-.284, p<0.01) was significant. Further, the direct effect of STEM Attitude on STEM Career Interest (β =.597, p<0.01) was significant, indicating partial mediation (Table 5). The indirect effect of STEM Attitude on Subjective Well-being through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β = .632, p<0.01) was significant. Further, the direct effect of STEM Attitude on Subjective Well-being (β = .035, p>0.01) was not significant, indicating full mediation. The indirect effect of 21st Century Skills on STEM Career Interest through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β = .163, p<0.01) was significant.

Table 5. Path analysis of the conceptual model

Hypothesis	Paths	β	Direct effect	Indirect effect	Total effect	Decision
1	STEM Career Interest <--- STEM Attitude	.597**	.597**	-.284**	.313**	Partial mediation
2	Subjective Well-being <--- STEM Attitude	.035	.035	.632**	.667**	Full mediation
3	STEM Career Interest <--- 21st Century Skills	-.401**	-.401**	.163**	-.238**	Partial mediation
4	Subjective Well-being <--- 21st Century Skills	.107**	.107**	-.169**	-.063	No mediation
5	STEM Career Interest <--- Technology Use	-.922**	-.922**	.624**	-.298*	Partial mediation
6	Subjective Well-being <--- Technology Use	.032	.032	-.126**	-.094**	Full mediation

Further, the direct effect of 21st Century Skills on STEM Career Interest (β =-.401, p<0.01) was significant, indicating partial mediation. The indirect effect of 21st Century Skills on Subjective Well-being through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β =-.169, p<0.01) was significant. Further, the direct effect of 21st Century Skills on Subjective Well-being (β = .107, p<0.01) was significant; however, the total effect was not significant, indicating no mediation. The indirect effect of Student Technology Use on STEM Career Interest through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β = .624, p<0.01) was significant. Further, the direct effect of Student Technology Use on STEM Career Interest (β = -.922, p<0.01) was significant, indicating partial mediation. The indirect effect of Student Technology Use on Subjective Well-being through Mathematics and Science Teaching Efficacy, Mathematics and Science Engagement, and Teacher Leadership (β = .126, p<0.01) was significant. Further, the direct effect of Student Technology Use on Subjective Well-being (β = .0325, p>0.01) was not significant, indicating full mediation.

SEM analysis is used to test the proposed conceptual model (Figure 1) for model fit and path analysis. The model fit indices are extracted from SEM analysis: CMIN/DF = 4.693 (<5), GFI = .970, AGFI = .945, NFI = .962, RFI = .939, IFI = .969, TLI = .951, CFI = .969 (closer to 1), RMSEA =.053 (<.08), RMR= .022 (<.08) PCLOSE=0.177 (>0.05). Based on the values, it is confirmed that the mediation model (Figure 2) is a good fit.

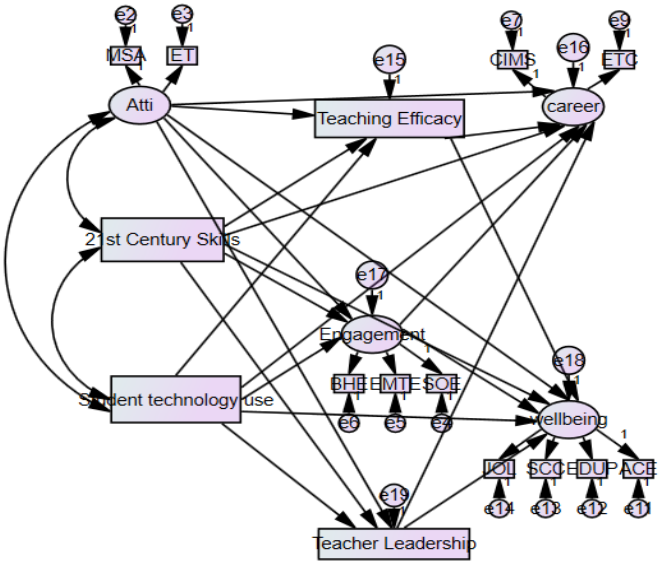

Figure 2. Conceptual model of the study

Note: MSA - Mathematics & Science attitude, ET - Engineering & Technology attitude, Atti-STEM attitude, CIMS - Mathematics & Science career interest, ETC - Engineering & Technology career interest, BHE - Behavioral engagement, EMTE - Emotional engagement, SOE - Social engagement, JOL - Joy of learning, SOC - School connectedness, EDUP - Educational purpose, ACE - Academic efficacy.

Theoretical implications

The findings of this study contribute significantly to the growing body of literature on STEM career interest among adolescents. The results support existing theories such as the Social Cognitive Career Theory (D. Wang et al., 2022), which emphasizes the role of self-efficacy, outcome expectations, and personal goals in career development. As investigated by Novianti et al. (2018), this study reinforces the notion that students' interest in STEM is influenced by multiple interconnected factors, including academic engagement, gender socialisation, and perceived career opportunities.

Furthermore, the study's exploration of gender and educational board as variables offers a refined understanding of how contextual and demographic factors moderate the engagement-well-being relationship. In contrast to Gok (2021), who investigated male students exhibiting higher STEM attitudes compared to female students, the present study reveals no significant difference in STEM attitude and STEM career interest across categories of gender and locality. This highlights the importance of adopting generalized models of classroom engagement that integrate socio-cultural factors and individual variations. Such insights support the development of refined theoretical frameworks that reflect population diversity, thereby advancing inclusive research in the STEM field. The research extends the theoretical understanding by integrating the concept of subjective well-being as a contextual factor influencing career aspirations. By linking subjective well-being to career interest, the study proposes a holistic model of career development that goes beyond academic achievement alone. This provides a foundation for further theoretical exploration of the interplay between emotional factors and career motivation in STEM education.

Moreover, the SEM analysis highlights the significant influence of student-related factors- STEM attitude, 21st century skills, and technology use-on both academic and affective outcomes. Among these, STEM attitude emerges as a key predictor, positively influencing teaching efficacy, classroom engagement, teacher leadership, and STEM career interest. This underscores the critical role of student mindset and motivation in shaping learning experiences and future aspirations, aligning with theories such as the Theory of Planned Behaviour (Ajzen, 1991) and Social Cognitive Theory (Bandura, 1991). Although STEM attitude did not have a direct effect on subjective well-being, its indirect effect through mediators like engagement and efficacy was significant, suggesting that positive attitudes translate into well-being only when supported by active classroom participation and effective instructional environments. In contrast, 21st-century skills showed a complex pattern: despite being essential for future readiness, their negative direct influence on teaching efficacy, engagement, and career interest indicates a possible mismatch between skill acquisition and traditional STEM instruction. This points to a need for integration of these skills into classroom practices.

Technology use also showed a negative direct impact on academic variables, particularly STEM career interest, possibly due to issues like cognitive overload or lack of purposeful use. Supporting Akasaka et al. (2023), its indirect effect on well-being through classroom process was significant, suggesting that student use of technology must be meaningfully mediated by the learning environment. Overall, these findings emphasize that student-level factors alone are not sufficient to enhance outcomes unless embedded within supportive classroom practices. Thus, theoretical models should incorporate both individual student dispositions and the mediating role of instructional and contextual elements. The interaction between attitude, skills, and technology use reveals a dynamic ecosystem where student engagement and well-being are shaped not only by what students bring to the classroom but also by how these factors are activated through the teaching and learning process.

Practical implications

The findings of the study highlight the importance of creating a learning environment that enhances both cognitive and emotional skills to stimulate STEM career interest among adolescents. Building on the findings of Kareem et al. (2022), this study also emphasizes the importance of incorporating 21st-century skills into STEM education, highlighting the need for schools and educators to make learning more practical, relevant, and aligned with real-world applications. By embedding real-world problem-solving activities and technology-enhanced pedagogies into the curriculum, educators can enhance students' intrinsic motivation and engagement in mathematics and science (Mohammed et al., 2021; Sasidharan & Kareem, 2024). This, in turn, can cultivate sustained interest in STEM careers.

Additionally, as highlighted by X. Luo et al. (2024), the present study also underscores the influential role of teacher efficacy and leadership in shaping students' STEM attitudes and career aspirations. The strong influence of STEM attitude on teaching efficacy, engagement, teacher leadership, and career interest highlights the importance of fostering positive perceptions of STEM among students through early exposure, real-life applications, and encouragement from teachers and mentors. Thus, professional development programs for teachers should emphasize not only subject mastery but also pedagogical innovation and leadership skills. Building teachers' confidence and ability to facilitate engaging STEM learning environments will help students connect academic content to future career possibilities (Shen et al., 2020). The findings related to technology use are consistent with those of Gaur and Kalita (2024), who advocate for schools to invest in structured and purposeful technology integration, avoiding unregulated digital exposure that could negatively affect students' focus and well-being. The full mediation of technology use on well-being suggests that this factor must be supported by engaging classroom practices and effective teaching strategies to enhance student well-being. Supporting Bharti et al.'s (2023) findings, school environments should promote student-centred teaching practices that nurture engagement, confidence, and leadership opportunities in STEM contexts. Curriculum planners should ensure that digital literacy, problem-solving, and collaboration are embedded meaningfully with STEM subjects rather than taught in isolation. Simultaneously, efforts to support students' subjective well-being – through supportive relationships, school connectedness,

and emotional support – can indirectly enhance academic interest and long-term career planning in STEM fields. Overall, the findings emphasize that promoting STEM success and well-being among adolescents requires a balanced approach that considers student attitudes, purposeful skill development, and supportive, well-structured classroom experiences.

CONCLUSION

The study contributes valuable insights into the interconnected dynamics of STEM attitude, 21st-century skills, and student technology use in shaping adolescents' STEM career interest and subjective well-being within the 21st-century classroom. By employing Structural Equation Modeling, the research demonstrates that, while students' attitude toward STEM strongly predicts both engagement and career aspirations, their influence on well-being is indirect and mediated by teaching efficacy, teacher leadership, and classroom engagement.

Notably, while 21st-century skills and technology use were found to support engagement and career interest, their impact on subjective well-being was less straightforward, indicating the need for more refined pedagogical strategies that balance cognitive skill-building with emotional development. The study also underscores the critical role of teacher efficacy and leadership in fostering engaging and supportive learning environments that cultivate both academic success and subjective well-being. Importantly, the full mediation effect observed in several pathways reinforces the importance of considering indirect influences and mediating variables in educational research and policy.

Building on these findings, it becomes evident that fostering adolescents' STEM career interest and subjective well-being requires a multifaceted approach that goes beyond curriculum reforms or isolated skill development. A holistic educational model that integrates cognitive, emotional, and social dimensions of learning is essential in the 21st-century classroom. The study suggests that when students perceive their teachers as confident, supportive, and effective leaders, they are more likely to engage meaningfully in classroom activities, which in turn enhances their academic motivation and subjective well-being. This chain of influence highlights the interdependence of teacher quality, instructional design, and student outcomes. Moreover, while the development of 21st-century competencies such as critical thinking, collaboration, and digital literacy remains crucial, the findings caution against a purely instrumental approach to education. Instead, they call for pedagogical practices that internationally nurture emotional resilience, a sense of belonging, and learner autonomy. By attending to both direct and indirect pathways of influence, stakeholders in education, including policy makers, school leaders, and teacher educators, can design more relevant interventions that not only prepare students for future STEM careers but also support their holistic growth and long-term well-being.

LIMITATIONS AND FUTURE WORK

Several limitations are present in this study. The cross-sectional design and reliance on self-report measures restrict causal inferences, meaning that the observed relationship should be interpreted with caution. In addition, the study's focus on a specific regional context (Kerala, India) with its distinctive educational policies and cultural context may limit the generalizability of findings to other Indian states or international contexts. The demographic variables location, district, and gender showed significant differences in subjective well-being, indicating that this was not controlled in this study. Furthermore, future research should adopt longitudinal designs to examine how these relationships evolve over time, particularly as students transition through different educational stages and career decision points. Moreover, further exploration into how digital literacy, when coupled with emotional intelligence and adaptive learning environments, affects long-term academic and career outcomes is warranted. Also, in this study, 21st-century skills were found to enhance engagement; the reverse possibility- that engagement fosters these skills- cannot be ruled out. This limitation highlights the need for longitudinal research to establish the directionality of these relationships.

Moving forward, a more integrated approach is essential; one that brings together educators, curriculum designers, technologists, and psychologists to design interventions that not only build STEM competencies but also support students' mental health and motivation. Training teachers in both technological integration and socio-emotional support will be vital to ensure that classrooms evolve into inclusive, engaging, and future-ready learning spaces.

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