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The effects of specialist co-teaching STEM intervention on primary students' attitudes, perceptions, behaviors, and career aspiration: A mixed-methods study in China

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Abstract

STEM education, essential for imparting problem-solving skills, is increasingly emphasized in primary schools worldwide. However, the efficacy of specialist co-teaching STEM interventions at this level is less explored than in higher education. This study evaluates the impact of a specialist co-teaching STEM intervention on primary students' attitudes, perceptions, behaviors, and STEM-related career aspiration. The intervention, rooted in the Theory of Planned Behavior (TPB), introduces students to notable STEM professions. The pilot study was conducted for survey validation and involved 203 targeted primary students. Of these, 40 underwent a one-month intervention after obtaining parental consent. A mixed-methods approach was adopted, introducing hands-on tasks associated with two STEM professions: airplane piloting and bridge engineering. The study employed pre and post quasi-experiment surveys and video-recorded class observations to gauge changes in students' attitudes, perceptions, and career aspiration, and to capture learning behaviors during the intervention. The study revealed enhanced attitudes, perceptions, and STEM career aspiration among students after the intervention. Observations emphasized the interactive nature of the intervention, underscoring its effectiveness in enriching students' STEM learning experiences and fostering positive STEM career aspiration.

Keywords: Career aspiration, Co-teaching with STEM specialist, STEM attitudes, STEM perception, STEM intervention

Introduction

With the advancement of science and technology, talents with techniques and skills reflect a country's capability for technological innovation and, to a large extent, represent a country's overall competitiveness (Li & Xu, 2020). Recognizing this, educators globally advocate for STEM (Science, Technology, Engineering, and Mathematics) education. Over the years, debates have continued among educators and scholars about whether the four fields should be treated as a collective entity in the definition (Gonzalez & Kuenzi, 2012). Researchers remain flexible when defining STEM in their context to reflect better the research they implement (Hasanah, 2020). Nadelson and Seifert (2017) described a continuum for defining STEM, with domain-specific STEM at one end and integrated domain-general STEM at the other. The complexity increases from domain-specific STEM to domain-general STEM, which is more integrated to the extent.

STEM disciplines not only impart academic knowledge but also foster 21st-century skills, such as adaptability and system thinking (Dare et al., 2021). Early exposure, especially during primary education, can influence students' future academic and career trajectories (Becker & Park, 2011). Research has shown that students' attitudes and perceptions towards STEM play a pivotal role in their career choices (McDonough et al., 2021). From a long-term perspective, it is a national priority to nurture positive attitudes and perceptions in the young generation for higher motivations of learning STEM skills, so that they can apply the rules of reason, scientific facts, aesthetics of art, and sparks of creativity to improve society (Wiebe et al., 2018). From a short-term perspective, understanding students' attitudes and the relationship between course choice and future career orientation can provide critical feedback to educators and teachers regarding pedagogy designs, teaching instructions, and course materials implemented (Tseng et al., 2013), thus, in turn, leading to instructional and curricular changes that may support and enhance students' STEM learning.

Teachers are at the forefront of this educational endeavor. Their pedagogical approaches can profoundly shape students' STEM experiences. STEM co-teaching, where two teachers collaboratively deliver instruction, has emerged as a promising strategy, especially when involving a STEM specialist. The most evident benefits for adopting the co-teaching strategy in STEM education are better student engagement (Friend, 2014). Specifically, co-teaching offers intensive support and mitigates problematic behaviors, while also providing students with an opportunity to observe authentic collaboration between their teachers, resulting in a good influence on students' emotional, social, and learning skills (Lynch et al., 2015). Suggested by Lochner et al. (2019), co-teaching between two teachers who work together can provide students with greater opportunities to be fully included in class and, therefore, lead to greater improvement in their cognitive engagement in the learning process. Roehrig et al. (2012) examined science and mathematics teachers' STEM lessons using a variety of pedagogical approaches including teaming, solo teaching, and co-teaching. They found that STEM instruction of its highest quality can be achieved through co-teaching when the two teachers co-plan and co-implement the lessons in class. A recent study that discusses the effectiveness of co-teaching in STEM education can be seen in the work by Kelley and colleagues. The study highlighted that when science and engineering teachers worked collaboratively through an engineering design within a community of practice, it significantly increased their teaching self-efficacy. This implies that high-quality STEM instruction can indeed be achieved through co-teaching, where teachers not only plan but also implement lessons together, fostering a deeper understanding and application of STEM concepts (Zhou et al., 2023).

Our study delves into the impact of specialist co-teaching on primary students' attitudes, perceptions, and STEM career aspiration. While prior research has highlighted the benefits of STEM co-teaching from teachers' perspectives (e.g., Kokko et al., 2021; Lichtenberg et al., 2008), this investigation offers insights from the students' viewpoint. In addition, this co-teaching approach is the collaboration between schoolteachers with the STEM specialist. A large body of literature pointed out that in practice, the use of STEM experts/specialists in STEM education is quite beneficial because experts in STEM areas play crucial educational roles by enticing and preparing children for STEM learning and future career plans (Gamse et al., 2017). Therefore, this study attempted to further investigate the influence of co-teaching with a STEM specialist on students' learning from the aspects of attitudes (i.e., perceived usefulness and perceived fun), perceptions (i.e., intention to learn and empowerment), and career aspiration, enriching the literature on how such collaboration enhances student outcomes. To fulfill the research goals, we therefore formulated the following research questions:

RQ1: How does the STEM intervention using specialist co-teaching influence students' attitudes and perceptions?

RQ2: How does the STEM intervention using specialist co-teaching influence students' career aspiration?

RQ3: What are the students' classroom behaviors and interactions emerging in the STEM intervention? How do these behaviors and interactions showcase the effect of the intervention?

Literature review

STEM education in China

China's focus on STEM education began in the 1990s as part of its transition from an agricultural to a science and technology-based economy. This initiative facilitated foreign expertise and technology transfer, while also sending Chinese students abroad to study STEM disciplines, particularly in the US. By 2017, China had approximately 6 million STEM students (Ma, 2021). In 2000, the Chinese government implemented new educational policies to encourage STEM studies, aiming to improve students' life prospects and societal contributions (Loyalka et al., 2021). STEM education expanded across all levels, from elementary school to university, with institutions motivated to increase STEM enrollment to remain competitive. China has made significant progress in delivering STEM education to strengthen its scientific capabilities and productivity in sectors, such as robotics, genetics, and bioengineering (Ma, 2021). For instance, non-profit organizations, such as Code Club Hong Kong, Mission To Learn, and Youth Technology Foundation, have been established to support STEM education. Collaborations between schools and higher education institutions are also encouraged. These efforts collectively demonstrate China's commitment to advancing STEM education, aiming to prepare students for future technological challenges and maintain the country's competitive edge in scientific and technological innovation.

Types of co-teaching in practice

With the increased popularity of STEM education in China, the demand for high-quality STEM education has skyrocketed among students of different ages (Mau & Li, 2018). Quality STEM learning experiences can increase students' motivation and career interests in STEM (Hiğde & Aktamış, 2022). However, many K-12 students lack interest in STEM due to inadequate exposure and engaging courses (Margot & Kettler, 2019). As a result, a variety of teaching strategies have been integrated in STEM to improve students' learning experience (Kong et al., 2019; Kong & Wang, 2023). Among the teaching strategies, co-teaching has been popularized among schools in China. Cook and Friend (1995) define it as a teaching delivery choice rooted in collaboration. This approach combines teachers' expertise to enhance students' attitudes and perceptions towards STEM (Kokko et al., 2021; Lynch et al., 2015), potentially improving efficacy, motivation, and career aspiration (Kang & Keinonen, 2017; Tran, 2018).

In China, educators and practitioners seek the optimal way to implement STEM education using co-teaching (Chen et al., 2020; So et al., 2021). For example, quite a few learning institutions and schools in Beijing, Shanghai, and Hangzhou have implemented co-teaching strategies in their STEM education, where they have successfully experimented with a variety of co-teaching strategies (NIES, 2021). In the co-teaching relationship, the standard form of collaboration is usually a general education teacher with another teacher specializing in a specific educational domain to support academic diversity in the classroom (Cheng & So, 2020). Five common co-teaching practices are identified in the literature (Brendle et al., 2017; Friend, 2014). Team Teaching: Both teachers take turns leading instruction, sometimes simultaneously illustrating points. Parallel Teaching: The class is divided into two groups, with each teacher instructing half the students on the same material concurrently. Alternative Teaching: One teacher instructs the majority, while the other teaches a smaller group using a modified version of the lesson. One-teach-one-observe: One teacher leads instruction while the other observes and collects data on student learning. One-teach-one-assist: One teacher leads the lesson while the other roams the classroom, providing individual support to students. Each approach has unique characteristics and benefits, requiring different levels of collaboration and planning between the co-teachers (Chitiyo, 2017).

In this study, the one-teach-one-assist approach was adopted. It was further adapted to incorporate online teaching, resulting in a hybrid co-teaching setup with an online STEM specialist and an offline class teacher supporting students' learning. This hybrid approach allows for the expertise of a STEM specialist to be leveraged while maintaining the support of a classroom teacher. It demonstrates how traditional co-teaching models can be adapted to incorporate technology and online learning, potentially offering new possibilities for collaborative instruction in STEM contexts.

The important role of a STEM specialist in co-teaching

STEM specialists play a pivotal role in preparing students for future STEM careers and enhancing their learning and motivation in STEM education (So et al., 2021). Their active participation in primary and secondary education is increasingly recognized, with science programs integrating these specialists showing a rising trend (Gamse et al., 2017). The impact of STEM specialists extends beyond mere knowledge transfer. Meaningful interactions and supportive relationships with these experts have been shown to significantly influence student outcomes across multiple dimensions, including academic achievement, psychological well-being, and behavioral development (Rhodes & DuBois, 2008). This multifaceted impact highlights the holistic nature of effective STEM education, where technical knowledge is intertwined with personal growth and mentorship.

In partnership with schoolteachers, STEM specialists can effectively create design-based activities that cater to student needs and their learning. Firstly, these activities broaden students' understanding of various STEM professions and their roles in society. Secondly, they ignite career aspiration in STEM fields, providing tangible connections between classroom learning and real-world applications (Cheng & So, 2020; So et al., 2021). This approach bridges the often-perceived gap between academic study and professional practice, making STEM careers more accessible and appealing to students. The role of STEM specialists is particularly noteworthy. Acting as mentors and role models, these professionals demonstrate first-hand how STEM knowledge is applied to solve complex, real-world problems (Gamse et al., 2017). This practical demonstration of STEM in action not only enhances students' understanding but also cultivates critical thinking and problem-solving skills essential for future STEM careers.

Students’ attitudes, perceptions, and career aspiration

This study attempted to explore two types of STEM attitudes among the students, namely, perceived usefulness and perceived fun. The investigation of these attitudes originated from computer/technology use proposed by the Technology Acceptance Model (Davis, 1989). Perceived usefulness is defined as “the degree to which a person believes that using a particular system would enhance his or her performance” (Davis, 1989, p. 320). Huang (2014) defined perceived fun as the degree to which the act of using a particular system is regarded to be joyful in and of itself, regardless of any anticipated performance outcomes. Over the decades, a growing body of research explored these attitudes among students in the context of STEM education (e.g., Mutambara & Bayaga, 2021; Toma et al., 2019).

In addition, two types of STEM perceptions were explored among the students, namely, intention to learn and empowerment. Intention represents an individual’s motivation in the sense of her or his conscious plan or decision to exert effort to enact the behavior (Conner & Armitage, 1998). Empowerment encompasses an individual’s perception of their ability to perform a behavior, which closely aligns with Bandura’s (1977) concept of self-efficacy. Both constructs relate to an individual’s belief in their capabilities, but empowerment extends beyond this to include a broader sense of control and mastery (Zimmerman, 1995). This expanded conceptualization allows for a more comprehensive understanding of students’ perceived agency in STEM fields, encompassing not only their belief in their abilities but also their sense of autonomy and impact. Indeed, Kong et al. (2019) explained that empowerment entails an enabling process in which people show awareness and motivation for the desirable outcomes.

STEM-related career aspiration refers to students’ future vision and anticipation for careers in STEM disciplines (Du & Wong, 2019). This aspiration is crucial in helping students define career goals and internalize relevant work or learning experiences. Research has shown that positive STEM experiences, including effective pedagogy and student-teacher relationships, can foster career aspiration (e.g., Quinn & Lyons, 2011). These experiences increase students’ motivation and engagement in STEM learning, positively influencing their decisions to pursue post-secondary STEM education and related careers (Kitchen et al., 2018).

Theoretical framework

This study is primarily grounded in the Theory of Planned Behavior (TPB) introduced by Ajzen (1991), while also drawing insights from the cognitive apprenticeship model (Collins et al., 1991) to provide a comprehensive framework for understanding STEM education in a co-teaching context. TPB, an extension of the Theory of Reasoned Action (Ajzen & Fishbein, 1980), offers a comprehensive lens to understand human behavior by emphasizing the role of attitudes, subjective norms, and perceived behavioral control in shaping intentions and actions. Attitude is defined as an individual's predisposition to a certain course of action. Basically, it is how an individual feels about something and what drives his decision to follow through with that course of action or not. Subjective norms are defined as the perceived social norms for engaging in a behavior. Whether the perception is irrelevant, as long as an individual believes that engaging in a behavior can result in either positive or negative responses. Perceived behavioral control is defined as the perceived ease or difficulty of performing a particular behavior. If an individual perceives a behavior as easy, he is likely to perform that behavior. Conversely, if he thinks something is too difficult or challenging to accomplish, then there is a chance that he might not follow through with it. Conner (2020) characterized TPB as a deliberative processing model, positing that individuals engage in a systematic process when forming attitudes and intentions towards a behavior. This process involves weighing potential outcomes, considering social norms, and assessing one's ability to perform the behavior. Ajzen (2020) added further that more favorable attitudes and subjective norms, coupled with greater perceived control, lead to stronger behavioral intentions and, consequently, an increased likelihood of performing the behavior. In our study, we leverage TPB constructs to investigate students' attitudes (perceived usefulness and perceived fun), perceptions (intention to learn and empowerment), and actual classroom behaviors in STEM education. The alignment of our study variables with the core constructs of TPB is illustrated in Table 1.

TPB is a versatile model for predicting attitude (past/current) –behavior (future) relationships in a complex social context. Over the years, TPB has been used as an overarching theoretical framework in the STEM literature. For instance, Moore and Burrus (2019) successfully applied TPB to predict STEM majors and career intentions. Davenport et al. (2021) applied TPB to investigate STEM career choices among high school students. In addition, Nadlifatin et al. (2020) investigated students' intention to use the blended learning system using TPB. The robustness and adaptability of the theory have been validated across diverse STEM contexts to predict students' attitude-behavior relationships (Teo & Lee, 2010).

While TPB provides a robust framework for understanding individual cognitive processes, the cognitive apprenticeship model (Collins et al., 1991) offers complementary insights into the social and contextual aspects of learning, particularly relevant in our co-teaching STEM environment. Cognitive apprenticeship emphasizes the processes of modeling, coaching, scaffolding, articulation, reflection, and exploration in learning, aligning closely with the collaborative nature of co-teaching and the hands-on approach often employed in STEM education. The integration of these two theoretical perspectives allows for a more holistic examination of students' STEM learning experiences. TPB helps us understand the internal cognitive processes that shape students' attitudes and

Table 1 Definitions of the study variables and connection with the theory of planned behavior

	TPB definitions	Study variable definitions
1	"Attitudes": This is the degree to which a person views the behavior of interest in a positive or negative perspective.	Perceived fun of STEM: This is a positive attitude towards STEM. Perceived usefulness of STEM: This value or attitude is usually socially embedded as students learn within groups, schools, and communities. All the important ones have influential impact on their formation of subjective norms.
2	"Perceived behavioral control": This relates to a person's sense of how easy or difficult he is to perform the behavior of interest.	Empowerment in STEM: This is a psychological construct that refers to implicit ability beliefs over certain behaviors involved/or the feeling of gaining control over them.
3	"Behavioral intentions": This refers to the motivating factors that impact a certain behavior, the greater the intention to perform the behavior, the more likely it will be accomplished.	Intentions to learn STEM: This refers to the motivational intention to engage in learning STEM.
4	"Actual behaviors": The behaviors are actually carried out by the individual.	Classroom behaviors: This refers to actual classroom learning behaviors and interactions observed in the STEM class.

intentions towards STEM, while cognitive apprenticeship illuminates how these attitudes and intentions are influenced and reinforced through structured social interactions and guided experiences in the co-teaching environment. For instance, the modeling and coaching aspects of cognitive apprenticeship may influence students' perceived behavioral control and subjective norms (TPB constructs), as they observe and receive guidance from both the STEM specialist and the classroom teacher. Similarly, the scaffolding and articulation processes may enhance students' attitudes towards STEM by making complex concepts more accessible and allowing students to verbalize their understanding, potentially increasing their perceived usefulness and fun (TPB constructs). This integrated approach not only addresses the multifaceted nature of STEM learning but also provides a theoretical basis for understanding the unique dynamics of co-teaching in shaping students' STEM attitudes, perceptions, and career aspiration.

Methodology

Analytical method

Our study employed a mixed methods design (Creswell & Plano Clark, 2011), integrating both quantitative and qualitative data to comprehensively address the research questions. This approach is championed by scholars like McKim (2017) and Toomela (2008) for its

Table 2 Summary of the mixed methods research design of the study

	Survey Data1	Survey Data2	Video Data
Methodologies	Survey questionnaires - Pilot study for scale validation	Survey questionnaires - STEM intervention for pre- and post-changes	Class observations - Class observations conducted for all 8 STEM units across 4 classes
Tools	Instrument	Instrument	Observation protocol
Sample Involved	*N* = 203	*N* = 40 for intervention	The same students from the intervention *N* = 40
Research Questions	NIL	RQ1, RQ2 RQ1: How does the STEM intervention using specialist co-teaching influence students' attitudes and perceptions? RQ2: How does the STEM intervention using specialist co-teaching influence students' career aspiration?	RQ3 RQ3: What are the students' classroom behaviors and interactions emerging in the STEM intervention? How do these behaviors and interactions showcase the effect of the intervention?
Analytical Strategies	Pilot study - Confirmatory factor analysis	STEM intervention - Paired sample T test	Class observations - Coding - Descriptive analysis - One-way ANOVA

ability to provide a holistic view of the investigated phenomena. In our study, we assessed the impact of a specialist co-teaching intervention in STEM education on primary students. Specifically, we utilized questionnaires to capture changes in students' attitudes, perceptions, and career aspiration. Additionally, class observations during the intervention captured students' behaviors and interactions with teachers, offering insights to potentially scaffold why these changes occurred in the specialist co-teaching. This mixed methods design thus leveraged the strengths of both methodologies, synthesizing different perspectives for a more comprehensive understanding. Table 2 provides a summary of the research methods, data, and analyses aligned with the proposed research questions.

Participants and sample procedures

Students who were from similar socio-economic backgrounds and had no prior experience of STEM learning in the target school were invited to participate. Students on the contact list were invited for the one-month STEM intervention. In total, 203 students submitted a one-time survey of this study. Among these participants, the average age of was 10.8 (*SD* = 1.02). The big proportion of them were from fifth grade (65.6%), the remaining were from fourth grade (15.9%) and sixth grade (18.5%). In addition, 57.7% were males, while 42.3% were females. The students were further contacted to participate in the STEM intervention. After obtaining parental consent, 40 students were enrolled. These students were randomly divided into four classes (A-D) for the intervention. Each class contained 10 students. They had the STEM intervention for four consecutive weeks, with sessions held twice a week. The majority (80.5%) were fifth graders, with an average age of 10.4 (SD = 1.14). There were 64.9% males and 35.1% females in the sample. These 40 students were also observed using video recordings over the eight units of the intervention. Online surveys for both pre- and post-intervention were developed using the WENJUAN platform (https://www.wenjuan.com/). The post-survey included additional items about the students' course experiences. Students accessed the surveys via a QR code, which they could complete on mobile devices or computers.

Survey measures

The survey questions were all adapted from earlier scales that had been tested and published by other researchers. Perceived usefulness, perceived fun, and intention to learn STEM were measured by the three subscales developed by Chintalapati and Daruri (2017). These were modified for the STEM context, resulting in 12 items. STEM empowerment was measured by seven items from Kong et al.'s (2019) digital empowerment scale. Students' career aspiration was measured by five items about career interest/preference towards STEM from the Career Interest Questionnaire (CIQ) developed by Christensen and Knezek (2017). All scales were anchored on a 4-point Likert scale. Demographic variables, such as age, gender, grade, parents' job position, daily computer use, and interest in STEM were also collected and included as control variables in our study.

Design of specialist co-teaching STEM intervention

Our study utilized specialist co-teaching as a primary tool in the intervention. The learning environment, including course units, hours, technology support, and instructors, was identical for all. In our study, a professor (male) renowned for his STEM expertise was invited to instruct the course. A science teacher (female) from the target school was assigned as the class teacher. The specialist and the teacher collaborated extensively beforehand, refining course content, teaching materials, and co-teaching strategies. They integrated design-based activities to enhance students' grasp of STEM professions, supplemented by multimedia resources like short videos about an airplane pilot and a bridge engineer. The course, spanning eight hours over a month, blended theoretical and hands-on knowledge, emphasizing the roles of pilots and bridge engineers in order to nurture students' future STEM career aspiration (see details in Appendix A). The course was conducted in a multimedia classroom with interactive quizzes and educational games to engage students. Group experiments were also included, with the specialist highlighting key concepts and the class teacher assisting groups as needed.

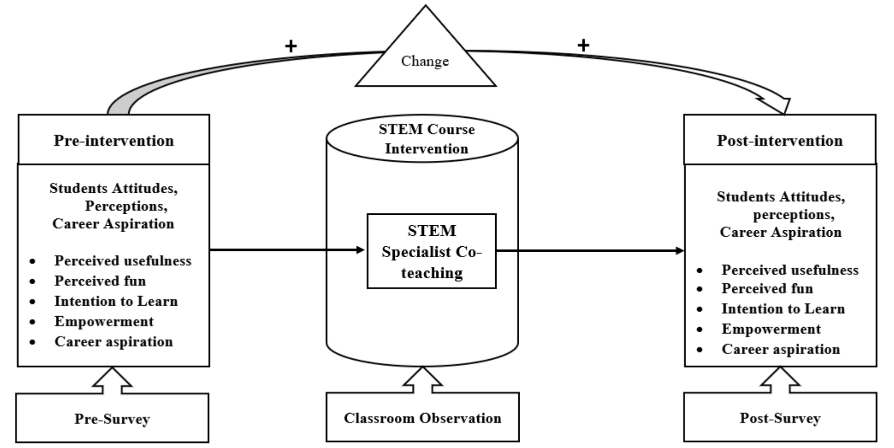

Fig. 1 STEM intervention design of the study

This figure shows details of the specialist co-teaching STEM intervention design with pre- and post-surveys and class observation methods in this study.

Class observation

Class observations provided insights into classroom dynamics and interactions (Granström et al., 2023). Our goal was to capture authentic teaching and learning experiences during the STEM intervention. Throughout the eight STEM units, every class was observed and documented. Four cameras, positioned at different classroom corners, recorded student behaviors and interactions, such as collaboration and feedback-seeking. The primary camera, near the interactive whiteboard, focused on both the board content and student interactions. The other three cameras offered alternative angles, ensuring comprehensive coverage. Each observation lasted approximately 60 minutes, totaling 32 hours for the entire STEM course across the four classes.

Due to the inherent diversity of teaching and learning practices, there is a growing call for researchers to measure the degree of practices carried out in classrooms that are in line with practice recommendations (Munter et al., 2015). Class observation protocols have emerged as valuable tools for this, offering insights into classroom dynamics (Gleason et al., 2017; Granström et al., 2023). Originating from the need to evaluate complex aspects of mathematics and science teaching (Horizon, 1998), these protocols have evolved to cover various subjects and focus on student learning (Smith et al., 2013). Smith et al. (2013) developed a protocol to assess time allocation in STEM classrooms, providing observers with standardized codes to gauge teaching and learning alignment. Based on their protocol, we developed a STEM protocol tailored for primary school settings. This protocol targets ten specific student behaviors central to our STEM intervention, as commonly observed in other STEM studies (Smith et al., 2013).

Results

Explorative analysis

Pilot questionnaires were administered to the students on the contact list. In total, 210 targeted students joined the pilot, and 203 students submitted their surveys for survey validation (response rate is .96). Specifically, confirmatory factor analysis (CFA) was conducted to test perceived usefulness, perceived fun, intention to learn, STEM empowerment, and career aspiration simultaneously. Results indicated good construct validity of the survey scales to ensure subsequent data analysis using the survey questionnaires in the study (χ^2 = 527.114, df = 233, CFI = .92; TLI = .90, RMSEA = .08).

Then descriptive statistics, such as means and standard deviations, were computed to obtain a quick understanding of the data collected during the STEM intervention. Skewness and kurtosis were checked for data normality. Results showed that the data were slightly skewed, particularly for perceived fun. As most of the participants indicated that the STEM course was fun and interesting, this skewed distribution was somewhat expected in this study. Nevertheless, most of the variables showed fairly normal distribution, as they were within the range of [-1,+1] for skewness and [-3,+3] for kurtosis (Kline, 2005). Cronbach's reliability test was also conducted for the scale reliability. Higher values of Cronbach's alpha are better, and the recommended value is 0.7 or higher (DeVellis, 2003). In this study, results indicated a high level of internal consistency for the scales used in the survey. Table 3 shows the descriptive statistics, reliabilities, and correlations of the study variables using pre-survey data.

We also conducted additional analyses on gender using independent sample T-tests to explore if there were any gender differences. Specifically, the Mann-Whitney U-test, a non-parametric alternative to an independent sample T test, was adopted as the data of the male student sample were not normally distributed for some study variables (i.e., empowerment and perceived fun). According to previous studies, gender significantly influences students' STEM learning experiences (Delaney & Devereux, 2019; Hazari et al., 2013). This influence manifests through students' attitudes, interests, confidence,

Table 3 Descriptive statistics, scale reliabilities (in parentheses), and correlations

Pilot Study (*n* = 203)									
	M	*SD*	Skewness	Kurtosis	PU	PF	IL	EP	CA
PU	2.03	.44	-1.61	1.72	*(.882)*				
PF	2.23	.38	-1.89	2.84	.821**	*(.878)*			
IL	2.09	.46	-1.10	.31	.830**	.783**	*(.903)*		
EP	1.92	.27	-1.60	1.95	.801**	.806**	.830**	*(.933)*	
CA	1.73	.37	-1.15	.58	.760**	.700**	.775**	.818**	*(.869)*

Note. PU is perceived usefulness; PF is perceived fun; IL is intention to learn; EP is empowerment; and CA is career aspiration. * stands for $p < .05$; **stands for $p < .01$, and *** stands for $p < .001$.

Table 4 Independent-sample T test for the students' gender role

	Male students (n = 109)		Female Students (n = 58)		
	M	*SD*	*M*	*SD*	*p*-value
PU	3.47	.81	3.25	.89	.013*
PF	3.55	.78	3.39	.88	.114
IL	3.31	.85	3.00	.86	.003**
EP	3.40	.82	3.27	.75	.032*
CA	3.27	.85	2.98	.79	.004**

Note. PU is perceived usefulness; PF is perceived fun; IL is intention to learn; EP is empowerment; and CA is career aspiration. * stands for $p < .05$; **stands for $p < .01$, and *** stands for $p < .001$.

persistence, and motivation in STEM subjects. This study explores gender influences on students' STEM attitudes (perceived usefulness and fun), perceptions (intention to learn and empowerment), and career aspiration, contributing to the ongoing effort to understand and mitigate gender disparities in STEM education.

Results showed that male students reported a higher level of perceived usefulness (Mmale = 3.47, Mfemale = 3.25, p = .013), intention to learn (Mmale = 3.31, Mfemale = 3.00, p = .003), empowerment (Mmale = 3.40, Mfemale = 3.27, p = .032), and career aspiration (Mmale = 3.27, Mfemale = 2.98, p = .004) than the female students. However, there appeared to be no significant gender differences in terms of perceived fun between the male students (Mmale = 3.55) and female students (Mfemale = 3.39), even though the male students reported slightly higher perceived fun than their counterparts. Table 4 summarizes the results of the independent sample T tests based on gender.

Paired sample T test results for the STEM intervention

For RQ1 and RQ2, paired sample T tests were conducted in order to examine the potential changes in the students' attitudes, perceptions, and career aspiration after the students completed the intervention adopting STEM specialist co-teaching. Results suggested that students showed a significant increase in perceived usefulness, perceived fun, intention to learn, STEM empowerment, and career aspiration after the intervention. Table 5 shows the results of the paired sample T tests, indicating that this intervention course seemed to be quite effective in enhancing the students' attitudes and career aspiration. Results answered RQ1 and RQ2, indicating that the students, after completing the course, reported changes in perceived usefulness, perceived fun, intention to learn, empowerment, and career aspiration.

Class observation results for the STEM intervention

To explore RQ3, video content analysis (Baveye et al., 2017; Wang & Ji, 2015) was conducted with the guideline of the class observation protocol. In total, 10 categories for

Table 5 Results of the paired sample T test

Co-teaching group						
	Pre-survey (*n* = 40)		Post-survey (*n* = 40)			
Item	*M*	*SD*	*M*	*SD*	Mean diff	t
PU	2.03	.44	3.64	.51	-1.61	-18.17***
PF	2.23	.38	3.80	.48	-1.58	-18.85***
IL	2.09	.46	3.17	.79	-1.08	-8.98***
EP	1.92	.27	3.48	.49	-1.56	-17.19***
CA	1.73	.37	3.19	.76	-1.46	-10.98***

Note. PU is perceived usefulness; PF is perceived fun; IL is intention to learn; EP is empowerment; and CA is career aspiration. * stands for $p < .05$; **stands for $p < .01$, and *** stands for $p < .001$.

student classroom behaviors were included: (1) Listening to STEM specialist /notes-taking (Ls); (2) Problem-solving/individual thinking (INDs); (3) Group discussion; (4) Group STEM activities (WGs); (5) Other group activities (OGs); (6) Student answering questions (QAs); (7) Student asking questions (SQs); (8) Student ability of predicting and analyzing (PRDs); (9) Student presentation of their ideas (SPs); (10) Interactive test or quiz (TQs). By having the classes observed, students' behaviors and interactions with their teachers could be analyzed using the following analytical steps which are common in video content analysis, including feature extraction, structure analysis, abstraction, and indexing (Dimitrova et al., 2002). Students' classroom behaviors were coded according to the STEM class observation protocol.

As mentioned, the class conditions, including the teachers, units taught, and materials used, were identical across the four classes. Thus, we assumed that the differences in the students' behaviors and classroom interactions observed across the four classes would be minimal. Tables 6 and 7 show the average classroom behaviors and interactions observed across the four classes. The one-way analysis of variance (ANOVA) results indeed provided evidence that there were no differences across the four classes regarding the students' classroom behaviors as well as classroom interactions observed. For students' classroom behaviors, (F (3, 36) = .009, n.s.), and Tukey post hoc test also revealed that behaviors observed were not statistically different between classes. Similarly, for classroom interactions, (F (3, 24) = .043, p = n.s.), and the Tukey post hoc test also showed no statistical difference in classroom interactions between classes.

Table 6 Average counts of the students' behaviors observed across classes

	L	IND	CG	WG	OG	QA	SQ	PRD	SP	TQ
Class A	10	7	11	14	10	8	1	7	1	7
Class B	10	7	11	15	10	7	1	7	1	7
Class C	11	7	11	15	10	8	1	7	1	7
Class D	12	6	10	15	9	8	1	7	1	6

Table 7 Average counts of the classroom interactions observed across classes

	IGs	IGc	TQs	TGs	QAs	DSs	TCs
Class A	9	7	4	3	8	5	2
Class B	10	8	4	3	8	5	3
Class C	11	7	4	3	9	5	2
Class D	12	8	3	3	9	5	2

Descriptive results also indicated that students showed active learning behaviors, such as problem-solving, group discussion, teamwork, group reflection, assumption making and predictions, according to the class observations over the eight units across the four different classes (Figure 2). In addition, the students were also given opportunities for experiments and in-class tests which, in turn, allowed them to interact with their classmates by teaming up for the same task and discussing the questions before proposing the responses. It was also observed that students in this intervention course tended to show active participation in other class tasks (e.g., task collaboration between students and the specialist), because the intervention course with STEM specialist co-teaching utilized interactive educational technology, such as answering devices for online quizzes, games, animations, and a smart whiteboard that automatically showed student scores, task instructions, and teacher feedback. As a consequence, students were found to be active and engaged in discussions and interactive in the learning process.

Results of the class observations suggested that there was a general pattern in the students' behavior observed over the eight units of the intervention. Though the teachers' class behaviors were out of the scope of the current study, investigation of the students' classroom behaviors out of the teacher context was deemed to be limiting, because the

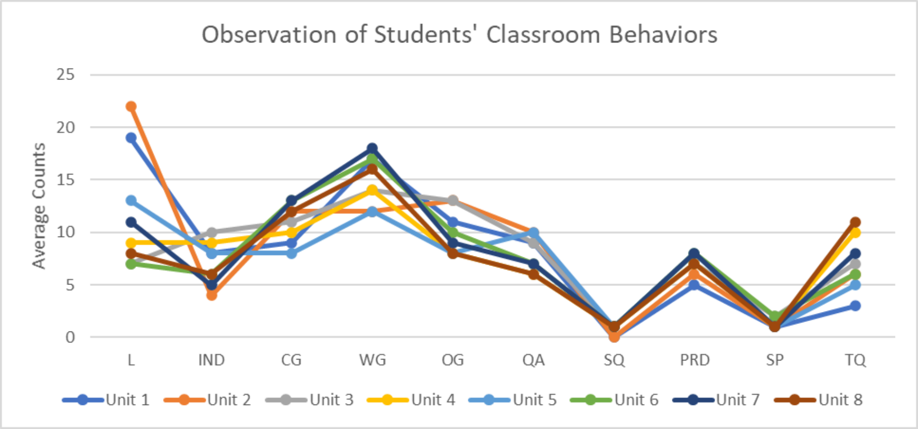

Fig. 2 Observation of the students' behaviors over the eight units

This figure illustrates the frequency of various learning behaviors observed in students during the STEM intervention across eight units of learning.

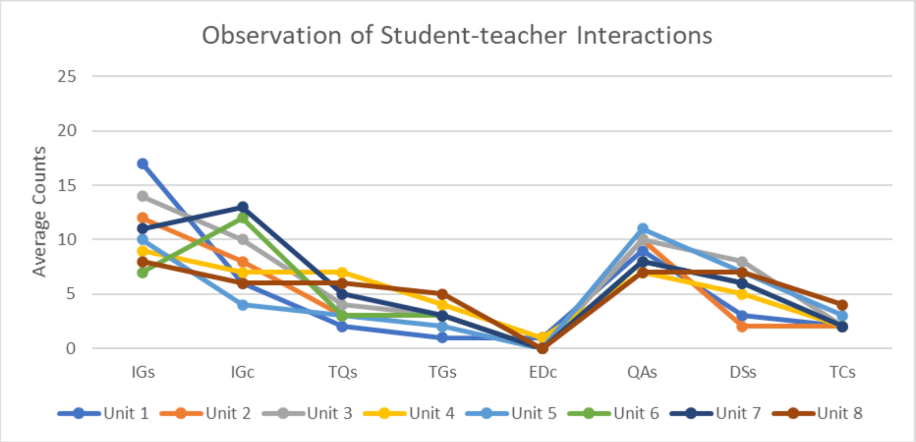

Fig. 3 Observations of the classroom interactions over the eight units

This figure illustrates the frequency of various students' behaviors, specifically stimulated by both the specialist and the class teacher, observed during the STEM intervention across eight units of learning.

teachers played the key role in the lesson implementation, and their interaction with students might have strongly influenced the students' learning in class. Therefore, classroom interactions were also examined in this study (Figure 3).

According to the video content analysis, classroom interactions were extracted. By further analyzing the nature of the interactions, these behaviors roughly fell into the following interaction categories: (1) instructional guidance to the students (IG), (2) technological-supported in-class quizzes and tests (TQ), (3) technological-supported in-class games (TG), (4) experiment demonstration (ED), (5) question and answer (QA), (6) discussion and sharing (DS), and (7) task collaboration (TC). Different from the behavioral categories provided by the STEM protocol for observing students' classroom behaviors, these interaction categories emphasized the students' behavioral reactions provoked by either the STEM specialist or the class teacher. These interaction categories were considered complementary to the STEM protocol in order to provide a more comprehensive understanding of how students acted and reacted in this course co-taught by a STEM specialist and a class teacher. Results thus answered RQ3, further indicating the positive effect of the specialist co-teaching on students' STEM attitude, perception, and behavior during the intervention.

Discussion

Co-teaching and students' changes in attitudes and perceptions

In our study, the results from the paired sample T test underscore a significant increase in students' attitudes, perceptions, and career aspiration towards STEM. Complementary insights from class observations provide a more in-depth understanding of students' learning behaviors and interactions in class with the co-teachers. Starting with perceived usefulness, the co-teaching approach, where the STEM specialist led online sessions and the class teacher provided in-person support, significantly enhanced students' perceived STEM usefulness. This approach not only improves classroom dynamics but also fosters students' social, emotional, and learning skills (Granström et al., 2023). In our study, the students highlighted their enhanced interaction with peers and teachers and improvements in their social skills, like teamwork and communication, along with their STEM-specific knowledge and skills. In addition, students actively applied interdisciplinary skills in the STEM projects, which enabled accumulation of hands-on experiences, leading to higher levels of cognitive engagement and motivation in STEM learning. Consistent with prior research (Bozkurt et al., 2019), our findings also highlighted that the STEM intervention actively encourages students to engage with problem-solving, learn from mistakes, and iteratively refine their solutions.

This engagement seamlessly transitioned into students' perceived fun. Derived from students' feelings of enjoyment during learning activities, perceptions of fun can be enhanced through positive peer and teacher relationships, dynamic instructional strategies, and hands-on activities (Han, 2021). In our study, the intervention course was designed with a variety of interactive activities such as group discussions, team projects, and quizzes. For example, a group experiment involved students designing a weight-bearing bridge. The STEM specialist guided students through problem-solving and brainstorming sessions, leading to hypothesis formation and hands-on exploration. Students collaborated to improve the design until a satisfactory prototype was achieved. Such engagement was credited for the enjoyable learning experience of students in our study. The interactive whiteboard in the multimedia classroom further enhanced the interactive nature of STEM learning. Additionally, educational games integrated into the STEM intervention course further contributed to the perception of fun. The integration of such interactive and game-based elements resulted in a STEM course that was not just instructive but highly enjoyable for students, immersing them in the learning process from start to finish (Solanes et al., 2023).

According to our findings, the main contributing factor for the positive changes in the students' intention to learn was the quality time that the two teachers devoted to students' learning experience. According to the class observations, the students were taken care of by the two teachers. Because the class teacher did not have to lecture in class, she was able to devote more time to supporting the entire class, including providing additional instructional guidance to augment the STEM specialist's knowledge display and example illustration if the students looked confused. This approach, indeed, allows more student time which directly influences the learning experiences in STEM, thus fostering students' intrinsic motivation for STEM learning in the future (Zach, 2020).

Lastly, the influence of the STEM intervention in increasing student empowerment cannot be understated. Both the STEM specialist and the class teacher provided multifaceted support. While the specialist focused on instructional and appraisal support, the class teacher often stepped in with informational guidance. This comprehensive support led students to experience enhanced confidence and competence in STEM tasks. Such findings resonate with previous studies, emphasizing that positive teacher-student relations can improve student achievement, engagement, and self-efficacy (e.g., Skinner et al., 2008). Indeed, some students in our study reported great learning experiences in STEM, confidence in designing airplanes and bridges, and competence in doing experiments with the support and guidance from the two teachers.

The role model of STEM specialist and students' career aspiration

For this intervention, the co-teaching approach provided the students with a chance to observe authentic collaboration modeled by their teachers (Lynch et al., 2015). The STEM specialist, in particular, provided a good role model for the students to gain a better understanding of STEM-related fields and the people working in these professions. According to the class observations, the STEM specialist organized sharing sections in each lesson of the course, during which, he provided examples of a STEM profession, including the daily work routines, what to learn before working in this profession, and the famous individuals known for this profession, etc. Adopting a storytelling approach in the sharing, the specialist integrated his experience and knowledge in a vivid narrative that was concrete and interesting to the students. Young students might, indeed, have lost track and become disengaged if these facts were lectured in plain words. Instead, students showed attentive listening and frequent eye contact with the specialist during the sharing section. Some students also raised a few questions when they wanted to know more details about the aspect the specialist was sharing. For instance, one sharing section was on the famous bridges in China. The specialist showed pictures of the bridges on the whiteboard and started by first asking the students to provide the locations for these bridges. By doing so, students' curiosity and interest were apparently stimulated. They worked in teams and searched the information about the bridges. The specialist then shared how the designers came to the design ideas. He was not merely repeating the facts. Instead, he was trying to build the students' knowledge about bridge designers with small questions to engage them in active learning by themselves in the sharing section. In the intervention, the students were given the opportunity to harvest further understanding of these STEM professions. These learning experiences contributed to a higher chance of the students' future choices of STEM professions in their future career plans.

Gender explorations of differences and similarities

Research has extensively discussed gender differences in various aspects of STEM education, including learning, performance, cognitive development, attitudes, perceptions, and career preferences (e.g., Chen et al., 2020; Kong & Wang, 2023; Yang & Quadir, 2018). Regarding STEM attitudes, our finding revealed that male students reported higher perceived usefulness. Past studies indeed indicated a gender gap regarding students' attitudes in various STEM fields, such as computer science (Wang et al., 2020), mathematics (Niepel et al., 2019), and engineering (Ro & Knight, 2016). However, the findings of gender differences may not always be consistent across studies due to the different methodologies adopted and sample population used (Kulturel-Konak et al., 2011). Interestingly, both genders reported similar levels of perceived fun in STEM, suggesting a positive attitude towards STEM across the genders. This similarity likely stems from a shared basic understanding of the STEM course. Indeed, the STEM course in this study, designed to be interactive, multimedia-supported, and project-based, may have contributed to this common perception of fun. This finding highlights the potential for well-designed STEM curricula to engage students regardless of gender. In addition, male students reported higher intention to learn, empowerment towards STEM, and career aspirations in STEM fields, consistent with recent studies (Wang & Degol, 2017). This gender disparity reflects the persisting male-dominated nature of many STEM professions. These differences are potentially influenced by societal stereotypes, parental attitudes, and gender socialization processes (Ceci & Williams, 2011; Master et al., 2017).

Practical implications

This study underscores the significance of the specialist co-teaching STEM intervention in fostering engagement in constructive learning. The essence of co-teaching is the collaborative effort of two or more teachers with different expertise and ways of thinking in teaching and learning (So et al. 2021). Previous studies showed that co-teaching improves the teacher-to-student ratio, allowing for more personalized attention and faster response to student queries (Chen et al., 2020). Indeed, Lochner et al. (2019) suggest that co-teaching, when implemented with close collaboration between teachers, fosters full student inclusion and potentially enhances cognitive engagement in learning. This approach facilitates more personalized feedback and guidance, supporting students in developing crucial metacognitive skills such as planning, monitoring, and evaluating their learning processes. Consequently, students become more adept at taking control of their education, transitioning from passive recipients to active, self-directed learners. This shift aligns with the principles of self-regulated learning, where students develop the capacity to strategically manage their own learning experiences (Zimmerman, 2002). Class observations of this study indeed supported that co-teaching can provide a good response to students' diverse needs, thus, encouraging students' active participation in class activities and discussions, and increasing students' learning engagement. Specifically, the expert encouraged the students to take on design-based STEM activities, while the class teacher directed more personal care and help to facilitate student learning. The idea is that students learn best when they are actively involved in designing their own experiments, creating models of phenomena, making observations, and analyzing data. This design process is important as it fosters students' creativity in learning to search for solutions beyond those prescribed by traditional methods or formulas.

Co-teaching, while promising, faces several challenges in implementation. These include a shortage of qualified teachers, insufficient staffing, and teacher reluctance to participate (Chitiyo & Brinda, 2018). The most significant barrier is often the perceived lack of teacher readiness and qualification for co-teaching roles (Brendle et al., 2017). To address these challenges, professional development focused on co-teaching strategies and skills is crucial. This training can enhance teacher competence and confidence in collaborative instructional approaches (Ricci et al., 2019). Additionally, school leaders are encouraged to facilitate teacher seminars where experienced co-teachers share their successes and challenges. These peer-led sessions can serve as powerful motivators, inspiring other teachers through relatable role models. Furthermore, administrative support is vital in creating a school culture that values and prioritizes co-teaching. This includes providing adequate planning time, resources, and ongoing support for co-teaching teams (Chitiyo, 2017). By addressing these factors comprehensively, schools can overcome initial resistance and foster an environment where co-teaching thrives, ultimately benefiting student learning and school outcomes.

Limitations and future research directions

This study presents several limitations that are worth discussing. Firstly, the reliance on self-reported surveys may introduce social desirability bias (Krumpal, 2013) or common method bias (Podsakoff et al., 2013), suggesting future research should incorporate multiple rating sources for more robust data collection. Secondly, while our focus on primary students in China provides valuable insights, it limits the generalizability of findings to other educational levels or cultural contexts, though it serves as a foundation for future cross-cultural investigations. Another limitation is our failure to systematically account for the potential impact of teacher gender roles, despite noting the genders of the

STEM specialist (male) and class teacher (female). This oversight restricts our ability to fully interpret the impact of co-teaching intervention, particularly given that past research has demonstrated the influence of teacher gender on students' STEM attitudes, performance, and career aspirations (Gong et al., 2018). Future studies should address this by systematically investigating teacher gender in co-teaching STEM interventions, potentially employing various gender combinations of specialists and teachers, and assessing students' perceptions of teacher gender's influence on their STEM attitudes and aspirations. Moreover, the one-month, one-time STEM course may have limited the effectiveness of our intervention in producing lasting attitude and perception changes. Future research should consider implementing longer-term programs with follow-up training to better assess sustained impacts (Barnett, 2011). Lastly, the absence of control groups restricts our ability to draw robust conclusions about the STEM intervention compared to alternative teaching strategies. Addressing these limitations in future research will provide more comprehensive and generalizable insights into the effectiveness of STEM interventions in shaping students' attitudes, perceptions, and career aspirations, ultimately contributing to the development of more effective STEM education.

Conclusion

Both quantitative and qualitative results of this study demonstrated that the specialist co-teaching strategy employed in the STEM course proved particularly effective in engaging students, significantly improving their attitudes, perceptions, and career aspiration towards STEM. These findings offer valuable insights for educators and school leaders on nurturing students through carefully designed STEM courses.

Appendix

In this STEM intervention course, two STEM professional topics with eight total units including four units of airplane pilot and four units of bridge engineer were designed and prepared. The course materials were mainly designed to familiarize the students with the work routine, work content, and skills and knowledge acquired for the airplane pilot and bridge engineer. Table A1 below shows the detailed course content covered in the STEM intervention course.

Table A1 Course content (eight units) of the two STEM professions in the intervention

Learning Objectives	Teaching Content	Student Activities	Remarks
Airplane pilot			
Unit 1: Understand the flight principle of airplane	• Tumble wing as a flying machine • The reasons and conditions for flying • Airplane wing shape • Bernoulli's principle of flight	• Make a tumble wing glider • Designs of tumble wing gliders • Compare the tumble wing gliders with those made by other team members	Experiment was conducted outside the classroom. The class teacher brought the class out, and let students try to fly the tumble wing gliders that they made.
Unit 2: Understand gravity, lift force and wind resistance	• How to read a spring dynamometer	• Wind tunnel testing • Discussion with team members	Watched documentary videos on aerobatic performance.
Unit 3: Understand the principle of Aerobatics	• Observation of the different positions of the crankpin in the plane • How to change the flying trajectories of the plane • How to make a hover plane	• Make a paper airplane and fit it with a crank pin for flight experiments	Watched documentary videos on aerobatic performance cont.
Unit 4: Know how to make your own plane	• Classification of aircraft engines • More flight principles of the airplane • Difference principles used in a propeller plane and a catapult plane	• Make a foam airplane • Design it to fly as far as possible • Compare the airplane with those made by other members	Group discussion was organized, and students made reflections and raised questions.
Bridge engineer			
Unit 1: The properties of a stable triangle	• Introduce various famous bridges in the world • Introduce the shapes included in bridges • Learn the design of bicycle supports - why it is triangular	• Make cylinders, triangles, and quadrangles and compare the load-bearing properties	Watch documentary videos on bridges and their designs.
Unit 2: The properties of circles and arcs	• Introduction of the arch bridge • Learn why arch bridges can carry more loads	• Compare paper sheets of arch shape and parallel paper sheets for load-bearing capacity • Build an arch bridge	Watch documentary videos on bridges and their designs.
Unit 3: Bridge structures	• Introduce different bridge structures • Learn the characteristics of the bridge structures • Learn about China's famous bridges	• Make various bridges with wood sticks to see what shape is the most stable • Discussion with team members	Teacher-student collaboration to conduct some team experiments together.
Unit 4: Bridge and the Environment	• Learn which bridge is the most suitable if it is built between valleys • Learn the concept of suspension bridges	• Make a suspension bridge with the mood sticks	Group discussion was organized, and students made reflections and raised questions.

Abbreviations

STEM: Science, Technology, Engineering, and Mathematics; TPB: Theory of Planned Behavior; CFA: Confirmatory Factor Analysis; ANOVA: One-Way Analysis of Variance.

Authors' contributions

Yu-Wei Chen designed the study, conducted data analysis, and wrote the manuscript, Ying Wang edited the manuscript and provided comments for revision, and Winnie Wing Mui SO edited the manuscript and provided comments for revision.

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Availability of data and materials

The datasets of the current study are not publicly available but are accessible from the first author upon reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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References

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Ajzen, I. (2020). The theory of planned behavior: Frequently asked questions. *Human Behavior and Emerging Technologies*, *2*(4), 314–324. https://doi.org/10.1002/hbe2.195

Ajzen, I., & Fishbein, M. (1980). Theory of reasoned action. *Journal of Experimental Social Psychology*, *6*, 466–487.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191–215. https://doi.org/10.1037/0033-295X.84.2.191

Barnett, W. S. (2011). Effectiveness of early educational intervention. *Science*, *333*(6045), 975–978. https://doi.org/10.1126/science.1204534

Baveye, Y., Charmaret, C., Dellandréa, E., & Chen, L. (2017). Affective video content analysis: A multidisciplinary insight. *IEEE Transactions on Affective Computing*, *9*(4), 396–409. https://doi.org/10.1109/TAFFC.2017.2661284

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education*, *12*(5/6), 23–37.

Bozkurt, A., Ucar, H., Durak, G., & Idin, S. (2019). The current state of the art in STEM research: A systematic review study. *Cypriot Journal of Educational Sciences*, *14*(3), 374–383. https://doi.org/10.18844/cjes.v14i3.3447

Brendle, J., Lock, R., & Piazza, K. (2017). A study of co-teaching identifying effective implementation strategies. *International Journal of Special Education*, *32*(3), 538–550.

Ceci, S. J., & Williams, W. M. (2011). Understanding current causes of women's underrepresentation in science. *National Academy of Sciences*, *108*(8), 3157–3162. https://doi.org/10.1073/pnas.1014871108

Chen, Y., Chow, C. F. S., & So, W. M. W. (2020). School-STEM professional collaboration to diversify stereotypes and increase interest in STEM careers among primary school students. *Asia Pacific Journal of Education*, *42*(3), 556–573. https://doi.org/10.1080/02188791.2020.1841604

Cheng, Y. C., & So, W. W. M. (2020). Managing STEM learning: A typology and four models of integration. *International Journal of Educational Management*, *34*(6), 1063–1078. https://doi.org/10.1108/IJEM-01-2020-0035

Chintalapati, N., & Daruri, V. S. K. (2017). Examining the use of YouTube as a learning resource in higher education: Scale development and validation of TAM model. *Telematics and Informatics*, *34*(6), 853–860. https://doi.org/10.1016/j.tele.2016.08.008

Chitiyo, J. (2017). Challenges to the use of co-teaching by teachers. *International Journal of Whole Schooling*, *13*(3), 55–66.

Chitiyo, J., & Brinda, W. (2018). Teacher preparedness in the use of co-teaching in inclusive classrooms. *Support for Learning*, *33*(1), 38–51. https://doi.org/10.1111/1467-9604.12190

Christensen, R., & Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science, Environment and Health*, *3*(1), 1–13. https://www.jeseh.net/index.php/jeseh/article/view/31

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator*, *15*(3), 6–11.

Conner, M. (2020). Theory of planned behavior. In G. Tenenbaum, R. C. Eklund & N. Boiangin (Eds.), *Handbook of sport psychology: Social perspectives, cognition, and applications* (4th ed., pp. 3–18). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119568124.ch1

Conner, M., & Armitage, C. J. (1998). Extending the theory of planned behavior: A review and avenues for further research. *Journal of Applied Social Psychology*, *28*(15), 1429–1464. https://doi.org/10.1111/j.1559-1816.1998.tb01685.x

Cook, L., & Friend, M. (1995). Co-teaching: Guidelines for creating effective practices. *Focus on Exceptional Children*, *28*(3), 1–16.

Creswell, J. W., & Plano Clark, V. L. (2011). *Choosing a mixed methods design.* In J. W. Creswell & V. L. P. Clark (Eds.), *Designing and conducting mixed methods research* (2nd ed., pp. 53–105). Sage.

Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F. (2021). Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education. *Education Sciences*, *11*(11), 737. https://doi.org/10.3390/educsci11110737

Davenport, C., Dele-Ajayi, O., Emembolu, I., Morton, R., Padwick, A., Portas, A., Sanderson, J., Shimwell, J., Stonehouse, J., Strachan, R., Wake, L., Wells, G., & Woodward, J. (2021). A theory of change for improving children's perceptions, aspirations and uptake of STEM careers. *Research in Science Education*, *51*(4), 997–1011. https://doi.org/10.1007/s11165-019-09909-6

Davis, F. D. (1989). *Technology acceptance model: TAM.* In M. N. Al-Suqri & A. S. Al-Aufi (Eds.), *Information seeking behavior and technology adoption* (pp. 205–219). IGI Global.

Delaney, J. M., & Devereux, P. J. (2019). Understanding gender differences in STEM: Evidence from college applications. *Economics of Education Review*, *72*, 219–238. https://doi.org/10.1016/j.econedurev.2019.06.002

DeVellis, R. F. (2003). *Scale development: Theory and applications* (2nd ed.). Sage Publications.

Dimitrova, N., Zhang, H.-J., Shahraray, B., Sezan, I., Huang, T., & Zakhor, A. (2002). Applications of video-content analysis and retrieval. *IEEE Multimedia*, *9*(3), 42–55. https://doi.org/10.1109/MMUL.2002.1022858

Du, X., & Wong, B. (2019). Science career aspiration and science capital in China and UK: A comparative study using PISA data. *International Journal of Science Education*, *41*(15), 2136–2155. https://doi.org/10.1080/09500693.2019.1662135

Friend, M. (2014). *Co-teaching: Strategies to improve student outcomes*. National Professional Resources Inc. Dude Publishing.

Gamse, B. C., Martinez, A., & Bozzi, L. (2017). Calling STEM experts: How can experts contribute to students' increased STEM engagement? *International Journal of Science Education*, *7*(1), 31–59. https://doi.org/10.1080/21548455.2016.1173262

Gleason, J., Livers, S., & Zelkowski, J. (2017). Mathematics classroom observation protocol for practices (MCOP2): A validation study. *Investigations in Mathematics Learning*, *9*(3), 111–129. https://doi.org/10.1080/19477503.2017.1308697

Gong, J., Lu, Y., & Song, H. (2018). The effect of teacher gender on students' academic and noncognitive outcomes. *Journal of Labor Economics*, *36*(3), 743–778. https://doi.org/10.1086/696203

Gonzalez, H. B., & Kuenzi, J. J. (2012). *Science, technology, engineering, and mathematics (STEM) education*: *A primer*. Library of Congress.

Granström, M., Kikas, E., & Eisenschmidt, E. (2023). Classroom observations: How do teachers teach learning strategies?. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1119519

Han, F. (2021). The relations between teaching strategies, students' engagement in learning, and teachers' self-concept. *Sustainability*, *13*(9), 5020. https://doi.org/10.3390/su13095020

Hasanah, U. (2020). Key definitions of STEM education: Literature review. *Interdisciplinary Journal of Environmental and Science Education*, *16*(3), e2217. https://doi.org/10.29333/ijese/8336

Hazari, Z., Sadler, P. M., & Sonnert, G. (2013). The science identity of college students: Exploring the intersection of gender, race, and ethnicity. *Journal of College Science Teaching*, *42*(5), 82–91. https://www.jstor.org/stable/43631586

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity*, *43*, 101000. https://doi.org/10.1016/j.tsc.2022.101000

Horizon. (1998). *Core evaluation manual: Classroom observation protocol*. Horizon Research.

Huang, Y. (2014). *Empirical analysis on factors impacting mobile learning acceptance in higher engineering education*. (Ph.D. dissertation). The University of Tennessee.

Kang, J., & Keinonen, T. (2017). The effect of inquiry-based learning experiences on adolescents' science-related career aspiration in the Finnish context. *International Journal of Science Education*, *39*(12), 1669–1689. https://doi.org/10.1080/09500693.2017.1350790

Kitchen, J. A., Sonnert, G., & Sadler, P. M. (2018). The impact of college-and university-run high school summer programs on students' end of high school STEM career aspirations. *Science Education*, *102*(3), 529–547. https://doi.org/10.1002/sce.21332

Kline, T. J. B. (2005). *Psychological testing: A practical approach to design and evaluation*. Sage Publications.

Kokko, M., Takala, M., & Pihlaja, P. (2021). Finnish teachers' views on co-teaching. *British Journal of Special Education*, *48*(1), 112–132. https://doi.org/10.1111/1467-8578.12348

Kong, S. C., & Wang, Y. Q. (2023). Monitoring cognitive development through the assessment of computational thinking practices: A longitudinal intervention on primary school students. *Computers in Human Behavior*, *145*, 107749. https://doi.org/10.1016/j.chb.2023.107749

Kong, S. C., Wang, Y. Q., & Lai, M. (2019). *Development and validation of an instrument for measuring digital empowerment of primary school students.* In M. Zhang, B. Yang, S. Cooper & A. Luxton-Reilly (Eds.), *Proceedings of the ACM Conference on Global Computing Education CompEd '19* (pp. 172–177). ACM. https://doi.org/10.1145/3300115.330952

Krumpal, I. (2013). Determinants of social desirability bias in sensitive surveys: A literature review. *Quality & Quantity*, *47*, 2025–2047. https://doi.org/10.1007/s11135-011-9640-9

Kulturel-Konak, S., D'Allegro, M. L., & Dickinson, S. (2011). Review of gender differences in learning styles: Suggestions for STEM education. *Contemporary Issues in Education Research*, *4*(3), 9–18. https://doi.org/10.19030/cier.v4i3.4116

Li, X., & Xu, H. (2020). Effect of local government decision-making competition on carbon emissions: Evidence from China's three urban agglomerations. *Business Strategy and the Environment*, *29*(6), 2418–2431. https://doi.org/10.1002/bse.2511

Lichtenberg, J., Woock, C., & Wright, M. (2008). *Ready to innovate: Are educators and executives aligned on the creative readiness of the US workforce*? Research Report R-1424-08-RR. The Conference Board, Inc.

Lochner, W. W., Murawski, W. W., & Daley, J. T. (2019). The effect of co-teaching on student cognitive engagement. *Theory & Practice in Rural Education*, *9*(2), 6–19. https://doi.org/10.3776/tpre.2019.v9n2p6-19

Loyalka, P., Liu, O. L., Li, G., Kardanova, E., Chirikov, I., Hu, S., Yu, N., Ma, L., Guo, F., Beteille, T., Tognatta, N., Gu, L., Ling, G., Federiakin, D., Wang, H., Khanna, S., Bhuradia, A., Shi, Z., & Li, Y. (2021). Skill levels and gains in university STEM education in China, India, Russia and the United States. *Nature Human Behaviour*, *5*(7), 892–904. https://doi.org/10.1038/s41562-021-01062-3

Lynch, D., Madden, J., & Doe, T. (2015). *Creating the outstanding school*. Oxford Global Press.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*, 2. https://doi.org/10.1186/s40594-018-0151-2

Master, A., Cheryan, S., Moscatelli, A., & Meltzoff, A. N. (2017). Programming experience promotes higher STEM motivation among first-grade girls. *Journal of Experimental Child Psychology*, *160*, 92–106. https://doi.org/10.1016/j.jecp.2017.03.013

Mau, W. C. J., & Li, J. (2018). Factors influencing STEM career aspirations of underrepresented high school students. *The Career Development Quarterly*, *66*(3), 246–258. https://doi.org/10.1002/cdq.12146

McDonough, E., Sawyer, K. S., Wilks, J., & Jacque, B. (2021). Students attitudes surrounding STEM: A social cognitive career theory instrument for high school. *BioRxiv*, *11*. https://doi.org/10.1101/2021.11.29.470294

McKim, C. A. (2017). The value of mixed methods research. *Journal of Mixed Methods Research*, *11*(2), 202–222. https://doi.org/10.1177/1558689815607096

Moore, R., & Burrus, J. (2019). Predicting STEM major and career intentions with the theory of planned behavior. *The Career Development Quarterly*, *67*(2), 139–155. https://doi.org/10.1002/cdq.12177

Munter, C., Stein, M. K., & Smith, M. S. (2015). Dialogic and direct instruction: Two distinct models of mathematics instruction and the debate(s) surrounding them. *Teachers College Record*, *117*(11), 1–32. https://doi.org/10.1177/016146811511701102

Mutambara, D., & Bayaga, A. (2021). Determinants of mobile learning acceptance for STEM education in rural areas. *Computers & Education*, *160*, 104010. https://doi.org/10.1016/j.compedu.2020.104010

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, *110*(3), 221–223. https://doi.org/10.1080/00220671.2017.1289775

Nadlifatin, R., Miraja, B., Persada, S., Belgiawan, P., Redi, A. A. N., & Lin, S. C. (2020). The measurement of university students' intention to use blended learning system through technology acceptance model (TAM) and theory of planned behavior (TPB) at developed and developing regions: Lessons learned from Taiwan and Indonesia. *International Journal of Emerging Technologies in Learning*, *15*(9), 219–230. https://doi.org/10.3991/ijet.v15i09.11517

National Institute of Educational Sciences (NIES). (2021). *Research report on STEM education in China*. Unpublished report from National Institute of Educational Sciences.

Niepel, C., Stadler, M., & Greiff, S. (2019). Seeing is believing: Gender diversity in STEM is related to mathematics self-concept. *Journal of Educational Psychology*, *111*(6), 1119–1130. https://doi.org/10.1037/edu0000340

Podsakoff, N. P., Podsakoff, P. M., MacKenzie, S. B., & Klinger, R. L. (2013). Are we really measuring what we say we're measuring? Using video techniques to supplement traditional construct validation procedures. *Journal of Applied Psychology*, *98*(1), 99–113. https://doi.org/10.1037/a0029570

Quinn, F., & Lyons, T. (2011). High school students' perceptions of school science and science careers: A critical look at a critical issue. *Science Education International*, *22*(4), 225–238.

Rhodes, J. E., & DuBois, D. L. (2008). Mentoring relationships and programs for youth. *Current Directions in Psychological Science*, *17*(4), 254–258. https://doi.org/10.1111/j.1467-8721.2008.00585

Ricci, L. A., Persiani, K., & Williams, A. D. (2019). From 'training wheels for teaching' to 'cooking in your mother-in-law's kitchen': Highlights and challenges of co-teaching among math, science, and special education teacher candidates and mentors in an urban teacher residency program. *International Journal of Whole Schooling*, *15*(2), 24–52.

Ro, H. K., & Knight, D. B. (2016). Gender differences in learning outcomes from the college experiences of engineering students. *Journal of Engineering Education*, *105*(3), 478–507. https://doi.org/10.1002/jee.20125

Roehrig, G. H., Moore, T. J., Wang, H. H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44. https://doi.org/10.1111/j.1949-8594.2011.00112.x

Skinner, E., Furrer, C., Marchand, G., & Kindermann, T. (2008). Engagement and disaffection in the classroom. *Journal of Educational Psychology*, *100*(4), 765–781. https://doi.org/10.1037/a0012840

Smith, M. K., Jones, F. H., Gilbert, S. L., & Wieman, C. E. (2013). The classroom observation protocol for undergraduate STEM (COPUS): A new instrument to characterize university STEM classroom practices. *Life Sciences Education*, *12*(4), 618–627. https://doi.org/10.1187/cbe.13-08-0154

So, W. M. W., He, Q. W., Chen Y., & Chow, C. F. S. (2021). School-STEM professionals' collaboration: A case study on teachers' conceptions. *Asia-Pacific Journal of Teacher Education*, *49*(3), 300–318. https://doi.org/10.1080/1359866X.2020.1774743

Solanes, J. E., Montava-Jordà, S., Golf-Laville, E., Colomer-Romero, V., Gracia, L., & Muñoz, A. (2023). Enhancing STEM education through interactive metaverses: A case study and methodological framework. *Applied Sciences*, *13*(19), 10785. https://doi.org/10.3390/app131910785

Teo, T., & Lee, C. B. (2010). Explaining the intention to use technology among student teachers: An application of the theory of planned behavior (TPB). *Campus-Wide Information Systems*, *27*(2), 60–67. https://doi.org/10.1108/10650741011033035

Toma, R. B., Lederman, N. G., Jiménez, J. P., & Meneses-Villagrá, J. A. (2019). *Exploring students' acceptance of coding activities during integrative STEM lessons*. NARST 2019 Annual International Conference, Baltimore, MD.

Toomela, A. (2008). Noncognitive correlates of education. *Learning and Individual Differences*, *18*(1), 19–28. https://doi.org/10.1016/j.lindif.2007.07.006

Tran, Y. (2018). Computer programming effects in elementary: Perceptions and career aspirations in STEM. *Technology, Knowledge and Learning*, *23*(2), 273–299. https://doi.org/10.1007/s10758-018-9358-z

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87–102. https://doi.org/10.1007/s10798-011-9160-x

Wang, M. T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): Current knowledge, implications for practice, policy, and future directions. *Educational Psychology Review*, *29*, 119–140. https://doi.org/10.1007/s10648-015-9355-x

Wang, S., & Ji, Q. (2015). Video affective content analysis: A survey of state-of-the-art methods. *IEEE Transactions on Affective Computing*, *6*(4), 410–430. https://doi.org/10.1109/TAFFC.2015.2432791

Wiebe, E., Unfried, A., & Faber, M. (2018). The relationship of STEM attitudes and career interest. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(10), 1–18. https://doi.org/10.29333/ejmste/92286

Yang, J. C., & Quadir, B. (2018). Individual differences in an English learning achievement system: Gaming flow experience, gender differences and learning motivation. *Technology, Pedagogy and Education*, *27*(3), 351–366. https://doi.org/10.1080/1475939X.2018.1460618

Zach, S. (2020). Co-teaching – An approach for enhancing teaching-learning collaboration in physical education teacher education (PETE). *Journal of Physical Education and Sport*, *20*(3), 1402–1407. https://doi.org/10.7752/jpes.2020.03193

Zhou, X., Shu, L., Xu, Z., & Padrón, Y. (2023). The effect of professional development on in-service STEM teachers' self-efficacy: A meta-analysis of experimental studies. *International Journal of STEM Education*, *10*(1), 37. https://doi.org/10.1186/s40594-023-00422-x

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice*, *41*(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2

Zimmerman, M. A. (1995). Psychological empowerment: Issues and illustrations. *American Journal of Community Psychology*, *23*(5), 581–599. https://doi.org/10.1007/BF02506983

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