THE EFFECTIVENESS OF STEM INTEGRATION MODULE USING ENGINEERING DESIGN PROCESS (iSTEM-EDP) TO ENHANCE FIFTH GRADERS' COLLABORATION, PROBLEM-SOLVING, AND STEM ATTITUDES IN CHINA

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by

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LIST OF ABBREVIATIONS

3D	3 Dimensional
ABET	Accreditation Board for Engineering and Technology
CIS	Career Interest Survey
CPS	Collaborative Problem-solving
CQ-STEM	Curiosity towards STEM Education Questionnaire
CVI	Content Validity Index
DCIs	Disciplinary Core Ideas
DVs	Development variables
EDP	Engineering Design Process
EiE	Engineering is Elementary
EPCOT	Engineering Preschool Children Observation Tool
HSLS	High School Longitudinal Study
ICTs	Information and Communications Technologies
ID	Instructional Design
IPISD	Interservice Procedures for Instructional Systems Development
ISLS	Informal STEM Learning Settings
iSTEM-EDP	Integrating Science, Technology, Engineering, Mathematics using Engineering Design Process
IV	Independent variable
MANOVA	Multivariate analysis of variance
MBI2	Multimedia-based Integrated Instruction
MCSCE2022	Mathematics Curriculum Standard for Compulsory Education (2022 Edition)
MKO	More Knowledgeable Other
MOE	Ministry of Education of the People's Republic of China
NAE	National Academy of Engineering

N-Gain	Performing the Average Score of Normalized Gain
NGSS	Next generation science standard
NRC	National Research Council
NSF	National Science Foundation
OECD	Organization for Economic Cooperation and Development
PAM	Positive Attitudes towards Math
PCAST	The President's Committee of Advisors on Science and Technology
PIL	Project-Based Inquiry Learning
PISA	Programme for International Student Assessment
POD	Process of Design
POD-PB	Problem and Background
POD-PI	Plan and Implement
POD-TE	Test and Evaluate
ROI	Return on Investment
SAI II	Science Attitude Inventory
SCSCE2022	Science Curriculum Standard for Compulsory Education (2022 Edition)
SD	Standard Deviation
SLED	Science Learning through Engineering Design
SS	Semantics Survey
STS	Science Technology Society
TLS	Teaching and learning Sequence
ZPD	Zone of Proximal Development

LIST OF APPENDICES

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KEBERKESANAN MODUL INTEGRASI STEM MENGGUNAKAN PROSES REKA BENTUK KEJURUTERAAN (iSTEM-EDP) UNTUK MENINGKATKAN KOLABORASI, PENYELESAIAN MASALAH DAN SIKAP STEM MURID GRED 5 DI CHINA

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji keberkesanan modul iSTEM-EDP terhadap kolaborasi, penyelesaian masalah, dan sikap STEM dalam kalangan murid gred lima di sekolah rendah Cina. Kajian ini menggunakan teori perkembangan kognitif Piaget, teori perkembangan sosial Vygotsky, teori pembelajaran sosial Bandura, dan rangka kerja untuk pendidikan kejuruteraan berkualiti K-12. Modul iSTEM-EDP dibangunkan berdasarkan standard kurikulum sains baharu dan buku teks Cina mengikut model reka bentuk pengajaran ADDIE. Kajian ini menggunakan reka bentuk eksperimen kumpulan kawalan tidak setara, praujian-pascaujian. Satu kelas gred lima (kumpulan rawatan) mengambil modul iSTEM-EDP selama 6 minggu, manakala kelas lain (kumpulan kawalan) mengambil kelas sains seperti biasa. Terdapat 60 orang pelajar dalam setiap kumpulan, dengan bilangan pelajar perempuan dan lelaki yang sama. Data dikumpul daripada ujian pra dan ujian pasca melalui tiga skala Likert bagi setiap kumpulan dan dianalisis menggunakan IBM SPSS Statistics versi 26. Keputusan MANOVA sehala mendedahkan bahawa modul iSTEM-EDP mempunyai kesan positif yang signifikan terhadap kolaborasi, penyelesaian masalah, dan sikap STEM murid gred lima. Selain itu, kajian ini juga mendapati bahawa modul iSTEM-EDP menggalakkan kesaksamaan jantina dalam kerjasama dan penyelesaian masalah tetapi memburukkan jurang jantina dalam minat kerjaya STEM dan sikap terhadap STEM.

THE EFFECTIVENESS OF STEM INTEGRATION MODULE USING ENGINEERING DESIGN PROCESS (iSTEM-EDP) TO ENHANCE FIFTH GRADERS' COLLABORATION, PROBLEM-SOLVING, AND STEM ATTITUDES IN CHINA

ABSTRACT

The purpose of this study was to examine the effectiveness of the iSTEM-EDP module on collaboration, problem-solving, and STEM attitudes among fifth graders in Chinese primary schools. The study applied the theories of Piaget's cognitive developmental theory, Vygotsky's social development theory, Bandura's social learning theory, and the framework for K-12 quality engineering education. The iSTEM-EDP module was developed based on the Chinese new science curriculum standard and textbook according to the ADDIE instructional design model. The study employed a nonequivalent control group, pretest-posttest experimental design. One fifth-grade class (treatment group) took a 6-week iSTEM-EDP module, while another class (control group) took science classes as normal. There were 60 students in each group, with equal numbers of girls and boys. The data was collected from pretest and posttest via three Likert scales for each group and analysed by IBM SPSS Statistics version 26. The one-way MANOVA results revealed that the iSTEM-EDP module had significant positive effects on fifth graders' collaboration, problem-solving, and STEM attitudes. In addition, the study also found that the iSTEM-EDP module promoted gender equality in collaboration and problem-solving but exacerbated the gender gap in STEM career interest of STEM attitudes.

CHAPTER 1

INTRODUCTION

1.1 Introduction

STEM is an acronym for Science, Technology, Engineering, and Mathematics. STEM education refers to the teaching and learning of science, technology, engineering and mathematics. A National Science Foundation (NSF) program officer first proposed the term "STEM" in 2001 (Marrero et al., 2014; Akgunduz, 2016), with the aim of reforming the STEM curriculum of US colleges and universities and addressing the STEM talent shortage. In 2007, the National Governors Association of the United States began to pay attention to the connection of STEM education between colleges and K-12 schools. STEM education grounds itself in the integration of disciplines (Yamada, 2018) and covers the entire educational levels from preschool to higher education.

Integrative STEM education, as technological/engineering design-based approaches, intentionally integrates the content and processes of science and/or mathematics with the content and processes of technology and/or engineering (Sanders, 2015). Engineering has the potential to integrate STEM (Moore et al., 2014) via EDP (Engineering Design Process), which is a pedagogical technique for integrating STEM into learning to solve open issues, foster creative thinking, generate answers, make decisions, and take into account alternative options to overcome varied challenges (Shahali et al., 2016). EDP offers a successful path as an instructional framework for adopting STEM and encourages students to think creatively (Siew et al., 2017). EDP is a methodical and intelligent process that creates, assesses, and decides on concepts for accomplishing learning goals (Lin et al., 2021). EDP is a new concept that guides the development of learning in K-12 classrooms (Haik & Shahin, 2011).

The phrase "21st- century skills" refers to a broad range of abilities, work habits, and personal qualities that are crucial for leading a great life in the modern world, especially in the context of education and future employment, including communication, collaboration, critical thinking and problem-solving, creativity, and innovation, etc. (Binkley et al., 2012). Problem-solving is one of the most important ways of thinking and a skill that runs through people's learning, work, and life in the 21st century (Topsakal et al., 2022; Rahman, 2019). Students with motivation should learn problem-solving from an early age through observations and experiences (Bingham, 1983). Exposing students to real-world situations and incorporating multiple STEM disciplines into the solution process is a significant objective in STEM education (Williams, 2011).

Collaboration is also one of the skills and ways of working in the 21st century (Rahman, 2019). Collaboration is beneficial for students' inquiry learning, such as STEM learning, which can explore solutions and complete tasks by labour division and coordination, facilitating the incorporation and innovation of resources, ideas, experience, and perspectives (PISA, 2013; Child & Shaw, 2016). The teamwork learning approach in STEM education can enhance students' collaboration attitude and skills.

Most countries urgently need STEM talents to maintain their leadership positions in the era of intense global competition. Students' attitudes towards STEM subjects and STEM career interest in K-12 can positively predict the likelihood of working in STEM in the future (Business-Higher Education Forum, 2010). By experiencing the STEM learning in class, students, especially women with lower attitudes towards STEM, are more likely to generate positive attitudes towards STEM disciplines and increase the likelihood and inclination of choosing STEM-related careers (Erkut & Marx, 2005; Faber et al., 2013).

1.2 Background

In China, there are four school education stages: preschool education, compulsory education, high school education, and higher education. Compulsory education (grades 1-9) consists of primary school from grade 1 to grade 6 and junior high school from grade 7 to grade 9. Primary school is divided into three stages: lower grades (grades 1-2), middle grades (grades 3-4), and senior grades (grades 5-6). In primary school, courses like Chinese, mathematics, science, English, physical education, and other courses are required to set up for all students. Chinese and mathematics have always been offered to all grades and students and have been highly valued. At the same time, with the energetic promotion of all-rounded education, the abundance of educational resources, and the development of society, other courses, especially science courses, are also receiving increasing attention.

China is also exploring STEM integration education in K-9, following the global trend of STEM education. In 2022, the Science Curriculum Standard for Compulsory Education (2022 Edition) (SCSCE2022) (MOE, 2022b), formulated by the Ministry of Education of the People's Republic of China (MOE), was released, adjusting the science education' goals and content of primary school and junior high school. The new standard makes a new interpretation of the relationship between science and technology and engineering: science provides the theoretical basis for technology and engineering; science, technology, and engineering mutually promote the development of productivity, economic prosperity, and social progress and push the transformation of people's production mode and lifestyle. Science encompasses engineering and technology in a broad sense.

There are 4 cross-disciplinary concepts in SCSCE2022: matter and energy, structure and function, system and model, and stability and change. These four cross-disciplinary concepts are acquired through 13 core concepts that are (a) the structure and properties of matter, (b) changes in matter and chemical reactions, (c) the motion and interaction of matter, (d) energy conversion and conservation of energy, (e) the constituent levels of living systems, (f) homeostasis and regulation of organisms, (g) the interrelationship between living things and their environment, (h) the continuation and evolution of life, (i) earth in space, (j) earth system, (k) human activity and the environment, (l) technology, engineering, and society, (m) engineering design and materialization.

China implements a nine-year compulsory education; all school-age students are required to receive it. Grade 5 belongs to the primary senior stage; fifth graders are about 10-11 years old. There are 7 editions of science textbooks for primary school students as stipulated by the state, which are pressed by Educational Science Publish House, People's Education Press, Hebei People's Publishing House, Hubei Education Press, Hunan Science & Technology Press, Phoenix Education Publishing, Ltd., and Qingdao Publishing House. In the science textbook (2020 Edition) of fifth grade volume 1 pressed by Educational Science Publish House (ESPH, 2020), which is used by students in some provinces of China, there are four topics: *light*, changes in the earth's surface, *time measurement*, and *healthy lives*, which are related to these core concepts, respectively: (c) the motion and interaction of matter; (j) earth system; (c) the motion and interaction of matter; (f) homeostasis and regulation of organisms; and (g) the interrelationship between living things and their environment.

This study selected three activities related to fifth grade's science textbook and the SCSCE2022. The topics are *Health Manager*, *Timer*, and *Periscope*, respectively corresponding with the science textbook of *healthy lives*, *time measurement*, and *light*. These three topics all cover STEM content and solve real problems related to students using EDP. In *Health Manager*, students immerse themselves in the role of a *Health Manager* to design a week health plan from diet, exercise, and sleep for primary students and implement their plan for 4 weeks. In *Timer*, students design and make a 30-second *Timer* for a four-year-old child with asthma. In *Periscope*, students design and make a retractable *Periscope* of 50-80 cm for people to see the higher objects without standing on a stool.

Each of these three activities challenges students to use EDP to address a problem that pertains to their lives. They analyse the story context issues and specific requirements and acquire required STEM knowledge and skills via different ways; they design different problem solutions on the design worksheet and then implement them in the form of a model, product, or prototype; they test the results they create and evaluate them by identifying the weaknesses based on the contextual problems and requirements to improve them. The EDP consistently groups students into four-person teams.

Students have the ability to do STEM activities. Students are natural "scientists" and "engineers" (Brophy et al., 2008; Petroski, 2003); they are good at asking questions and making explorations. By touching, tasting, building, dismantling, creating, learning, and exploring, kids attempt to make sense of their environment.

This is not instruction, but fun for kids. A study shows that students can acquire STEM skills through multimedia technology and migrate to non-mediated contexts. During inquiry-based STEM activities, students use at least one science process skill (observing, comparing and classifying, measuring, communicating, inferring, predicting) to participate and feel content in the activities and enjoy the group atmosphere (DiLek et al., 2020).

EDP appears in students' lives and play. Scholars (Gold et al., 2020) argue that students' building games are very similar to engineers' workflows, and engaging in engineering play has positive effects on students' STEM awareness and interest. Engineering is inherently a social-constructive process, dependent on effective social communication to construct the best version of a planned physical structure (Petre, 2004).

Chinese science education in primary school emphasizes the application of engineering design. SCSCE2022 (MOE, 2022b) proposes that the goal of science education for Grades 1-9 is to cultivate students' practical ability in technology and engineering, which is one of its practical literacies. Specifically, it includes understanding the general processes and methods of technology and engineering, clarifying problems for practical needs, proposing creative solutions, and screening according to scientific principles and constraints; implementing, planning, processing, and manufacturing utilizing tools and materials; modifying and iterating according to the actual effect; verifying or demonstrating certain principles, phenomena, and ideas with simple homemade devices and mock-ups. The whole process is exactly engineering design process.

EDP is a relatively new and effective way in STEM education in the K-12 stage for that, (a) engineering always doesn't exist as an individual subject in the K-12 stage, and engineering is introduced into K-12 as the form of STEM integration education. STEM education in K-12 is just noticed in almost one-decade years, EDP as the part of STEM education is newer; (b) the embodiment of engineering in STEM education is not to learn engineering knowledge, but the engineering design thinking through EDP; (c) researches (English & King, 2015; English et al., 2017)) show that, EDP has a systematic structure to help students solve authentic problems in their lives; (d) engineering education, especially engineering design is stressed both in NGSS (Next Generation Science Standard) and SCSCE2022; (e) The EDP is a processing tool that has the potential to enhance learning by enabling students to address various issue types with a similar methodology and to do so using the same language (Tupsai, 2021).

The POD (Process of Design) for Quality K-12 Engineering Education includes Problem and Background (POD-PB), Plan and Implement (POD-PI), and Test and Evaluate (POD-TE) (Moore et al., 2014). Students utilize engineering thinking and EDP (design, test, refine, and evaluate their designs and products) in the context of inquiry-based STEM activities. Engineers design technologies using their understanding of science and math. In this way, engineering provides the glue to hold science and math together and provides meaningful situational context (DiLek et al., 2020).

People view the early years as the ideal time to begin engineering education. Taking the Engineering Elephants book as an example, teachers introduce engineering design techniques to students through stories, drawings, and discussions. It is found that reading engineering-centred books helps students develop their creativity, identify as engineers, and continue to explore engineering activities (Pantoya et al., 2015).

Moreover, being interested in engineering in early childhood could increase interest in STEM career fields (Dejarnette, 2012). Communication between teachers and students in engineering design could enable students to think in multiple ways, form their own self-conceptions as engineers and scientists, build interdisciplinary cognition, and be able to complete a long, multifaceted engineering design project (Tank et al., 2018b).

China has entered the ranks of middle-high-income countries; the key to successful socio-economic transformation is to promote the shift from a labour-intensive economy to a knowledge-intensive economy. Whether it is economic transformation and upgrading or coordinated development of the economy and society, education is the most basic and fundamental link. The continuous and effective implementation of STEM education will positively promote the labour level and production and help the transformation of our economy from labour-intensive to technology-intensive (National Institute of Education Science, 2017).

The Theory of Action Causes indicates that a person's attitude affects his/her behaviour (Wei & Maat, 2020); STEM attitudes will influence whether they will work on STEM careers or not. International economic development requires STEM talents; the cultivation of talents requires to the formation positive attitudes towards STEM fields, which requires STEM education. Yan and Ahmad (2025) found that boys took more positive STEM attitudes than girls. The President's Committee of Advisors on Science and Technology (PCAST) (PCAST, 1997) notes that K-12 students' attitudes towards STEM subjects and their interest in STEM careers play a role in how likely they are to pursue a STEM career. Exposure to STEM education helps students form positive STEM attitudes. For example, Women in Engineering strategy significantly improved 8th graders' attitudes towards science (Erkut & Marx, 2005); an integrated STEM approach in engineering and EDP was more useful for students' favourable views towards STEM than teaching single STEM disciplines separately; students' attitudes towards STEM in Grade 6 increased dramatically as a result of STEM instruction (Baran et al., 2019).

Collaboration is one of the learning and innovation skills of the 21st century, which can help students succeed in various fields of formal education and is also essential for an individual to be able to adapt and prosper in a constantly changing environment (Stehle & Peters-Burton, 2019). One critical competence for success in the 21st century is to work cooperatively with a variety of individuals in a range of complex settings (Suárez-Orozco & Sattin, 2007). Collaboration is also a necessity for engineers to make a success (Capobianco et al., 2021). Collaboration is important in cross-disciplinary STEM education for group members to share a common goal and identify talents by sharing knowledge in different fields to reach a successful solution (Ejiwale, 2014). Each team member shows the goodness and idea to contribute to the problem-solving from different perspectives.

SCSCE2022 also includes specific requirements regarding collaboration in science education. The goal of SCSCE2022 (MOE, 2022b) stipulates that students must respect the emotions and attitudes of others, excel in collaboration, be open to sharing, and tolerate different viewpoints. Specifically, for students in grades 5-6, they are not blindly obedient or superstitious about authority and can make independent judgments based on facts; are willing to adjust their own ideas in the face of persuasive evidence; are willing to try to use a variety of ideas and methods to complete the research and practice and have an initial interest in innovation; are willing to communicate and debate with others on differences in understanding of scientific issues, and reflect and adjust research activities based on evidence.

As the technology develops, problem-solving is a necessary 21st-century skill in the workplace or daily life. The ability to solve problems collaboratively is crucial and useful in both the classroom and the workplace (OECD, 2017). Many countries take students' problem-solving ability seriously; for example, PISA (Programme for International Student Assessment) is designed to assess 15-year-old students' problem-solving in mathematics, science, and reading across many countries and districts, while mathematics and science are both involved in STEM education. Greene (2011) emphasizes that education should focus on the process of problem-solving instead of solving only one domain or subject problem or only reaching a solution. STEM education, which combines inquiry-based learning strategies with an integrated approach to teaching and learning science, aims to improve students' problem-solving and problem-framing abilities as well as their capacity to contextualize scientific ideas in everyday contexts (Roungos et al., 2020). In school levels, STEM education is to cultivate students of the new generation to ask questions, search, produce, and solve problems by using science, mathematics, technology, and mathematics knowledge and skills through their efforts (Malçok & Ceylan, 2020).

One of the goals of SCSCE2022 (MOE, 2022b) is to cultivate students' ability to solve simple practical problems, enabling them to use evidence and reasoning to describe, explain, and predict research problems. Specifically, students in grades 5-6 should master the basic methods of inductive reasoning and deductive reasoning and apply them to solve simple problems in real situations; be able to propose hypotheses for specific problems, propose opinions based on communication situations, and establish links between evidence and hypotheses or opinions; and have the ability of initial construction, design, implementation, verification, and improvement.

Studies prove that STEM practice is an efficient instruction to promote students' problem-solving and collaboration. For example, learning activities based on STEM-PjBL improved students' problem-solving ability (Triana et al., 2020); preschoolers exhibited most problem-solving behaviours and had problem-solving ability in EDP-STEM activities (Anggoro et al., 2021); In STEM activities, students sought common points while reserved difference for achieving the common goal (Triana et al., 2020), they shared ideas and resources, supported each other, conducted time management (Soros et al., 2018; Kurniahtunnisa & Wowor, 2023; Kurniahtunnisa et al., 2023), and students learned to work as a team, took a responsibility of different roles, worked efficiently, develop empathy towards others (Putri et al., 2023) .

There is a gender bias against STEM attitudes in childhood, which is mainly found in boys but not in girls. Boys are considered to be good at and capable of doing STEM. The STEM fields exhibit a pronounced gender gap (Hill et al., 2010), with a male advantage that begins early and persists throughout an individual's life (Coyle & Liben, 2020). However, in the study of Sun et al. (2021), Chinese girls in primary school presented more positive attitudes toward STEM than boys. McGuire et al. (2020) showed a tendency of an equality gender stereotype in STEM from childhood to adolescence. The first step for people interested in equal representation in STEM is to develop strategies to encourage early views about women's STEM aptitude in young students without reinforcing notions of adult male supremacy (McGuire et al., 2020).

In problem-solving, there are gender differences. In a computer-based problem-solving task, 11–12-year-old boys outperformed girls, regardless of the type of pair they were in (boy-boy, girl-girl, boy-girl), or the verbal interaction (Barbieri & Light, 1992). Preschool girls were more adept at building complex structures using blocks than boys, but boys were more efficient in building tasks (Ramani, 2005). Lu

(2021) found that in students' self-report problem-solving, boys demonstrated a higher ability in exploring and understanding, while girls excelled in representing and formulating, planning and executing, and monitoring and reflecting these three dimensions.

Gender differences also exist in the domain of collaboration. Women were more likely to take a positive cooperative attitude than men (Tang, 1999). In building tasks, preschool girls showed more cooperative behaviours, joint communication, and shared more task responsibilities and less uncooperative behaviours than boys (Ramani, 2005). Women in teams, especially in male dominated STEM fields, are beneficial for collaboration by promoting collective intelligence for that, (a) women have higher social sensitivity to read nonverbal cues and make accurate inferences, (b) show more equal take-turn conversation to produce more ideas, knowledge, and skills, and (c) women focus more on interpersonal relationships and are more democratic than men in communicating behaviours (Bear & Woolley, 2011).

Given the significance of STEM education, some research has been conducted to study the development and effects of STEM curricula and activities for primary schools in China. The design-based STEM learning incorporating information and technology focuses on the topic of “constructing smart Hong Kong through STEM design” related to students’ social and living environment to improve primary students’ STEM creativity and epistemic beliefs (Wan et al., 2023). An online STEM education campus through Dingtalk is designed and implemented for students in grades 3-4 in the Xinjiang Uygur Autonomous Region, China. The study showed positive effects on third- and fourth-grade primary school students’ self-efficacy, computational thinking, and task value. The STEM education employed the 6E teaching model to improve students’ self-efficacy, computational thinking, and task values (Chiang et al., 2022).

A STEM+C module is developed to improve primary students' computer thinking (Li, 2022). Lu (2021) developed a STEM program based on 5E and EDP to prompt 5th graders' problem-solving.

The positive impacts of various STEM programs on students' development can be seen from the primary STEM education practices in various regions in China mentioned above. However, most STEM programs' development was not for all students, for the program didn't conform to the textbook students were learning, which is against the policy of education being inclusive of all children. The evaluation of STEM education involves students' different aspects; however, there is limited study about the effects of STEM education on students' problem-solving, collaboration, and STEM attitudes, which are focused by the new science curriculum and important 21st-century skills. Furthermore, some researchers examined gender differences in problem-solving, collaboration, and STEM attitudes within Chinese society, where traditional patriarchal values coexist with the promotion of gender equality; however, most studies are cross-sectional and do not consider these gender differences in STEM education.

1.3 Problem statement

One of the key competencies of successful and culturally inclusive educators is creating and modifying curricula to fit particular sociocultural situations (Rodriguez, 2021). STEM education should be established based on Chinese national situation of a developing country which needs STEM talents in all fields especially for top talents, the educational concept of providing education to all children and promoting the localization of STEM education. The curriculum standard for grades 1-9 of SCSCE2022 (MOE, 2022b) includes engineering and technology from goal to content and emphasizes the engineering design, indicating that STEM integration education using engineering design is embedded in the primary science curriculum standard. Therefore, developing an integrated STEM curriculum not only uses the EDP but also conforms to the science textbook and the new science curriculum standards.

There are still some problems with STEM education in China. First, the STEM education implementation has marginal characteristics. The SESCE2022 advocates integrating STEM using EDP in science classes for all students; however, the actual situation is that STEM practice in China in elementary schools is most developed in schools' related STEM education clubs for a small number of students. For example, the participants of STEM activities were fifth graders from a STEM club in City Nanjing (Lu, 2021); the subjects were grade 4-5 students in the Internet of Things Club in a primary school to explore the STEM +C teaching approach (Li, 2022).

Second, the development of the STEM module is not based on the current Chinese science curriculum standard of primary school and the science syllabus or textbooks. The main pathway of the implementation of STEM education is through science classes in primary school. If the design of STEM education is not based on the existing science curriculum standard and science textbooks what teachers teach and students learn, there will no extra time to conduct the STEM education; thus, it will be meaningless to design. For example, the STEM activities design of Plane (Lu, 2021), Smart Duck Shed, and Smart Transport (Li, 2022), and Build Bookshelves (Zhang, 2022) just took consideration of the new standard but didn't base on the students' science textbook. Also, many schools' STEM curricula were either the expansion of scientific and technological innovation activities or directly borrowed from abroad (Wang & Wang, 2018).

Third, STEM integration instruction is not sufficient in primary schools in China due to the lack of teachers' STEM literacy including understanding the value of STEM education, possessing the foundation of STEM subjects knowledge, STEM interdisciplinary understanding and practice, STEM curriculum development and integration, conducting STEM education and evaluation (National Institute of Education Sciences Center for STEM Education, 2018). Specifically, (a) primary school science teachers have insufficient understanding of interdisciplinary content and even cannot tell the similarities and differences between scientific inquiry and engineering design (Lin et al., 2019); (b) it has been customary to teach knowledge points independently in primary science education, and many subjects such as technology, engineering, mathematics, art, etc. are not well integrated into science.

Fourth, seldom integrated STEM modules designed with the engineering design process for Chinese primary science classes. By using science and mathematics to create new technologies, engineering effectively integrates STEM (Moore et al., 2014). EDP is emphasized in NGSS and SCSCE2022; however, EDP is less employed in the STEM integration in Chinese primary STEM education. In recent years, there have been some STEM instructional designs or practices for Chinese students; however, only a few STEM curriculums have been developed using EDP (Wan et al., 2023; Chiang et al., 2022; Lu, 2021), and the validity of these STEM education programs is unknown.

Students' STEM attitudes present a number of obstacles in China. These problems may affect students' interest in STEM subjects as well as their long-term motivation and excitement for a STEM future.

First, due to the increasing academic pressure in the high grades in primary school, lecture is the primary teaching method used in traditional STEM (Huang & Zhou, 2023). Students view passing exams and performing well in academic tests as the primary learning goals, and there is a positive relationship between students' interest in STEM subjects and their testing scores and ranking (Li, 2019), which can result in a dry understanding of STEM and a lack of understanding of its relevance to real-world situations. This approach does not foster a genuine interest in STEM education among students. Traditional STEM education based on subject teaching sees STEM as a means to acquire high scores and focuses on memorization and testing strategies. This situation results some students with good academic performance show positive mathematics or science attitude. Under this condition, students view STEM subjects as challenges to overcome, rather than areas of exploration and de*light*, and they are unable to cultivate genuine interest and passion for STEM.

Second, students have a narrow understanding of the scope of STEM education by learning science and mathematics subjects separately, especially in primary school, which is more limited to science fields such as physics and geography, etc., and mathematics, while ignoring broader STEM fields such as engineering design, biological engineering, technologists, etc., which may interest more students with different interests (Shao, 2019). Without the integration of STEM education with EDP, students may lose the opportunity to further broaden the horizons of STEM and the possibility of entering STEM fields in the future.

Third, despite China's encouragement and efforts for educational equity in policy and action, particularly gender equality, long-standing gender stereotypes persist, suggesting that boys are more suited for STEM fields and girls for humanities and social sciences fields (Yuan & Zhao, 2017). Such perceptions may discourage girls from generating a positive attitude about STEM fields. Boys showed significantly more positive interest in science than girls in primary school (Huang & Zhou, 2023). Girls in fifth grade have a stereotypical cognition of engineers, and a 12-week STEM-themed course in engineering has improved their self-efficacy in engineering (Sun, 2021). The study showed that Chinese students' STEM attitudes from grades 1 to 6 did significantly improve with the project-based integrated STEM program; however, the STEM program just significantly improved the boys' performance in STEM attitudes, while girls STEM attitudes didn't change significantly, which goes against the goal of education equality (Zhou et al., 2019) and the possibility of increasing girls working on STEM careers in the future.

Fourth, traditional STEM education primarily focuses on knowledge acquisition and pays little attention to fostering creativity and independent thinking (Ye et al., 2020). In an environment without adequate encouragement for creative thinking, students will not see STEM as an area where they can innovate or explore their ideas, leading to negative attitudes or a lack of interest in further pursuing STEM careers. STEM education not only focuses on the acquisition of knowledge but also focuses on problem-solving creatively from multiple perspectives.

Although students in K-12 in China have solid basic discipline knowledge, they are relatively weak in innovation and practice, and early learning of science is more conducive to cultivating scientific literacy (Wang & Wang, 2018), which includes technology application, cooperation ability, social responsibility, aesthetic taste, and other qualities (Lin et al., 2019; MOE, 2022b). The majority of the studies focused on students' performance-level activities, such as working on the assignment itself, and to a much lesser amount, their meta-level activities, like how they control the collaboration and learning process (Van Leeuwen & Janssen, 2019).

The Chinese education system places a strong emphasis on individual achievement, primarily evaluating students through highly competitive exams such as the National College Entrance Examination. Typically, students are trained to complete tasks independently, emphasizing personal success over teamwork. Individual academic performance is evaluated by exam scores and rankings primarily, fostering a competitive rather than cooperative atmosphere among students. Using exam scores as the evaluation standard makes it simple for students to see their peers as competitors rather than potential collaborators. There is a space to develop primary students' sense of collaboration, and there is no gender difference (Lv, 2017).

In traditional classrooms, the primary teaching methods are teacher-centered lectures and completing individual assignments, which lack opportunities for peer collaboration within groups to solve problems. This reduces students' development of positive collaborative attitudes, the exchange of ideas, arguing and compromise, and management of group dynamics, etc., essential STEM collaboration skills. The current education system, which focuses on examination skills training and academic performance, provides students with few opportunities to develop interpersonal skills such as listening, communicating, conflict resolution, leadership, and the spirit of compromise, leading to a lack of effective collaboration skills within groups. There is an unequal relationship between peers about collaboration, such as some people's autocracy or some people just enjoying the success without efforts in groups (Peng, 2024).

Traditional gender stereotypes in collaboration view girls as supportive and empathetic and boys as competent in leadership and technical tasks (Woolly et al., 2010). When collaborating in a team, girls often receive supportive tasks such as recording and obeying boys' opinions, while boys typically express their viewpoints and make decisions. This can result in a lack of recognition for women's contributions, which goes against equality and collaboration among students. The study showed that in project learning in STEM education, fourth graders improved their team exploration and cooperation; the gender difference in collaboration was unknown (Luo, 2023).

The heavy academic burden causes students to focus on studying and testing isolated subject knowledge points, spending a lot of time preparing for exams and training to find fixed answers, leaving little room for creative problem-solving that would help them in real-world applications of STEM. Out of consideration for time-saving, problems and knowledge are presented to students directly (Lu, 2021); the time for them to explore and find questions actively is so limited that grasping problem-solving process abilities couldn't be cultivated well (Wu, 2024). Students can easily distinguish the problems and looked for answers based on their existed experiences. They don't have much time and opportunities to experience the problem-solving for complex problems. This situation makes it difficult for students to find clear answers when faced with open-ended questions in STEM education.

In traditional education, which primarily relies on listening and recitation as learning methods, results in students lacking hands-on learning activities that apply theoretical knowledge to practice, thereby promoting problem-solving skills. The lack of practical experience makes it difficult for students to creatively solve problems when faced with dynamic and complex issues; they can just solve some easy problems (Sun, 2022). They lose opportunity to plan and execute solutions by themselves. In the real world, solving problems often requires interdisciplinary thinking, and students need to integrate knowledge from multiple fields to develop solutions. In the current school education system, STEM primarily focuses on the separate teaching of mathematics and science, and the lack of an integrated STEM education approach can hinder the development of problem-solving (Wang & Yao, 2018).

Despite little difference in skills and knowledge between genders, the long-standing social gender roles see men as intelligent, logical, assertive, and proficient at STEM problem-solving and women as collaborative and emotional. Social bias manifests in problem-solving, demonstrating that (1) girls exhibit more hesitation in voicing their opinions and suggesting solutions, and (2) the evaluation of equal problem-solving outcomes varies, characterizing girls as diligent workers and boys as brilliant. This unequal support is shaping students' differences in problem-solving confidence and skills development, with girls demonstrating more attention focus and collaboration and boys demonstrating more planning and generalization abilities (Shi & Liu, 2024).

Problem-solving in STEM education among primary students is studied rarely. Lu (2021) studied the effectiveness of a STEM program based on 5E and EDP on 5th graders' problem-solving; however, the participants were not normal students but from the STEM club, and the number of samples of boys and girls was below 30 respectively, and there was no control group in the research design. The sample in utilizing the STEAM platform to improve students' problem-solving is also only 12 primary students (Li, 2019). The representativeness of the sample remains to be discussed. In addition, there were no significant gender differences in problem-solving and each dimension on statistic; however, according to interviews and observations boys preferred analysing problems, whereas girls were more inclined to assume the role of auxiliary coordination (Lu, 2021).

STEM education in China, while advocated in national curriculum standards like SCSCE2022, which emphasize engineering design and interdisciplinary integration, faces significant implementation challenges that hinder its potential to develop students' collaboration, problem-solving skills, and positive STEM attitudes in an equitable manner. Current STEM practices remain marginal, often limited to extracurricular clubs rather than integrated into core science classrooms, and most existing modules are not systematically designed based on formal science textbooks or standards, reducing scalability and relevance. Teachers lack adequate STEM literacy and interdisciplinary training, leading to continued emphasis on lecture-based, exam-focused instruction that prioritizes knowledge acquisition over experiential, collaborative, and real-world problem-solving learning. This approach fails to cultivate genuine interest, creativity, or a broad understanding of STEM fields and perpetuates gender stereotypes that discourage girls' participation and recognition. Furthermore, the lack of engineering design process (EDP)-driven, integrated STEM modules tailored to the national curriculum results in missed opportunities to engage all students—regardless of gender—in meaningful, hands-on projects that foster metacognitive skills, collaborative competence, and equitable attitudes toward STEM. Therefore, there is a critical need to develop and implement a localized, EDP-integrated STEM module that aligns closely with primary science topics, supports teachers with ready-to-use resources, and creates inclusive, collaborative learning experiences aimed at enhancing problem-solving abilities, teamwork, and positive STEM attitudes across both genders.

1.4 Research objectives (RO)

The study is to develop an iSTEM-EDP module for Chinese students in grade 5 in elementary school, and the study examines the effectiveness of the module on students' collaboration, problem-solving, and STEM attitudes. The objectives of the research are stated specifically as below.

RO1. To develop an iSTEM-EDP module that is suitable for fifth graders in China;

RO2. To determine the effectiveness of iSTEM-EDP module on collaboration which consists of collaborative attitude and collaborative behaviours for fifth graders;

RO3. To determine the effectiveness of iSTEM-EDP module on problem-solving which consists of exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting for fifth graders;

RO4. To determine the effectiveness of iSTEM-EDP module on STEM attitudes which consist of attitudes towards STEM subjects and STEM career interest for fifth graders;

RO4.1 To determine the effectiveness of iSTEM-EDP module on attitudes towards STEM subjects which consist of mathematics attitude, science attitude, and engineering and technology attitude for fifth graders;

RO5. To determine the gender difference of iSTEM-EDP module on collaboration which consists of collaborative attitude and collaborative behaviours for fifth graders;

RO6. To determine the gender difference of iSTEM-EDP module on problem-solving which consists of exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting for fifth graders;

RO7. To determine the gender difference of iSTEM-EDP module on STEM attitudes which consist of attitudes towards STEM subjects and STEM career interest for fifth graders.

RO7.1 To determine the gender difference of iSTEM-EDP module on attitudes towards STEM subjects which consist of mathematics attitude, science attitude, and engineering and technology attitude for fifth graders.

1.5 Research questions (RQ)

According to the research objectives, the research questions are stated as below.

RQ1. How to develop iSTEM-EDP module for Chinese fifth graders?

RQ2. Is there any significant difference for the mean score of posttest on collaboration which consists of collaborative attitude and collaborative behaviours between treatment group and control group?

RQ3. Is there any significant difference for the mean score of posttest on problem-solving which consists of exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting between treatment group and control group?

RQ4. Is there any significant difference for the mean score of posttest on STEM attitudes which consist of attitudes towards STEM subjects and STEM career interest between treatment group and control group?

RQ4.1 Is there any significant difference for the mean score of posttest on attitudes towards STEM subjects which consist of mathematics attitude, science attitude, and engineering and technology attitude between treatment group and control group?

RQ5. Is there any gender difference of iSTEM-EDP module for the mean score of posttest on collaboration which consists of collaborative attitude and collaborative behaviours for fifth graders?

RQ6. Is there any gender difference of iSTEM-EDP module for the mean score of posttest on problem-solving which consists of exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting for fifth graders?

RQ7. Is there any gender difference of iSTEM-EDP module for the mean score of posttest on STEM attitudes which consist of attitudes towards STEM subjects and STEM career interest for fifth graders?