Journal of Turkish Science Education, 2023, 20(4), 649-668.
DOI no: 10.36681/tused.2023.037

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

The Development and Validation of an EDP-STEM Module—Taking Heat Transfer, Mechanics, and Buoyancy as Examples

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ABSTRACT
This study aimed to develop a STEM module for eighth-grade middle school learners through the engineering design process. The module was developed based on the ADDIE model, primarily concentrating on the stages of analysis, design and development. The study consisted of two main phases: module development and module evaluation. During the development phase, 26 science teachers and 30 eighth-grade middle school pupils were purposefully selected from a public sector' middle school in China. Subject themes of the EDP-STEM module were determined by data analysis using coding of responses to interview questions and questionnaires seeking to elicit perceived needs. The EDP-STEM module's learning objectives, engineering design process, and STEM knowledge were subsequently developed. In the evaluation phase, five experts and 50 ninth-grade middle school pupils were recruited to verify the reliability and validity of the EDP-STEM module. The Content Validity Index (CVI) for the EDP-STEM module was 0.92, and the Cronbach's Alpha reliability coefficient was 0.76. Based on their feedback and suggestions, the researcher made modifications and improvements to the EDP-STEM module. The results of the study showed that EDP-STEM module has good reliability and validity and can be used as a learning module to carry out STEM learning in eighth-grade classrooms.

RESEARCH ARTICLE

ARTICLE INFORMATION

Received:
06.09.2023
Accepted:
29.11.2023

KEYWORDS:

STEM Education, Engineering design process, Module development, ADDIE

To cite this article: Xue X., Ahmad N. J., Liu X. (2023). The Development and Validation of an EDP-STEM Module—Taking Heat Transfer, Mechanics, and Buoyancy as Examples. *Journal of Turkish Science Education*, 20(4), 619- 631.

Introduction

"Every country's goal for knowledge economy and development is to create a sustainable knowledge capital dominated by STEM-skilled human resources" (Morales et al., 2022, p.235). Consequently, due to high demands for technological and scientific skills in today's society, rather than muscular or physical strength, there is now a need for well-educated individuals for the STEM workforce (Medine et al., 2021). STEM (Science, Technology, Engineering and Mathematic) education comprises methods of teaching and learning which aim to solve real-world problems (Wahono et al., 2020; Usman et al., 2023). STEM education has the potential to provide an inclusive learning environment, allowing all learners to engage, participate and learn confidently (Haddad et al., 2022). STEM education research in China has entered a stage of rapid development since 2013 and exhibited explosive growth in 2016 (Dong & Hu, 2017). It is important for a nation with the intention to achieve its future progress goals to prepare curricula based on interdisciplinary STEM education (Cinar et al., 2022; Usman et al., 2023). The China National Institute of Education Sciences and the STEM Research Centre collaborated to create the 2017 China STEM Education White Paper, which explicitly states that one of the primary tasks of education in China at this time is to actively develop STEM education (Ministry of Education, 2015). This document suggests the China STEM Education 2029 Innovation Action Plan after analysing the history and current state of STEM education in advanced nations. The key objectives of this action plan are to promote high-level STEM education policy design, a seamless strategy for developing STEM talents, STEM curricula, and effective STEM education modules and models (Tian et al., 2017).

Nowadays, STEM education in China confronts several difficulties. There is a weakening of disciplinary integration due to an overemphasis on the acquisition of information in science and mathematics while ignoring the importance of engineering education (Zhou et al., 2022). Engineering education is currently lacking a solid presence in K-12 school education (Moore et al., 2014). Bybee points out that educators often overlook technology and engineering education in STEM education (Bybee, 2010). Throughout the history of primary and secondary education, the "E" in STEM education has been largely silent (NRC, 2010). In reality, engineering (E) in STEM education, serves as a "bridge" that links information from science, mathematics and technology disciplines. “It not only helps students employ scientific, mathematical, and technical tools to create and optimize project solutions and finish engineering tasks in specific engineering settings, but it also improves students' higher-order abilities such as problem-solving, cooperation, and creativity” (Shi & Li, 2019, p.37). However, the reality is that due to the relatively late emergence of engineering education, there is limited availability of teaching and learning resources related to engineering in Chinese STEM curricula.

The use of the engineering design process as a context or instructional technique is suggested by the Framework for K–12 Science Education in the United States as a way to improve engineering education and encourage integration between other STEM fields (NRC, 2009). Learners need to experience the engineering design process with engineering design-based activities (Uzel & Canbazoglu, 2022). Although the Chinese Ministry of Education has also advocated for the integration of the engineering design process into STEM education as a potential remedy for the gap in engineering education, there is still some research that needs to be done on the subject of how to do so successfully.

Background of the Study

The United States is currently focusing on developing its educational system around STEM education, and other nations are observing and imitating its methods (Ma, 2015). Countries may improve their overall national competitiveness by implementing and promoting STEM education, which can help them boost both the quantity and quality of highly trained individuals (Hu, 2018). According to the 2018 China Science and Technology Talent Development Report, China needs 65 million STEM graduates overall, but there are now fewer than 50 million. The present problems in engineering education in China are strongly tied to the lack of STEM talent in China (Gao, 2020). STEM education places a high priority on engineering education since it is a powerful tool for developing students' inventive and practical skills (Yalçın & Erden, 2021). Currently, China has not successfully integrated STEM as a cohesive discipline, and there is a deficiency in STEM educational resources. For the implementation of STEM education, teaching and learning resources are essential, however there are not many STEM textbooks available in China (Song, 2019). Due to this, educators are compelled to buy resources from other countries international STEM textbooks. Additionally, there are extremely few opportunities for students to engage in engineering practices, and issues like a severe shortage of professors with engineering practical experience have made it more difficult for students to improve their engineering skills (Zhao, 2016). Last but not least, engineering education has not been fully implemented in China's public K–12 schools. Only a few private schools and after-school tutoring centers have conducted STEM and engineering courses. There has been relatively little study on engineering education, particularly at the primary and secondary school levels.

Within the realm of K-12 education, the Chinese Ministry of Education emphasises the need to incorporate the engineering design process into STEM education, strengthening engineering education, and improving students' engineering practical abilities and engineering literacy (Zhang et al., 2019). The Chinese Academy of Engineering highlights the existing shortage of instructional resources and courses in China's STEM education, specifically in the field of the Engineering Design Process. The academy emphasises the pressing need for intensified research and development efforts to address this gap (Wan, 2020). Based on this, this study aimed to develop a STEM module based on the engineering design process, providing teaching and learning resources for engineering education, and enhancing learners' engagement in engineering education.

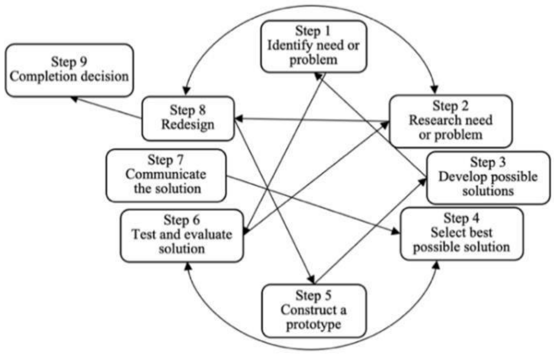
Engineering Design Process

Although engineering is considered one of today’s popular professions, it has roots as ancient as human history. It transcends being merely a profession; it is fundamentally a design process. Since the Stone Age, people have designed practical objects using materials obtained from nature, enabling them to survive, simplify their lives, and address various challenges (Acar, 2022, p.1222). Design is indicated as the most important dimension of the engineering enterprise, the aim of which has been to identify and satisfy economic, social, and cultural needs throughout history (NAE & NRC, 2009; Petroski, 1996). Engineering is defined as design realised within criteria and constraints (NAE, 2010). The National Assessment Governing Board defines engineering as a design process. Within this process, engineers employ various methods to devise solutions for needs or problems, and the formulated solutions encompass a systematic approach (NAE, 2010; NAE & NRC, 2009; NRC, 2012). “This process refers to as the engineering design process, is defined as the approach used by engineers to identify the best way to solve engineering problems, serve a given purpose and create a tool or process” (NAE & NRC, 2009, p. 38). Engaging students in engineering design-based activities facilitates meaningful learning in the fields of science and mathematics, while simultaneously fostering an understanding of engineering as a potential career and promoting familiarity with engineering design processes (NAE & NRC, 2009). The engineering design process is regarded as a pedagogical strategy that bridges concepts in science and mathematics to address ill-defined (open-ended) problems, foster creative thinking, formulate solutions and make decisions while considering alternative approaches to meet various constraints (Samsudin et al., 2007; Wang et al., 2011; Yasin et al., 2012).

The National Center for Engineering and Technology Education (NCETE) suggests the inclusion of engineering design challenges in STEM curricula, emphasising the potential for students to integrate STEM knowledge through the process of solving engineering design problems (Householder, 2012). This study utilised the engineering design process model proposed by NCETE to develop an EDP-STEM module. The process consists of nine steps, including identifying need or problem, researching need or problem, developing possible solutions, selecting best possible solution, constructing a prototype, testing and evaluating solution, communicating the solution, redesigning, and completing decision. Each step allows for iteration and redesign based on issues encountered during the process. Figure 1 shows the specific steps.

Figure 1

NCETE Engineering Design Process Model (Hynes et al., 2011)



STEM Education and Engineering Design Process

In comparison to other instructional methods, engineering and design stand out in STEM education (Akarsu et al., 2020; Jolly, 2014). The integration of the four disciplines is the key to STEM education, and the multidisciplinary character of engineering design naturally places it as an effective way for integrating STEM courses (Yang & Ni, 2017). Through the process of engineering design, students can apply abstract knowledge from different disciplines holistically and practically, leading to greater interest and deeper understanding of disciplinary knowledge (Capraro et al., 2013). Engineering design-based activities extend beyond the mere consideration and engagement of students in real-world problems. These activities additionally encompass the application of students' STEM knowledge in forecasting, analysing, and resolving engineering challenges (Fan & Yu, 2017). The engineering design process can motivate students to learn mathematical and scientific concepts that make the technology possible (Moore et al., 2013).

Chinese academics have progressively realised that the engineering design process may be used to effectively integrate STEM education. Zhu argues that engineering design can be effectively integrated with STEM education (Zhu et al., 2018). However, many studies on the incorporation of engineering design into STEM education have mostly focused on high school and university levels, with little study focusing on younger grades (English & King, 2015).

This study aimed to develop an EDP-STEM module for eighth-grade middle school pupils by integrating the engineering design process with STEM knowledge. The ADDIE model was employed for module development, focusing on the analysis, design, and development phases. After the module development, the applicability of the EDP-STEM module was assessed. This module has been developed with important implications for teachers, students and other researchers. By integrating the engineering design process into STEM, this module can help teachers make up for the lack of engineering teaching in conventional STEM teaching and break down the boundaries between the four disciplines. The engineering record sheet of this module provides pupils with a variety of roles, such as engineering designers, engineering builders and engineering evaluators, to help them experience the role of engineers to develop their interest in engineering careers. During the learning process, they will go through the engineering design process, produce engineering works and complete engineering challenges. This process can deepen their understanding and application of science, technology, mathematics, and engineering knowledge, solve real-world problems, and develop skills for the 21st century. The EDP-STEM module in this study can be used as a stepping stone to help researchers in the STEM field pay attention to the engineering design process and open up new ideas for developing STEM modules.

In line with this aim, the research questions are the following:

1. How to design an engineering design process-based STEM module?
2. What is the validity and reliability of the EDP-STEM module?

Methods

This study adopted a qualitative research design. The ADDIE model is used to develop the EDP-STEM module, which consists of two main phases: module development and module evaluation. In the module development phase, semi-structured interviews and open-ended questionnaires were conducted with 26 science teachers and 30 eighth-grade middle school pupils from a public sector middle school in Anhui Province, China, to ascertain their needs and requirements. Based on the collected data, the researcher designed and developed the module accordingly. In the module evaluation phase, five experts were invited to assess the validity of the EDP-STEM module. Fifty ninth-grade middle school pupils participated in the EDP-STEM module. Then, the researcher interviewed five students to express their views on the module.

Findings & Discussion

Phase 1: The Analysis

In the module development study, needs analysis research is a part of the module design and development process (Farihah, 2021). The analysis phase serves as the foundation for other stages in the ADDIE model (McGriff, 2000). The needs analysis phase provides crucial information for the design and development of the instructional materials in the subsequent stages (Gagne et al., 2005). Accordingly, the researcher conducted separate needs analyses for teachers and pupils.

(a) Needs Analysis for Teachers

The researcher invited 26 science teachers (T1-T26) from the public sector school to participate in semi-structured interviews. In the preliminary study, all participants' identities were kept confidential, and coded labels replaced their names. After the interviews, the researcher conducted analysis and coding of the interview data. To ensure the reliability of the coding, another researcher independently transcribed the raw data and compared the coding. The coding was 80% or more similar, ensuring the reliability of the coding (Saldaña, 2014). Table 1 presents a sample of interview coding and transcribed data.

Table 1

The Coding and Transcription Data for Teachers Interview

Quotes	Codes	Categories
...STEM Education is the interdisciplinary integration of science, technology, engineering, and mathematics...T1	Understand	Understanding STEM education
...I'm not sure, perhaps it's an education that brings the curriculum back to life...T9	Not sure	
...I'm not sure, the school has not conducted it before...T18		
...Choosing a topic from a practical perspective...T1	Starting from real life	The advantages of STEM education
...STEM Education emphasizes the integration of disciplines...T21	Discipline integration	
...focuses on strengthening the education of students in four aspects: scientific literacy, technical literacy, engineering literacy and mathematical literacy...T16	Cultivate comprehensive literacy	
...Mechanics is the most difficult...T5、T9、T10、T14、T18、T19、T20、T23、T24	Motion and mechanics	Difficult science themes

...Mechanical energy is the most difficult...T3	Mechanical energy	
...Buoyancy is the most difficult part...T8、T9、T12、T14	Buoyancy	
...It is difficult to design experiments and students do not have practical experience...T1	Experimental design	
...It can be integrated and requires the support of a practical problem scenario...T5	Feasible	Feasibility of integrating "heat transfer", mechanics," and "buoyancy" into STEM education
...While learning physics knowledge, students can also learn other knowledge across disciplines...T1	Subject knowledge	Learning outcomes
...Apply this knowledge to solve practical problems in life...T6	Problem-solving ability	
...Cultivate students' analytical and thinking abilities...T16	Thinking ability	
...The application of buoyancy in daily life...T7	Life applications	
...Due to limited class hours, it is difficult to provide STEM Education while ensuring grades...T1	Limited class hours	Implementation dilemma
...There is not much understanding of the current learning content in other disciplines, and it is unclear how to integrate the content...T5	Lack of teaching resources	
...Some knowledge points cannot be well integrated with STEM, lacking experience and professional guidance...T2	Lack of experience	

Based on the data, it can be inferred that although most teachers have some understanding of STEM education and believed that this educational approach can foster the integration of students' disciplinary knowledge and problem-solving skills. They did not formally implement STEM education in actual teaching, mainly limited by class hours, teaching resources, and their own experience. In their regular science instruction, they found it challenging to implement topics that involve experimental design, such as "energy conversion", "motion and force", and "buoyancy". All teachers acknowledged the high feasibility of integrating these three themes with STEM education and believed that it can greatly enhance the teaching of these topics. They believed that these topics are closely related to student's daily lives and can be approached through real-life contexts in design activities.

(b) Needs Analysis for Pupils

The pupil need analysis in this study was conducted using an open-ended questionnaire administered to 30 eighth-grade pupils (S1-S30) from public sector schools in Anhui Province, China. In the preliminary study, the identities of the participants were kept confidential, and the coded labels were used in place of their names. The researcher conducted analysis and coding of the open-ended questionnaire data. Again, another researcher independently carried out this exercise and again the codings were found to be reliable In most cases, the coding of the primary codes was 80% or more similar, ensuring the reliability of the coding (Saldaña, 2014). Table 2 presents a sample of questionnaire coding and transcribed data.

Table 2

The Coding and Transcription Data for Students Questionnaire

Quotes	Codes	Categories
...I've heard of it, but I haven't taken STEM classes...S3	Heard of	

...I haven't heard of it or understood it...S1	Not too clear	Understanding STEM education
...Take notes and organize mistakes...S8 ...Participate in hands-on practical activities...S24	Take notes Participate in practical activities	Methods to assist in learning science
...Mechanics is the most difficult...S1 ...Mechanical energy is the most difficult...S20 ...It's not too difficult...S26	Difficult Not difficult	The difficulty of "heat transfer", mechanics", and "buoyancy"
...Yes, because STEM education is a very novel and challenging way of learning that will arouse our great interest...S17 ...I will be interested because in practice, it will give me a greater sense of fulfillment, help me better understand knowledge, and enable me to innovate in practice...S11 ...Yes, it will be very interesting and can also improve my hands-on skills...S19 ...Learning in practice will help us remember knowledge more firmly...S30	Be interested Fulfillment Developing hands-on skills Strengthen knowledge learning	Interest in STEM education and hands-on practice

Through the analysis of the open-ended questionnaire data, it was found that 53% of the pupils had heard of STEM education, but none of them had formally received STEM education. Based on Question 2, it was evident that the majority of pupils were still influenced by the traditional exam-oriented education system, relying on note-taking and extensive practice to facilitate their learning. Although some believed that more hands-on activities should be incorporated, they lack the opportunity to engage in such activities. Most found the topics of "heat transfer", "mechanics", and "buoyancy" to be difficult. Finally, the majority expressed their interest in STEM education and their anticipation for hands-on practice, through which they can acquire STEM knowledge and develop practical skills by solving real-world problems.

Phase 2: The Design

The second stage of the ADDIE model is the design of the EDP-STEM module. In this research, the design stage was based on the data analysis results, and involved the formulation of learning objectives and the application of the engineering design process.

(a) Learning Objectives

This study aimed to develop an EDP-STEM module for eighth-grade middle school pupils. During the needs analysis stage with teachers and learners, the topics of "heat transfer", "mechanics", and "buoyancy" were identified. The learning objectives for each activity in the module were organized according to the revised Bloom's taxonomy sequence and were aligned with the content of the People's Education Edition (PEE). The learning objectives for each activity are as follows.

Table 3

Learning Objectives in EDP-STEM Module

Activity	Learning objectives

Save the Penguins	• Analyse the behaviours that contribute to global warming. • Define heat transfer as the transfer of thermal energy. • Compare the differences in insulation properties among different materials. • Combine the characteristics of different materials to complete a unique design.
Crossing the River	• Identify and distinguish common types of bridges. • Understand the spans of different types of bridges and be able to select an appropriate bridge design based on specific needs. • Estimate the actual dimensions of an object using the method of proportional mapping. • Combine the characteristics of different materials to complete a unique design.
Lekima Rescue	• Explain the factors that determine the magnitude of buoyancy. • Acquire knowledge about the conditions under which objects float or sink through experiments. • Understand that forces can alter the direction and speed of object motion. • Estimate the actual dimensions of an object using the method of proportional mapping.

(b) Engineering design process

The engineering design process is the core content of this module. STEM courses driven by engineering education can effectively integrate and apply knowledge from various disciplinary fields through the utilization of the engineering design process. STEM education can fully leverage engineering design to achieve an integrated instructional approach, accomplished through the use of engineering problem-based tasks that involve real-world contexts. This practice allows for the synthesis of knowledge and skills from different subject areas, enabling students to design solutions to practical problems, explore the development of new knowledge, and enhance their engineering thinking and interdisciplinary problem-solving abilities. The three thematic activities in this EDP-STEM module were designed according to the 9 steps of the engineering design process, aiming to help students experience the process of engineering design and learn STEM knowledge.

1. Save the Penguins. With global warming, large chunks of floating ice are melting, and penguins are gradually losing their habitats. The population of Antarctic penguins has drastically declined due to climate change. The penguins have lost their food sources, such as krill that rely on large floating ice as shelter and feed on algae growing beneath the ice. African penguins risk leaving their nests and venturing into the sea, even exposing their eggs to seagull attacks, just to cool themselves down in the water. Currently, engineers, scientists, and environmental organizations worldwide are working diligently to find ways to mitigate or halt global warming. Based on this background, the researcher integrated this activity with the engineering design process, as shown in the following Table 4.

Table 4

Engineering Design Process in "Save the Penguins"

EDP	Content
Identify need or problem	Observe visual aids and materials related to global warming and the melting of glaciers, comprehend the ecological challenges and living conditions that penguins experience, and delineate the current predicaments that penguins confront.
Research need or problem	Examine the effects of temperature fluctuations on penguins and investigate the underlying factors responsible for the reduction of their habitat. Consider strategies to aid penguins in resolving their present predicaments and identifying the engineering objectives of the undertaking.

Develop possible solutions	Conduct a jar experiment to compare the insulation effectiveness of five different materials, record the experimental results, correct misconceptions about heat transfer, and considering which material would be most effective in helping penguins with insulation.
Select best possible solution	Apply the acquired knowledge of thermodynamics, considering material selection, insulation design, etc., sketching a design diagram, and determining a practical and feasible solution.
Construct a prototype	Purchase materials for fabrication, define evaluation criteria, collaborate as a group, assign tasks, and construct a shelter to protect penguins from the impact of extreme temperatures.
Test and evaluate solution	Share and showcase engineering projects, summarising their strengths and weaknesses.
Communicate the solution	Share and summarise the strengths and weaknesses of the engineering projects produced. Considering ways in which they could be improved.
Redesign	Refine engineering projects and subsequently share the reasons for the improvements.
Completion decision	Share the final version of the engineering project that the team has produced.

Pupils engaged in the engineering design process to learn how engineers help penguins cope with global warming by designing energy-efficient buildings. They will learn about heat transfer principles, design experiments, test building materials, and take on the role of engineers to design and construct insulated and energy-efficient habitats for penguins. They will also conduct tests to evaluate the insulation performance of the constructed habitats.

2. Crossing the River. In 2020, the Ming Dynasty Haiqiao Bridge in Tunxi District, Huangshan City, Anhui Province, China, was destroyed by flooding. One of the bridge piers sustained damage after being struck by the floodwaters. Subsequently, the bridge structure was severed, resulting in its collapse and significant damage. The geographical location and significance of the Zhenhai Bridge were of great importance. The bridge connected Tunxi Old Street and Liyang Ancient Town, providing a vital link between the two towns. The disruption caused inconvenience to residents' daily lives after it was washed away. Local engineers were considering how to design a more resilient bridge to prevent future flood disasters. Based on this background, the researcher integrated this activity with the engineering design process, as shown in the following Table 5.

Table 5

Engineering Design Process in "Crossing the River"

EDP	Content
Identify need or problem	Watch the pictures and videos of the Ming Dynasty Zhenhai Bridge in Tunxi District, Huangshan City, Anhui Province being destroyed by floods, to understand the real problems and clarify the engineering tasks.
Research need or problem	Understand the types of bridges commonly seen in daily life, such as beam bridges, arch bridges, cable-stayed bridges, and suspension bridges. Know the uses of different types of bridges, distinguish the spans used by different types of bridges, and be able to choose the appropriate bridge according to actual needs.
Develop possible solutions	Understand the stress areas of different types of bridges and record the experimental results. Consider which type of bridge has a longer span and can carry more weight.

Select best possible solution	Determine the main material of the bridge, consider how to construct the bridge structure, etc. Draw a design sketch and determine a practical and feasible solution.
Construct a prototype	Purchase materials for production and clarify the evaluation criteria. Work in groups, divide tasks and make a bridge with a span of at least 35cm that can carry at least 10 adults (using weights for simulation) and can withstand floods.
Test and evaluate solution	Share and showcase the bridge built by your group and summarize the advantages and disadvantages of your group's bridge. Place the bridge in a simulated scenario (manually simulate flood conditions) and test the stability of the bridge.
Communicate the solution	Share and summarize the advantages and disadvantages of bridges built by other groups. Based on the opinions of other groups and adopting the advantages of other groups, consider how to improve the group's bridge.
Redesign	Refine engineering projects and subsequently share the reasons for the improvements.
Completion decision	Share the final version of the engineering work that the team has produced.

The "Crossing the River" activity was set in the context of the Zhenhai Bridge being washed away by floods in 2020. Based on the engineering design process, students will experience the role of bridge engineers by utilizing engineering, technology, mathematics, and science to design and construct a bridge with a minimum span of 30cm. The bridge should be able to support at least 10 adult individuals (represented by weights), and through the artificial simulation of flooding (pouring water flow from different heights), various flood levels will be created to test the structural integrity of the bridge.

3. Lekima Rescue. In 2019, Super Typhoon Lekima, designated as Typhoon No. 1909, made landfall in Wenling, Zhejiang Province. The typhoon brought unprecedented wind and rainfall, surpassing historical records in many areas and triggering various secondary disasters, including floods and landslides, resulting in severe damage in provinces and cities including Zhejiang, Fujian, Anhui, and Shanghai. Due to the impact of heavy rain brought by the typhoon, firefighters urgently required disaster relief supplies such as boats, raincoats, and life jackets. The reserve quantity and adaptability of lifeboats were insufficient to meet the rescue mission demands extreme weather disasters. Therefore, naval engineers were considering how to design a lifeboat specifically for adverse typhoon conditions to supply affected areas and make preparations for unexpected future typhoon disasters, emphasizing the urgency of proactive measures and preparedness. Based on this background, the researcher integrated this activity with the engineering design process, as shown in the following Table 6.

Table 6

Engineering Design Process in "Lekima Rescue"

EDP	Content
Identify need or problem	Watch images and videos of the various middle disasters induced by Typhoon Lekima, such as floods and landslides, is an effective means of gaining an understanding of the challenges faced by the public and can help to clearly define the engineering tasks at hand.
Research need or problem	Gain knowledge of the basic structure, classification, navigation and types, provides a more concrete and solid foundation for solving real-world tasks.

	Consider the factors that affect a vessel's ability to support a certain weight and remain afloat, such as weight, volume and materials, and analyze and construct the prototype of the boat.
Develop possible solutions	Understand the sinking and floating effects of different boat main materials and record the experimental results. Consider which material is better waterproof, lighter, and stronger.
Select best possible solution	Determine the primary materials and power system for the watercraft, as well as considering the structural framework of the vessel, are essential components in developing a feasible design. Draw design sketches to determine a feasible solution.
Construct a prototype	Purchase production materials and clarify evaluation rules. Work in groups and divide tasks to create a lifeboat that can accommodate at least 4 adults.
Test and evaluate solution	Share and showcase the lifeboat developed by the team, as well as conducting a self-assessment of its strengths and weaknesses, are key components of the project. The lifeboat is then to be placed in a simulated scenario, such as an artificial waterway or rapids, where it will be tested for speed and rescue capabilities along a straight route.
Communicate the solution	Share and summarize the strengths and weaknesses of other teams' lifeboats is a crucial step in the project. Based on feedback from other teams and adopting their positive attributes, the team will consider how to improve their lifeboat.
Redesign	Refine engineering projects and subsequently share the reasons for the improvements.
Completion decision	Share the final version of the engineering work that the team has produced.

The "Lekima Rescue" activity was designed and developed based on the real-life event of Typhoon Lekima hitting China. Students will assume the role of naval engineers through the engineering design process. During this process, they will learn about the concepts of buoyancy. They will be required to utilize engineering, technology, mathematics, and science to design and construct a lifeboat capable of accommodating at least four adults. In the simulation of the rescue process, the lifeboat should remain balanced without any issues such as leaks, capsizing, or structural failure. To test its performance in typhoon conditions, different wind levels will be artificially created using tools such as a fan or blower to assess its stability.

Phase 3: The Development Phase

The third phase of the ADDIE model is the development phase, which involves the development of the EDP-STEM module. In the previous phase, the learning objectives and STEM thematic activities were identified. In this phase, the specific STEM disciplinary knowledge associated with each activity was discussed. To assess the developed EDP-STEM module, the researcher sent the module for expert review. The expert review aimed to validate the content. Once the module was reviewed by the experts and refined accordingly, it had undergone a pilot study. Based on the feedback from participating students in the pilot study, the researcher further modified the EDP-STEM module.

(a) Integration of STEM Knowledge

During the development process, the researcher integrated the knowledge from all four STEM disciplines into each activity. Table 7 below illustrates the STEM elements included in each activity of the EDP-STEM module.

Table 7

STEM Knowledge in Each Activity

Save the Penguins	Science	• Learn about the various factors that contribute to global warming. • Develop an understanding of the fundamental principles and basic applications of force. • Understand the concept that heat is transferred from areas of higher temperature to areas of lower temperature. • Acknowledge that insulating materials can reduce the rate of heat transfer.
	Technology	• Compare the thermal insulation effect of various materials and analysis the thermal conductivity of each material. • Understand the functions and applications of different tools and materials. • Gain hands-on experience in using different materials to construct engineering projects. • Brainstorm ways to improve engineering projects and address minor discrepancies.
	Engineering	• Develop an understanding of the fundamental structure of the engineering project, including the functions and relationships of each component. • Appreciate the significance of the engineering design process in the project. Utilize knowledge and principles to draft sketches, design and fabricate products, and solve real-world problems. • Recognize that engineering design must consider available conditions and constraints and must be continually refined and perfected.
	Mathematics	• Acquire knowledge of basic arithmetic operations and master the skills of performing arithmetic operations. • Classify and compare data to comprehend the information contained within the data. • Familiarize oneself with the fundamental characteristics of geometric and planar figures. • Collect and organize data, presenting the results of data organization in written form, charts, tables, etc. (e.g., creating a cost estimate sheet for the "Save the Penguins" project, drawing design diagrams)
Crossing the River	Science	• Understand that the load-bearing capacity of a bridge is related to the shape of the bridge. • Understand the characteristics of bridges and be able to classify them according to different standards. • Understand that forces are everywhere and can change the motion state of an object. Even stationary objects are affected by forces.
	Technology	• Understand that most objects are composed of different structures that often affect each other. • Through the process of building a bridge, understand the important role that technology plays in bridge construction.

		• Understand that even a very sophisticated design can still fail, but taking certain measures beforehand can reduce the likelihood of failure.
	Engineering	• Understand the basic components of a bridge, such as the bridge deck, bridge piers, and bridge structure. • Understand the factors that affect the load-bearing capacity of a bridge, such as structure, shape, and material. • Through the process of researching problems, engineering design plans, building prototypes, testing, and improving prototypes, constructing a bridge prototype and solving real problems. • Be able to analyze available resources, estimate the effectiveness of their use, and iterate and optimize based on design intentions.
	Mathematics	• Able to use proportional mapping methods to estimate the true size of objects. • Record the load-bearing data and simulated flood levels of each bridge, draw a table, and compare the data. • Compare the stability of different shapes and understand the stability of triangular structures. • Collect and organize data and present the results of the data in the form of text, charts, tables (such as making a “Crossing the River” cost sheet, drawing design drawings).
Lekima Rescue	Science	• Understand the weight of an object per unit volume, i.e., its density, affects its buoyancy in water. • Know that an object’s buoyancy is related to the amount of buoyant force it receives. • Understand that the more submerged an object is in a liquid, the greater the buoyant force it experiences. • Understand that force can alter the direction and velocity of an object’s motion.
	Technology	• Understand that most objects are composed of different components that typically interact with each other. • Understand that if one component of an object is missing, damaged, worn, improperly installed, or not connected, it may malfunction. • Understand that even a very sophisticated design may still fail and that taking certain measures beforehand can reduce the likelihood of failure.
	Engineering	• Understand the basic structure, classification, propulsion, and braking of watercraft. • Understand the factors that affect the buoyancy of watercraft, such as weight, volume, and materials. • Through processes such as problem research, engineering design, prototype construction, testing, and improvement, a lifeboat prototype is built to solve real problems. • Analyze available resources, estimate performance, and iterate to optimize according to the design intent.
	Mathematics	• Proficient in using proportional mapping methods to estimate the actual dimensions of objects.

	• Capable of using numbers, geometric shapes, and images to describe and predict real-world phenomena around us.
	• Collect and organize data, and present the results in written form, charts, tables, etc. (e.g., making the "Lekima Rescue" cost sheet, drawing design diagrams).

Based on the analysis of teacher interviews, it was revealed that the majority of teachers expressed a lack of knowledge on how to integrate STEM knowledge. Consequently, in this module, the researcher organized and integrated the knowledge from the four STEM disciplines and included this section in the Teacher Guidebook of the EDP-STEM module, aiming to assist teachers in implementing the EDP-STEM module more effectively.

(b) Assessment of EDP-STEM Module

According to Sidek and Jamaludin (2005), the second phase of module development involves expert validation and reliability studies. The assessment of this module was conducted through two approaches: expert assessment and pilot study. Comments and feedback received during this phase enabled the researcher to fine-tune and further improved the developed module.

The EDP-STEM module consists of three activities, each spanning four class hours, totaling 12 weeks. Five experts were invited to participate in the validation of the module's effectiveness. The basic information of these five experts is shown in the Table 8.

Table 8

Experts Information

Expert	Field of specialisation	Educational attainment	Title	Length of service
Expert1	STEM education	PhD	Associate professor	17 years
Expert2	Curriculum Development	PhD	Associate professor	18 years
Expert3	Interdisciplinary education	PhD	Lecturer	5 years
Expert4	Engineering education	PhD	Lecturer	24 years
Expert5	Science education	PhD	Lecturer	6 years

This study adopted the validation form proposed by Maimunah (2016), adjusted and modified according to the research. The validation form for the EDP-STEM module consists of a total of 10 items. Subsequently, five experts evaluated the content validity of the EDP-STEM module. Content validity is then calculated using CVI (content validity index) as suggested by Polit, Beck and Owen (2007) and Zamanzadeh et al., (2015). The CVI is an index of inter-rater agreement that is widely used as an approach to calculate the proportion of agreement. CVI can be computed by calculating the average of experts' agreement on item (I-CVI) by denoting relevant item as 1 and irrelevant as 0. olit, Beck, & Owen, (2007) recommended the value of I- CVI must be at least 0.78 or above to indicate good content validity when there are three or more experts involved. S-CVI is the overall content validity for scale and researcher often use .80 as the lower limit of acceptability for S-CVI.

As can be seen from Table 9, the five experts agreed that the EDP-STEM module has good content validity. This was demonstrated by all of the ten items having an I-CVI above 0.80 while the S-CVI obtained is 0.92, which exceeded the minimum I-CVI (0.78) and S-CVI (0.80) value which was recommended by Polit, Beck, and Owen, (2007).

Table 9

I-CVI and SCI-Average to evaluate expert consensus on EDP-STEM module

Item	Relevant	Not relevant	I-CVIs
This module is suitable for the level of middle school students in grade 8.	5	0	1.00
The language that is used is suitable for middle school students in grade 8.	5	0	1.00
The usage of pictures and graphics are suitable for middle school students in grade 8.	4	1	0.80
The correct content of learning is used in this module.	4	1	0.80
The activities that are mentioned in this module suitable for the EDP-STEM approach.	5	0	1.00
The activities that are mentioned in this module are relevant to the real world.	5	0	1.00
Each activity in this module allows students to meet the lesson outcome.	5	0	1.00
The activity in this module encourages the students to integrate their knowledge in an interdisciplinary manner.	4	1	0.80
Each activity designed following the engineering design process accurately and it has been arranged systematically.	4	1	0.80
Each activity has been explained well and is easy to be understood by students.	5	0	1.00
Mean S-CIV/Average =0.92			

The five experts deemed the content of the module to be appropriate and they also proposed some modification suggestions. The researcher compiled and organized the suggestions provided by the five experts and summarized the modifications for the EDP-STEM module. Part of the content is shown in Table 10.

Table 10

Suggestions and Modifications

Expert	Reviews and Suggestions	Fine-tuning done
Expert1	The learning objectives should be classified such as knowledge, skills, and design practice, or divided into different dimensions of STEM to make the expressions clearer.	The researcher sorted the learning objectives of each activity following Bloom's taxonomy sequence.
Expert2	During the communication and solution process in Step 7, it is suggested to discuss not only the advantages but also the disadvantages of designs from other groups.	The researcher made modifications to step 7 of the engineering design process by adding a discussion of disadvantages.
Expert3	It is recommended to modify or add cost-related elements to the engineering materials involved in each engineering activity, as cost-saving is a crucial constraint for engineering projects.	The researcher established a production cost for each activity and required each group to purchase materials within the specified limit.
Expert4	It is recommended to include real images in the module to help students better understand the activity theme.	The researcher adjusted the images in the module to stimulate students' desire to solve problems.
Expert5	It is recommended that the learning objectives in the module correspond to the curriculum standards, to meet the cognitive level of eighth-grade middle school students.	The researcher based the learning objectives on the curriculum standards of the eighth-grade science textbook of the People's Education Edition, which are in line with the cognitive level of eighth-grade middle school students.

The pilot study is small-scale preliminary research aimed at investigating the feasibility of key components of the main study. It can be used to attempt improvements in various aspects of the research design (Junyong, 2017). To ensure the successful development of the EDP-STEM module, this study invited 50 ninth-grade middle school students to read the EDP-STEM module during the pilot study phase (45 minutes). Three activities in the EDP-STEM module were scored using the Five Point Likert Scale, and the internal consistency of the EDP-STEM module was tested. Most researchers suggest that the Alpha value of 0.80 and greater is typically a high level of reliability (Cohen, Manion, & Morrison, 2000; Sekaran & Bougie, 2010). However, according to scholars (Abd Ghafar, 1999; Konting, 2000), the Alpha Cronbach value of 0.60 is also sufficient for instruments developed in the social science field of education. Table 11 showed that the Alpha Cronbach values of the three activities are 0.76, 0.81, and 0.72 respectively. The Alpha Cronbach value for the EDP-STEM module is 0.76. Consequently, the Alpha values of the EDP--STEM module were considered to have an acceptable reliability in the context of measurement.

Table 11

Cronbach's Alpha Coefficient of the Activities in the EDP-STEM Module

Activity	Cronbach's Alpha
Save the Penguins	0.76
Crossing the River	0.81
Lekima Rescue	0.72
Overall alpha of EDP-STEM module = 0.76	

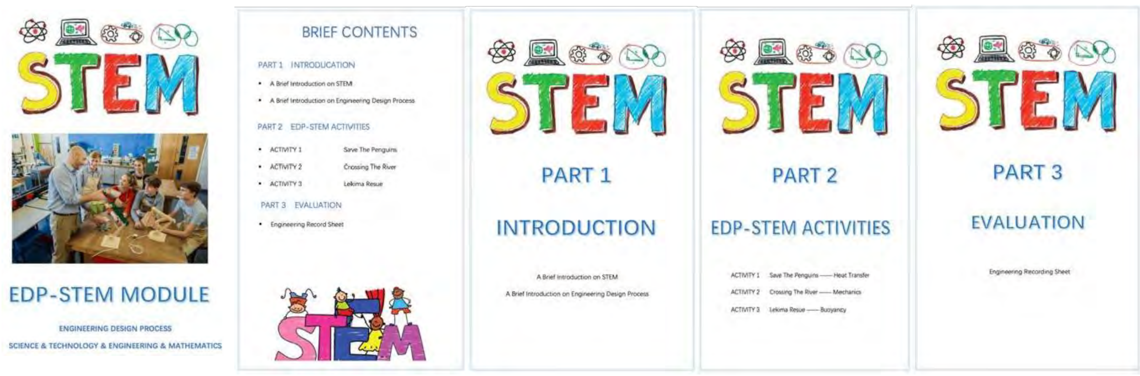
After the pilot study, the researcher randomly interviewed five students (S1-S5) and sought their opinions on the EDP-STEM module for a total of 30 minutes. Subsequently, the researcher transcribed and coded the recordings, and a portion of the content is presented below.

S1: "If the pictures in the module were in colour, it might be more appealing to us."
S2: "I think the module is well-designed, I don't have any comments."
S3: "The space under the questions is a bit small, it may not be enough for me to write."
S4: "I think it would be helpful if the engineering log sheet was printed out for us to fill in."
S5: "I think the module is already very comprehensive, and I will think about the problem according to the engineering design process, and I have no comments."

The feedback and suggestions provided by the students were taken into consideration by the researcher. Specifically, the researcher had adjusted the module's images to be in color and had also provided more space for students to answer questions and make design sketches by adjusting the space below the questions. Finally, the researcher provided each group with a printed engineering record sheet for easier record-keeping. Some students expressed satisfaction with the design of the module, noting that it helped them to conduct their activities effectively. The part of the EDP-STEM module is presented in the following Figure 2.

Figure 2

The EDP-STEM Module



Conclusion

Based on the ADDIE instructional design model, this study developed an EDP-STEM module. During the analysis phase, the requirements of teachers and students were prioritised, and three knowledge points ("heat transfer," "mechanics," and "buoyancy") were selected to address the current issues faced by teachers and students. The researcher incorporated information and activities during the design and development process, taking into account students' cognitive levels and utilising real-world problems and challenges as a starting point. Following the engineering design process, learning objectives and STEM discipline knowledge were developed for each activity. During the module evaluation phase, through expert review, it can be seen that the content validity S-CVI of the EDP-STEM module is 0.92, and the experts all agree that the development of the EDP-STEM module is successful. Through the pilot study, it was found that the reliability of the EDP-STEM module was 0.76, and students reported that they understood the module well. Finally, the researcher incorporated the recommendations from both experts and students to further refine the EDP-STEM module.

The research findings also indicated that due to constraints such as class hours, teaching resources, and personal experience, most teachers have not formally implemented STEM education in their actual teaching and are unfamiliar with the engineering design process. They perceive difficulties in implementing topics involving experimental design in their daily instruction, which can be effectively combined with STEM education and the engineering design process through the development of teaching and learning resources to improve instruction. Additionally, the majority of students didn't have formal exposure to STEM education and the engineering design process. However, most of the students demonstrated a high level of interest in the EDP-STEM module, expressing their eagerness to engage in hands-on activities and learn engineering knowledge while addressing real-world problems, thereby fostering their practical skills. Consequently, in future research, the researcher will focu on the cultivation of students' learning outcomes through the EDP-STEM module, such as cultivating engineering thinking, critical thinking, and engineering career interests.

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