MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(4), em2611
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/16084

Integrating design thinking into STEM education: Enhancing problem-solving skills of high school students

Le Chi Nguyện [1*], Ho Quang Hoa [1], Le Hoang Phuoc Hien [1]

[1] University of Education–Vietnam National University, Hanoi, VIETNAM

Received 15 December 2024 ▪ Accepted 24 January 2025

Abstract

This study explores the integration of design thinking into science, technology, engineering and mathematics (STEM) education to develop problem-solving skills among high school students. The study applied a design thinking model with five stages: empathy, problem identification, ideation, prototyping, and testing, through experimental STEM lessons with 334 students. The results show that the model of integrating design thinking into STEM education not only improves critical thinking ability but also increases the ability to apply STEM knowledge into practice. Confirmatory factor analysis (CFA) and indices such as CFI = 0.994 and RMSEA = 0.020 confirmed the high suitability of the model for STEM education. The strong correlations between stages, especially define-ideate (r = 0.731) and prototype-test (r = 0.709), show the effectiveness of repetition in the learning process. This article emphasizes that iteration between stages helps students continually refine and improve their solutions while developing their observation, creativity, and self-evaluation skills.

Keywords: design thinking, STEM education, STEM learning, problem-solving skills, CFA analysis

INTRODUCTION AND THEORETICAL FRAMEWORK

Science, technology, engineering and mathematics (STEM) education is increasingly becoming an essential educational approach, not only helping students develop the skills needed to solve complex 21st century problems but also providing a solid knowledge base to adapt to a rapidly changing world due to technology and science (Koh et al., 2015). STEM education not only imparts knowledge but also encourages students to integrate knowledge of subjects to solve real-world problems and develop critical and creative thinking (Honey et al., 2014). Integrating STEM subjects in STEM education not only helps students gain a deep understanding of theory but also helps them see the practical application of what they have learned, thereby encouraging students to learn proactively and creatively (Bybee, 2010). STEM education trains students to approach problems in a multidimensional and interdisciplinary way, encouraging logical and creative thinking to solve problems in life and learning. Importantly, the problem-solving skills developed in STEM education are not limited to the classroom but also prepare students to tackle real-world challenges in both academic and professional contexts (Honey et al., 2014).

Design thinking is a creative approach that focuses on problem-solving through empathy, identifying user needs (problems), ideation, prototyping, and testing (Pusca & Northwood, 2018). Design thinking is considered an effective tool for solving complex and ambiguous problems, known as difficult problems, using creative and experimental approaches (Buchanan, 1992). Design thinking is not simply a solution-finding process, but a flexible approach that connects engineering and science to solve complex problems (Koh et al., 2015). Although design thinking is often associated with technical and creative fields, it is also well-suited to STEM education because it focuses on developing critical thinking and problem-solving skills. Although practice and research are ongoing, there is still a lack of clear definitions and methods for STEM education (Yata et al., 2020). Design thinking is still a relatively new concept in the field of STEM education, and there is more

Le Hoang Phuoc Hien was funded by the Master, PhD Scholarship Programme of Vingroup Innovation Foundation (VINIF), code VINIF.2024.TS.104.

✉ Lcnguyendhhl@gmail.com **(*Correspondence)** ✉ hoaho82@gmail.com ✉ phuochien219@gmail.com

Contribution to the literature

- This study proposes a model for integrating design thinking into STEM education to help students develop critical thinking, creativity, and problem-solving skills.
- Empirical analysis confirmed the relevance of the model, emphasizing the role of iterations in STEM learning to optimize solutions.
- The findings highlight the close connection between the different stages of design thinking, reinforcing the importance of adaptive learning in STEM education.

research on teachers' instructional design processes than on student learning (Koh et al., 2015).

The purpose of this study was to integrate design thinking into STEM education as a tool to guide secondary school students in solving problems in STEM learning. The research questions (RQs) of this study are, as follows:

RQ1. Is the integrated design thinking model suitable for STEM education?

RQ2. What is the relationship between design-thinking skills: empathy, identifying user needs (problems), idea generation, prototyping, and testing in the context of STEM education?

RQ3. Is the integrated design-thinking model suitable for STEM education in secondary schools?

Design Thinking Model in STEM Education

Integrating design thinking into STEM education has been shown to enhance student learning through hands-on and experiential learning (Pusca & Northwood, 2018). Three popular models for applying design thinking to teaching are the double diamond model, Stanford model, and IDEO model (Koh et al., 2015). The design-thinking model in STEM education is a combination of these three models, selectively including the following stages:

Empathy: In this stage, students focus on understanding the needs, problems, and challenges they need to solve. This stage emphasizes listening and observing to grasp the true nature of the problem. Empathy helps students develop the ability to think empathetically, which is an important factor in identifying users' real needs and expectations (Brown, 2009). Students begin the process by deeply understanding the needs, problems, and expressions of users. The understanding stage helps students learn to listen, observe, and analyze the needs of society, thereby grasping the nature of the problem (Jonassen, 2011). In the context of STEM education, this process may include learning to use scientific and technological principles to solve social and environmental problems (Pusca & Northwood, 2018; Sanders, 2009).

The problem-solving stage helps students not only clearly define the problem but also explore different aspects of the problem from scientific, engineering, and technological perspectives. Problem-solving is an important step in ensuring that the proposed solutions are truly relevant and highly feasible (Buchanan, 1992).

Ideate stage: This stage encourages students to arrive at possible solutions to the identified problem. Students are encouraged to think creatively, beyond conventional boundaries, and use scientific methods to solve real-world problems (Harlen, 2015). This is an open stage where students are encouraged to think freely and are not limited by traditional barriers, which play an important role in stimulating creativity and exploring many different potential solutions that students can apply in a STEM context (Brown, 2009). The ideate stage provides students with unlimited imagination and creativity; this is the stage in which students can use STEM knowledge to come up with many potential solutions to an identified problem. Encouraging imagination and creativity will help students move beyond the obvious ideas to create a prototype: After generating multiple ideas, students will choose the best solution and begin designing and building a prototype. This is an opportunity for students to apply STEM knowledge, such as physics, chemistry, technology, and engineering, to realize their ideas for a specific product. The prototyping phase helps students quickly identify potential design constraints or problems before testing (Pusca & Northwood, 2018). During the prototyping phase, students chose the best solution from the ideas they had developed and proceeded to build a prototype. This phase is not only a demonstration of technical skills, but also an opportunity for students to experiment, receive feedback, and refine the solution (Jonassen, 2011).

Testing phase: The final phase of the design-thinking process involved testing and evaluating the prototype. Students conducted tests to gather feedback and refine the prototype to improve the solution. Testing not only helps students learn from failures but also promotes critical thinking and effective problem-solving (Kelley, 2017). The testing and evaluation phases of the prototype helped students effectively test the proposed solution. Students tested their prototype through multiple trials, thereby refining and improving the solution based on the experimental results. Testing allowed students to gain a better understanding of the feasibility of the solution and improve the solution to achieve the best results (Brown, 2009). Since students must learn from

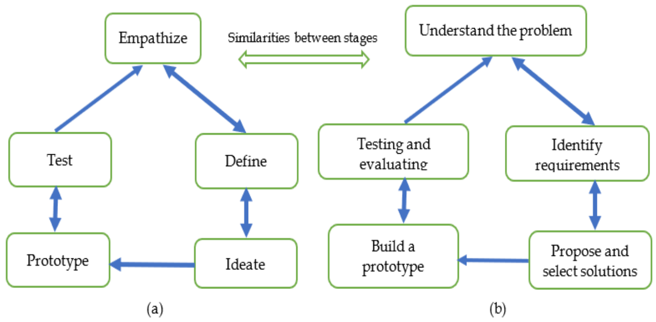


Figure 1. Design thinking process and engineering design process (Brown, 2009; Dym et al., 2005)

failures and improve their products to optimize outcomes, this stage is especially important in developing critical thinking and problem-solving skills and unique solutions (Kelley, 2017).

Repetition between stages (double arrows in **Figure 1**) helps students continually reassess their approaches, consider unresolved aspects, and seek to improve them. This helps them develop stronger critical thinking skills. Iteration in problem-solving occurs mainly in the following stages:

Empathize and problem definition stage: In fact, after gathering information and understanding the problem, students may return to this stage multiple times if they realize that the initial data is not deep enough or not accurate enough. Returning to the empathize stage helps them refine and clarify important elements to define the problem more accurately. In STEM education, this repetition is important because students must continue to dig deeper into the elements of science and engineering to ensure that they understand the basics of the problems they are solving (Pusca & Northwood, 2018).

Definition and ideation stage: After students have defined the problem and begin to develop ideas, they may realize that their initial definition of the problem is not completely accurate or complete. Therefore, they must return to the problem-definition stage to adjust and then continue to generate new or different ideas. The iteration between these two stages allows students to continually refine their approach, ensuring that their ideas are consistent with the latest information and data (Brown, 2009).

Prototyping and testing phase: This is one of the most iterative pairs of phases in the design thinking process. After students create and test a prototype, they often find flaws or shortcomings in their design. This iterative process helps students learn from their failures and continually improve their solutions until they achieve the best possible outcome. This promotes critical thinking and continuous problem-solving, increasing creativity and the ability to find optimal solutions (Kelley, 2017).

Sub-figure a and sub-figure b in **Figure 1** illustrate the similarities between the design-thinking stages and

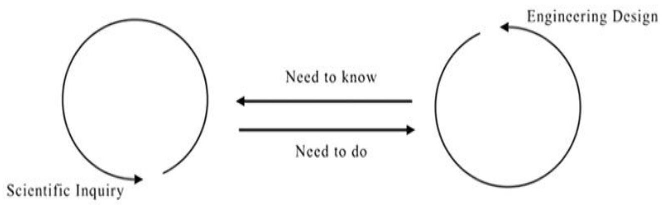


Figure 2. The learning model by design was simplified by Yata et al. (2022) by referring to Kolodner (2002)

STEM learning model. Sub-figure b in **Figure 1** was converted by the author from the IDOE model, called the design thinking learning model in STEM education. The two-way arrows in **Figure 1** represent the iteration process.

In science education, design learning environments have been studied to promote deep learning of scientific content and practices. Kolodner (2002) presented design learning as a project-based inquiry approach to learning scientific content and skills through hands-on experiences, by undertaking design challenges. The design-learning cycle consists of two processes presented in parallel: one is the "design/redesign" process and the other is the "investigate and discover" process. These two cycles are interconnected, allowing students to refine their designs step by step based on the insights gained from their investigations (**Figure 2**).

Recent STEM learning model studies have attempted to build a science teaching model that combines STEM learning. The 5E model of the research group, called BSCS (Bybee et al., 2006), is applied in STEM education and science teaching at the elementary level. STEM lessons are designed in five stages: engage, explore, explain, elaborate, and evaluate, and there is no iterative process. The 5E model is problematic because it does not fully represent the design process (Yata et al., 2020). Therefore, this model has been studied and improved in the 6E model, but the 6E model does not focus on the problem-solving process. According to the 6E model, students are free to create simple prototypes, with the main purpose of creating interest in scientific exploration.

Design Thinking–A Problem-Solving Tool in STEM Education

The term design thinking is often used as a unique approach to solving problems in creative ways. Design thinking, based on the same principles that designers use to create innovative solutions to engineering problems, is considered by Brown (2009) as a model for solving complex problems in any field of activity. According to Brown (2009):

> Design thinking originates from the professional training and practice of designers; however, these are principles that anyone can practice and extend to any field of activity.

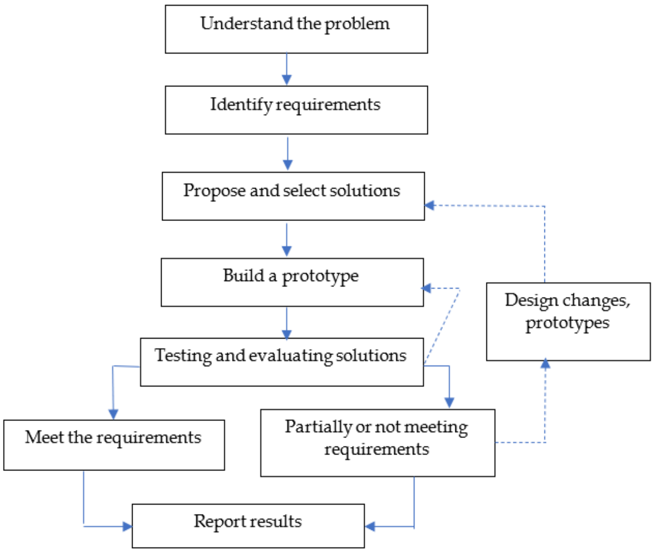


Figure 3. Design process in STEM education (Adapted from Brown, 2009; Dym et al., 2005; Kolodner, 2002)

In his study of design thinking, Pusca and Northwood (2018) pointed out that its proponents consider it particularly suitable for solving difficult problems. The suitability of the design thinking model as an adaptive use of engineering design methods and tools to solve complex problems has been demonstrated by the authors through empirical research conducted in the context of curriculum development. Douglas et al. (2010) also discuss the problem-solving strategies or inquiry methods used by engineers and advocate an empirical research strategy. Woods (2000) calls for a fundamental strategy for solving complex problems, typically beginning with a problem identification phase, followed by a definition phase, and ending with an evaluation or verification phase.

This strategy consists of six steps and can be used in an iterative manner, similar to the design thinking model proposed in **Figure 1**. In this study, the authors propose a problem-solving process in STEM education, as shown in **Figure 3**. The STEM lesson progresses according to the process (**Figure 3**), but the steps in the process may not need to be performed sequentially but in parallel or iteratively. Lesson-related knowledge research activities can be organized and performed concurrently with solution proposals, whereas prototyping activities can be performed concurrently with testing and evaluation. One step is both the goal and the condition for performing the other. The iterative process helps students understand that failure is not a negative thing but an opportunity to learn and improve.

Each failure in testing the prototype is a step towards identifying a more accurate solution (Kolodner et al., 2003).

RESEARCH DESIGN AND METHODS

Background

In this study, we use mixed methods, including theoretical and empirical research.

Regarding theoretical research (**RQ1**), the goal was to build a STEM teaching process that was suitable for research purposes (**Figure 3**). Then, consider the relationship between design-thinking skills: empathy, identifying user needs (problems), idea generation, prototyping, and testing in the context of STEM education (**RQ2**)?

The purpose of this empirical research was to test and evaluate the suitability of theoretical research results for research purposes and teaching practices in secondary schools (**RQ3**). The experimental design was randomly selected from 12 teachers and 334, 11th grade students from three high schools. Prior to conducting experimental teaching, STEM teachers were trained and commented on the STEM education lesson plans that we designed (see **Appendix A**).

Building Criteria-Based Measurement Tools

We began by reviewing the PISA frameworks on the constructs of students' problem-solving competencies and studying the requirements of high school students in STEM learning by the Vietnamese Ministry of Education and Training. These two documents were used as a theoretical basis for developing a criterion-based measurement tool. We developed a questionnaire to collect expert opinions using a face-to-face questionnaire combined with online feedback via Google Forms (the Delphi method), consisting of five questions. Each question was divided into two parts (i.e., two assessment criteria for each component). Responses were rated on a 5-point Likert scale ranging from "strongly agree" to "strongly disagree" to collect expert opinions. We then used the SPSS software to analyze the reliability of Cronbach's alpha (**Table 1**) and standardized the criteria used to assess students' competencies in teaching experiments.

The results of Cronbach's alpha analysis show that all scales have high reliability, with Cronbach's alpha coefficients of the factors exceeding the threshold of 0.9. This proves that the scales have good internal consistency and ensure high reliability for the factors of empathy, definition, ideation, prototype, and verification. In addition, the total item correlation coefficients of the indicators in each factor have high values, showing that these indicators have a close relationship with the overall factor and contribute significantly to the structure of each scale.

Table 1. Cronbach's alpha reliability

Skills	Criterion	Index	I-TCC	CAC
Empathy	Understanding the problem from the user's perspective	Emp_1.1, Emp_1.2, & Emp_1.3	0.611-0.995	0.963
	Analyze the context to understand the problem	Emp_2.1, Emp_2.2, & Emp_2.3		
Definition	Define the problem to be solved	Def 1.1, Def _1.2, & Def _1.3	0.837-0.988	0.975
	Analyze the causes and factors that influence the problem	Def _2.1, Def _2.2, & Def 2.3		
Idea	Develop creative, feasible solutions	Id_1.1, Id_1.2, & Id_1.3	0.644-0.973	0.899
	Link ideas to STEM knowledge	Id_2.1, Id_2.2, & Id_2.3		
Prototype	Design and build prototypes	Pro_1.1, Pro_1.2, & Pro_1.3	0.754-0.972	0.959
	Test and refine prototypes	Pro_2.1, Pro_2.2, & Pro_2.3		
Test/ evaluate	Self-evaluate prototype effectiveness based on clear criteria	Tes_1.1, Tes _1.2, & Tes 1.3	0.603-0.795	0.890
	Improve solutions based on testing results and feedback	Tes _2.1, Tes _2.2, & Tes_2.3		

Note. I-TCC: Item-total correlation coefficient & CAC: Cronbach's alpha coefficient

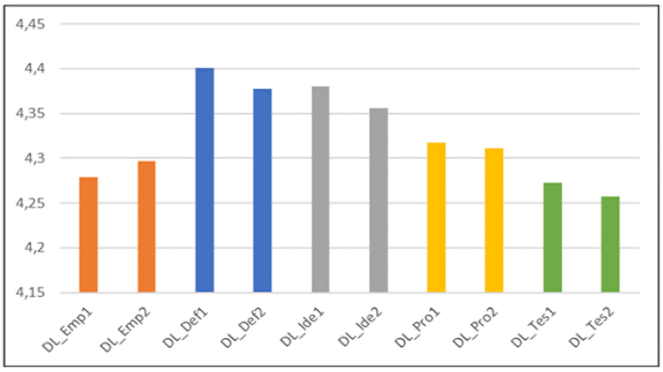


Figure 4. Results of assessing students' problem-solving skills (Source: Authors' own elaboration)

RESULTS AND DISCUSSION

During the experimental teaching, the teachers used the criteria (see **Appendix A**) to evaluate students' problem-solving skills and collected evaluation data in the form of scores. We used a 5-point Likert scale to analyze the evaluation results and draw a graph (see **Figure 4**). The analysis of the evaluation results showed the following.

RQ2. In the empathize phase, students were assessed for their ability to understand and analyze the problem from the user's perspective. The criterion "understand the problem from the user's perspective" had an average score of 4.24, indicating that students were able to identify the needs or problems relatively clearly from the user's perspective. The average score for the criterion "analyze the context to understand the problem" was 4.25, slightly higher, reflecting the students' ability to analyze the context to understand the problem more deeply. This score indicates that the students have a fairly good foundation for identification and analysis in the initial phase, although there is still room for further improvement. In the definition phase, the criterion "identify the problem to be solved" had the highest average score of 4.35. This result indicates that students did a very good job in defining the problem clearly and specifically based on the information collected in the empathisation phase. This is an important strength, because correctly defining the problem is a prerequisite for developing solutions. The criterion "analyzing the causes and factors affecting the problem" scored 4.33 points, reflecting that students analyzed the influencing factors in depth, helping them understand the root cause of the problem. High scores in the definition stage indicate that students have good skills in identifying and analyzing problems.

In the ideate stage, the criteria "developing creative and feasible solutions" and "linking ideas with STEM knowledge" both achieved an average score of 4.32, showing that students are not only creative in finding solutions but also know how to apply scientific and technical knowledge in the process of developing ideas. Achieving high and even high scores between these two criteria will create a good foundation for later learning stages.

In the prototyping stage, the criterion "design and build prototypes" achieved an average score of 4.28, indicating that students were able to design and create feasible prototypes based on the developed ideas. However, the criterion "testing and calibrating prototypes" only achieved 4.26, which is slightly lower, reflecting that testing and calibrating prototypes based on students' actual feedback still needs improvement. The final stage, testing, had the lowest average score for all stages. The criterion "self-assessment of prototype effectiveness based on clear criteria" was 4.22, reflecting that students were able to self-assess prototype effectiveness based on specific criteria; however, this skill still needed further improvement to ensure optimal solution effectiveness. In particular, the criterion "improving solutions based on test results and feedback" achieved the lowest score of 4.19, showing that students had difficulty adjusting and perfecting solutions based on test results and feedback.

Results of the Experimental Group of Students

According to Cleveland and McGill (1985), radar charts are an effective data visualization method when users need to evaluate the overall comparison rather than focusing on individual criteria. This is suitable for STEM education studies, where students' abilities must be compared in many aspects such as problem-solving skills, design, empathy, and STEM lesson products. Radar charts provide a visual view of the data, helping analysts easily identify trends and anomalies (Porter & Niksiar, 2018). Radar charts display multiple criteria simultaneously so that viewers can visually compare and analyze them (Friendly, 2008). The criteria are arranged in a concentric axis form, allowing for a correlation assessment between them and identifying the strengths and weaknesses in each subject (Nagy & Bokor, 2007). Clearly identify the criteria for improvement, helping optimize teaching and learning methods (Jüttler et al., 2019). The radar chart is suitable for assessing the improvement of students' skills experimental group (e-group) and control group (C-group) participating in the experimental model of integrating design thinking into STEM education (Enqvist et al., 2005). We randomly selected a group of 4 students in the experimental sample to examine how the model of integrating design thinking into STEM education affects the problem-solving skills of high school students (see chart **Figure 5**).

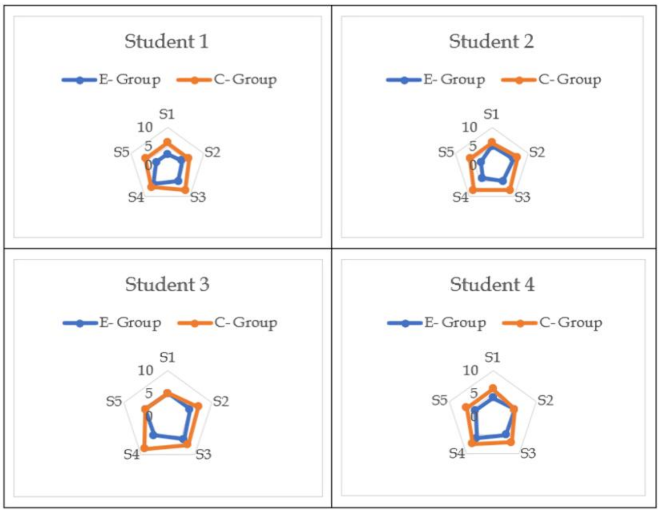


Figure 5. Graph showing students' skills (E-group and C-group) (Source: Authors' own elaboration)

RQ1 and **RQ2.** **Figure 5** shows that, in terms of area, group E area: 49.93 (relative units). Group C area: 23.78 (relative units). Area difference: 26.15 (relative units). Thus, the E-group demonstrated a much larger radar chart area, reflecting a higher skill proficiency across all dimensions. This indicates that the STEM approach, which integrates design thinking, effectively enhances students' abilities in a comprehensive and balanced manner. In terms of specific skills, S1 (understanding the problem), E-group showed a deep grasp of context and the ability to clearly define the problem, with higher scores reflecting engagement in empathy-building activities. Group C had limited development in this skill, possibly due to the less effective traditional teaching method, S2 (analyze and connect knowledge): E-group excelled in synthesizing interdisciplinary STEM knowledge as a result of interactive tasks, reflected in the curriculum. C-group struggled to link theoretical concepts to practical applications. S3 (suggest solutions), E-group proactively proposed innovative and feasible solutions, leveraging the creative thinking stimulated during the ideation phase. Group C demonstrated limited creativity and problem-solving abilities owing to a lack of experiential learning opportunities. S4 (implement and evaluate solutions), E-group effectively built prototypes, iterative designs, and refined solutions based on testing, demonstrating critical thinking and resilience. The C-group struggled with iterative processes and was unable to critically evaluate or optimize their designs.

To examine the relationship between design thinking stages and factors influencing students' problem-solving skills, we used IBM SPSS software to analyze Pearson correlations (see **Table 2**).

Table 2. Results of Pearson correlation analysis

		PT course	Empathy	Definition	Idea	Prototype	Test
PT course	Pearson correlation	1	.434**	.429**	.458**	.445**	.537**
	Significance (2-tailed)		.000	.000	.000	.000	.000
	N	334	334	334	334	334	334
Empathy	Pearson correlation	.445**	-.049	.037	.009	1	.039
	Significance (2-tailed)	.000	.372	.503	.869		.479
	N	334	334	334	334	334	334
Definition	Pearson correlation	.429**	-.034	1	-.041	.037	.076
	Significance (2-tailed)	.000	.542		.450	.503	.165
	N	334	334	334	334	334	334
Idea	Pearson correlation	.458**	.109*	-.041	1	.009	.030
	Significance (2-tailed)	.000	.047	.450		.869	.583
	N	334	334	334	334	334	334
Prototype	Pearson correlation	.434**	1	-.034	.109*	-.049	-.006
	Significance (2-tailed)	.000		.542	.047	.372	.914
	N	334	334	334	334	334	334
Test	Pearson correlation	.537**	-.006	.076	.030	.039	1
	Significance (2-tailed)	.000	.914	.165	.583	.479	
	N	334	334	334	334	334	334

Table 3. CFA results

Factor	Estimate (load factor)	Suitable model						CR	AVE	MSV	Square root of AVE
		CMIN/df	GFI	CFI	TLI	RMSEA	PCĐÓNG				
DL_Emp	0.881-0.890	1.133	0.922	0.994	0.994	0.020	1.000	0.956	0.785	0.006	0.886
DL_ Def	0.846-0.899							0.951	0.765	0.006	0.875
Id DL	0.853-0.901							0.947	0.750	0.014	0.866
DL_ Pro	0.823-0.901							0.947	0.748	0.002	0.865
DL_Tes	0.821-0.888							0.944	0.739	0.014	0.859

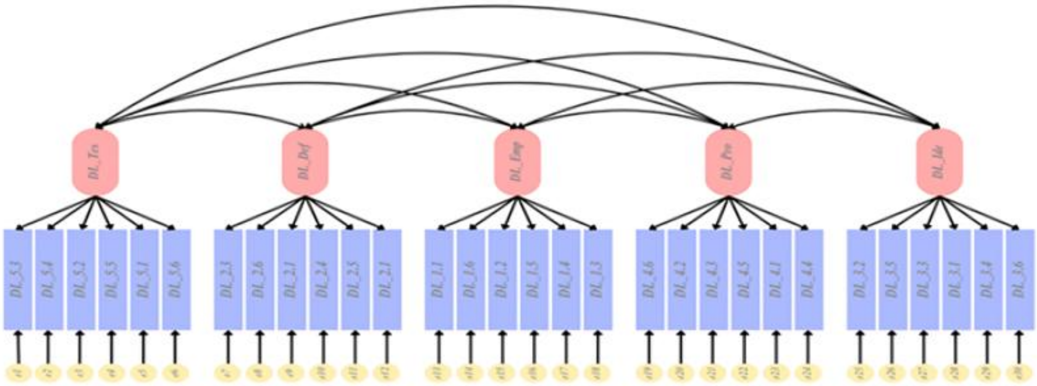


Figure 6. Schematic diagram of CFA (Source: Authors' own elaboration)

RQ2. The results of **Table 2** show the main correlation between skills in the design thinking stages: The empathize-define skill has r = 0.652, p < 0.001, which shows that understanding the problem from the user's perspective (problem) helps students define the problem more clearly. This proves that a solid foundation in empathize is necessary for success in define. This stage emphasizes the importance of helping students learn to observe and analyze from the user's perspective before defining the problem. The define-ideate skill pair had r = 0.731, p < 0.001. This means that when a problem is accurately defined, students are able to develop more creative solutions. This strong relationship shows that define acts as a guide for the ideas proposed in the ideate. In the define stage, teachers need to invest time to thoroughly support students to ensure that ideas are properly oriented. The ideate-prototype skill pair has r = 0.688, p < 0.001, showing that feasible and creative ideas from the ideate stage create a solid foundation for designing and building prototypes in prototype. At this stage, teachers need to encourage students not only to come up with many ideas but also to evaluate the feasibility of those ideas to transform them into real products. The prototype-test skill has r = 0.709 and p < 0.001, indicating that the prototype stage directly affects the effectiveness of the test. A well-designed prototype will help the testing process to proceed smoothly and achieve more accurate results. At this stage, teachers should focus on supporting students in the prototyping stage, ensuring that technical and practical criteria are met. The empathize-test skill has r = 0.563, p < 0.001; this pair of skills has a moderate correlation, indicating that understanding the problem from the empathize stage plays an important role in evaluating the effectiveness of the solution in the test stage, but this relationship is not strong enough. Teachers should strengthen the connection between empathy and testing by helping students reflect on real-world needs when evaluating solutions. High correlations (r > 0.7) between close stages, such as the define-ideate and prototype-test, indicate that the loop between these stages is a key factor in improving learning effectiveness. Lower correlations between more distant stages (e.g., empathize test) indicate the potential for improving the connection of feedback throughout the process.

RQ3. To evaluate whether the design thinking integration model is suitable in the context of STEM education in secondary schools? We used a confirmatory factor analysis (CFA) to test the model's suitability (see **Table 3**) and a description of the CFA (**Figure 5**).

From the CFA analysis results (**Figure 6**), it can be seen that The empathize stage has a standardized loading factor of 0.881-0.890. composite reliability (CR) = 0.956; AVE = 0.785, which shows that the empathize stage was accurately measured, and factors such as "understanding the problem from the user's perspective" and "analyzing the context" were clearly reflected. This confirms that the ability to observe and empathize is the foundation for the next stages of design thinking. The define stage has a standardized loading factor of 0.846-0.899. CR: 0.951.AVE: 0.765. This was one of the strongest stages in the model. Students define the problem clearly and accurately based on contextual analysis. This stage played an important role in orienting and reducing the risk of bias in subsequent steps. The ideal stage, with standardized loadings of 0.853-0.901, CR of 0.947, and AVE of 0.750. This stage measured students' ability to generate creative solutions based on a defined problem. Good convergence indicates the ability to connect ideas with STEM knowledge, confirming that this is the core creative skill of the model. (prototype), with standardized loadings of 0.823-0.901; CR: 0.947; AVE: 0.748. The prototype stage measured the ability to convert ideas into real products. High AVE values confirm that factors such as " building a model" and " testing the prototype" are reflected well. Standardized loadings: 0.821-0.888. CR: 0.944. AVE: 0.739. This is a highly complex stage that requires students to evaluate solutions based on real-world testing. Despite its high relevance, this stage often faces difficulties in students' self-evaluation and solution optimization.

The GFI = 0.922 and AGFI = 0.908 indices both exceeded the threshold of 0.9, indicating a good fit between the theoretical model and actual data, similar to the requirement of Schumacker and Lomax (2010). RMSEA = 0.020 and PClose = 1.000 did not show a significant deviation in the model, achieving a good fit, according to the criteria of Hu and Bentler (1999). Regarding the CR, the average CR reached 0.949, far exceeding the acceptance threshold of Nunnally and Bernstein (1994) of 0.7, demonstrating a high level of reliability of the scales. In addition, the AVE from 0.739 to 0.785 indicated that the scales had good convergent properties, according to the criteria of Fornell and Larcker (1981), confirming that the indicators in each scale measured the same concept.

CONCLUSION

Analysis of the research results shows that high correlations between define-ideate (r = 0.731) and prototype-test (r = 0.709) reflect the continuity and mutual support of the stages. The moderate relationship between empathize and test (r = 0.563) indicates that the feedback and iteration processes must be improved throughout the model to ensure consistency. Teachers need to design activities for students to regularly reflect from the test stage on previous steps, such as empathizing or defining. Encourage students to develop observation and critical thinking skills in empathize and define to build a solid foundation for later stages. The connection between the early (empathize) and late (test) stages should be strengthened by emphasizing the importance of evaluating solutions based on the real-world needs identified initially. This idea requires students to link concepts from STEM subjects to solution ideas.

The CFI = 0.994 and TLI = 0.994 indices in the RFA analysis were both above 0.9, indicating that the model of integrating design thinking into STEM teaching in high schools has high reliability. The average CR is 0.949, demonstrating that the stages in the process have high stability and repeated linkages that contribute to strengthening students' learning outcomes.

Design thinking offers a transformative approach to STEM education that emphasizes innovation, creativity, and problem-solving. When implemented effectively, it serves as a powerful tool for fostering critical thinking and collaboration among students, equipping them with the skills necessary to address complex real-world challenges. This study highlights the potential of design thinking to enhance student engagement, deepen their understanding of STEM concepts, and improve their ability to apply theoretical knowledge to practical situations.

This study has some limitations. The first limitation is the sample size of the study participants. A larger sample size and wider range of tests would increase the efficiency and reliability of the results. Second, we decided to test people with less experience in teaching and learning, which may affect the results. To ensure high reliability in CFA, a test with a large number of participants is required.

Author contributions: **LCN:** conceptualization, methodology, formal analysis, writing - original draft; **HQH:** writing - review and editing; **LHPH:** investigation and experimental teaching organization. All authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that the study did not use human or animal subjects; therefore, it did not require approval from the ethics committee. The authors further stated that the study was conducted in strict compliance with the ethical principles of scientific research. Written informed consents were obtained from the participants. All the data and information collected were honest, transparent, and did not violate the privacy of any individual or organization.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues, 8*(2), 5-21. https://doi.org/10.2307/1511637

Brown, T. (2009). *Change by design: How design thinking creates new alternatives for business and society*. Harper Business.

Bybee, R. W. (2010). What is STEM education? *Science, 329*(5995), 996-997. https://doi.org/10.1126/science.1194998

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness*. BSCS.

Cleveland, W. S., & McGill, R. (1985). Graphical perception and graphical methods for analyzing scientific data. *Science, 229*(4716), Article 828833. https://doi.org/10.1126/science.229.4716.828

Douglas, E. P., Koro-Ljungberg, M., & Borrego, M. (2010). Challenges and opportunities in engineering education: A qualitative analysis of the perspectives of women engineering faculty. *Journal of Engineering Education, 99*(3), Article 281294. https://doi.org/10.1002/j.2168-9830.2010.tb01063.x

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

Enqvist, K., Jokinen, A., Mazumdar, A., Multamäki, T., & Vaihkonen, A. (2005). Cosmological constraints on string scale and coupling arising from tachyonic instability. *Journal of High Energy Physics, 2005*(08), 084. https://doi.org/10.1088/1126-6708/2005/08/084

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research, 18*(1), 39-50. https://doi.org/10.1177/002224378101800104

Friendly, M. (2008). A brief history of data visualization. In *Handbook of data visualization* (pp. 15-56). Springer. https://doi.org/10.1007/978-3-540-33037-0_2

Harlen, W. (2015). *Teaching science for understanding in elementary and middle schools*. Heinemann.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM Integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press. https://doi.org/10.17226/18612

Hu, L. T., & Bentler, P. M. (1999) Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55. https://doi.org/10.1080/10705519909540118

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments*. Routledge.

Jüttler, M., Schumann, S., & Eberle, F. (2019). General or vocational education: The role of vocational interest in educational decisions at the end of compulsory schooling in Switzerland. *International Journal for Research in Vocational Education and Training, 6*(2), Article 130149. https://doi.org/10.1007/s12186-020-09256-y

Kelley, T. R. (2017). Design sketching: A lost skill. *Technology and Engineering Teacher, 76*(8), Article 812. https://eric.ed.gov/?id=EJ1141555

Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H.-Y. (2015). *Design thinking for education: Conceptions and applications in teaching and learning*. Springer. https://doi.org/10.1007/978-981-287-444-3

Kolodner, J. L. (2002). Learning by design: Theory and applications. *Instructional Science, 31*(1), 1-44.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B. B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design™ into practice. Journal of the Learning Sciences, *12*(4), Article 495547. https://doi.org/10.1207/S15327809JLS1204_2

Nagy, H., & Bokor, M. (2007). Cognitive sequence learning in Parkinson's disease and amnestic mild cognitive impairment: Dissociation between sequential and non-sequential learning of associations. *Neuropsychologia, 45*(7), Article 13861392. https://doi.org/10.1016/j.neuropsychologia.2006.10.017

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory* (3rd ed.). McGraw-Hill.

Porter, M. M., & Niksiar, P. (2018). Multidimensional mechanics: Performance mapping of natural biological systems using permutated radar charts. *PLOS ONE, 13*(9), Article e0204309. https://doi.org/10.1371/journal.pone.0204309

Pusca, D., & Northwood, D. O. (2018). Design thinking and its application to problem solving. *Global Journal of Engineering Education, 20*(1), 48-53. https://www.researchgate.net/publication/323277797_Design_thinking_and_its_application_to_problem_solving

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, 68(4), Article 2026.

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign*, *4*(1), 5-18. https://doi.org/10.1080/15710880701875068

Schumacker, R. E., & Lomax, R. G. (2010). *A beginner's guide to structural equation modeling* (3rd ed.). Routledge.

Woods, D. R. (2000). *Problem-based learning: How to gain the most from PBL*. Waterdown, Ontario: Donald R. Woods.

Yata, C., Ohtani, T., & Isobe, M. (2020). A STEM education framework based on traditional Japanese educational systems. *International Journal of STEM Education*, 7, Article 12. https://doi.org/10.1186/s40594-020-00205-8

APPENDIX A: STEM TOPIC–DESIGN OF HYDRAULIC ROBOT ARM

Time

3 periods in class + 2 weeks at home

Introduction to the Topic

Robots are being applied in all areas of life and society, bringing many strong changes to the economy. Robot technology is one of the 4 key areas of the 4.0 industrial revolution. One of the most popular and important applications is the robot arm.

Objectives

1. Present the basic content of some mechanical processing methods.
2. Establish the technological process of mechanical product processing and manufacturing.
3. Build a hydraulic robot arm design according to requirements.
4. Select and use mechanical materials and mechanical processing tools in the process of designing and manufacturing products safely and effectively.
5. Contribute to the formation and development of communication and cooperation skills; technology design skills; use of technology; technology assessment.

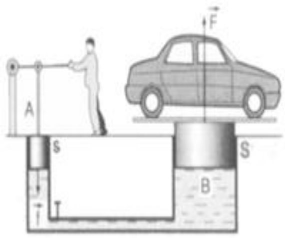
Student Guide

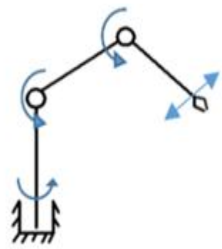
Activity 1. Understand the problem and identity requirements purpose

Purpose

1. Identify the purpose, design tasks and technical requirements for the design product.
2. Form ideas for designing a robotic arm.

Students' learning products



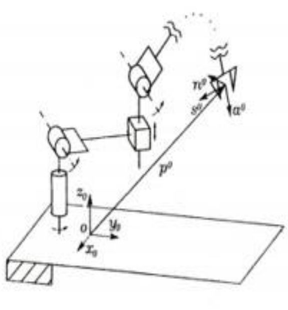


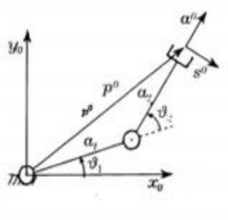
Activity 2. Proposed solutions

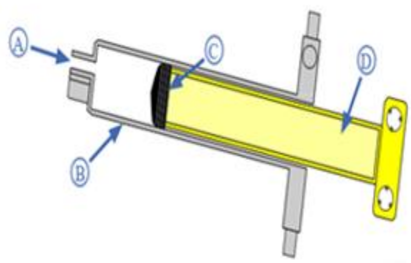
Purpose

1. State the basic concepts of some mechanical processing methods, mechanical product manufacturing processes.
2. Develop a technological process for manufacturing mechanical products.
3. Propose options for designing and manufacturing robotic arms.
4. Establish a technological process for manufacturing robotic arms according to the selected options.

Students' learning products





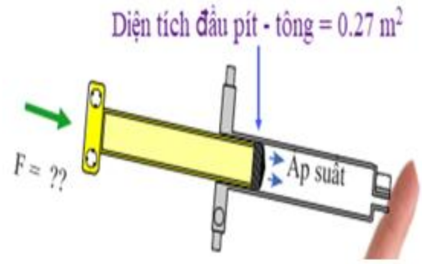


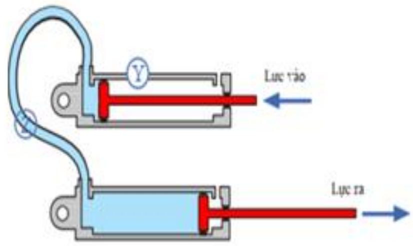
Activity 3. Choose a solution

Purpose

1. Report and defend the choice of design and manufacturing options for the robotic arm.
2. Adjust the design and technological process of manufacturing the product.

Students' learning products



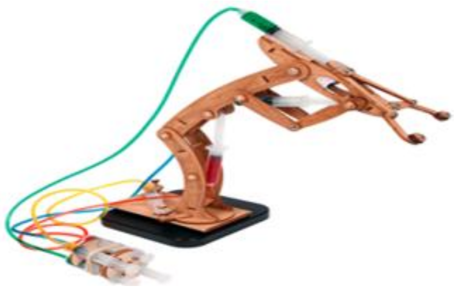


Activities 4 & 5. Build a prototype, testing, evaluation and adjustment

Purpose

1. Select and use the tools and materials needed to manufacture a robotic arm.
2. Implement the approved technological process and manufacture the product.

Students' learning products



https://www.ejmste.com