Applying the engineering design process to teach the physics course for engineering students using the flipped classroom combined with an instructional design model

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Abstract

Purpose – This study aims to examine the perceptions of students about learning science and physics using the engineering design process (EDP).

Design/methodology/approach – The study employed a mixed-methods research design: The quantitative session features a pre–post-test control group study. In the qualitative aspect, the study conducted semistructured interviews for data collection. In the experimental group, the flipped classroom (FC) model and an instructional design are combined to design, develop and implement a physics course using the steps of the EDP, while the conventional method was applied to the control group. The respondents are students of the Department of Mechanical Engineering at Cao Thang Technical College in Vietnam for the academic year 2022–2023. The control and experimental groups are composed of 80 students each. An independent sample Mann–Whitney *U* test is applied to the quantitative data, while thematic analysis is employed for the qualitative data.

Findings – The results demonstrate a statistically significant difference between the experimental and control groups in terms of perceptions about learning science and physics using the EDP, which, when combined with a FC, enhances physics learning for engineering students.

Research limitations/implications – This study implemented the EDP in teaching physics to first-year engineering students in the Department of Mechanical Engineering using the combined FC and instructional design models. The results revealed that a difference exists in the perception of the students in terms of integrating the EDP into learning physics between the experimental and control groups. The experimental group, which underwent the EDP, obtained better results than did the control group, which used the conventional method. The results demonstrated that the EDP encouraged the students to explore and learn new content knowledge by selecting the appropriate solution to the problem. The EDP also helped them integrate new knowledge and engineering skills into mechanical engineering. This research also introduced a new perspective on physics teaching and learning using the EDP for engineering college students.

Practical implications – The research findings are important for teaching and learning physics using EDP in the context of engineering education. Thus, educators can integrate the teaching and learning of physics into the EDP to motivate and engage student learning.

Originality/value – Using the EDP combined with a FC designed under stages of the analyze, design, develop, implement and evaluate (ADDIE) model has enhanced the learning of physics for engineering college students.

Keywords Engineering design process, Instructional design, Flipped classroom, Problem solving, Physics course

Paper type Research paper

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Introduction

In any engineering course, engineering sciences are based on mathematics and basic sciences. In general, engineering courses require physics knowledge as the basis of science. The majority of engineering courses begin with a foundation unit in physics. In these courses, students learn the fundamental science that forms the foundations of specific engineering disciplines and the application of the acquired skills and physics knowledge to real-world technical problems. However, many students claim that physical laws are less related to their actual experiences in the world of engineering. As a result, they become disengaged from the learning process. Thus, achieving the intended learning objectives becomes difficult in terms of motivation and academic achievement due to the lack of interest in physics courses among students. Therefore, facilitating engineering students in finding meaningful learning activities in physics courses is crucial. To enhance their physics learning activities, the study proposes the use of the engineering design process (EDP) (National Research Council [NRC], 2012). The EDP is a series of steps that engineering students can follow, from defining a problem to testing and validating a proposed solution. Out of these steps, one helps students identify potential solutions on the basis of physical laws, concepts and principles. Thus, using the EDP to teach physics lessons to engineering students is possible. Numerous studies are being conducted on the methods for applying the EDP in developing their competencies using problem-based learning or project methods in the K–12 curriculum. However, less research is conducted on using the EDP to teach science physics to first-year engineering students in college. Hence, finding teaching and learning approaches for engineering students to render physics content relevant and useful to them is the major concern of this study.

The EDP requires students to learn by action, and they should adopt deep learning models such as scientific inquiry and engineering design. This approach also requires students to apply basic science and mathematics to solve an engineering problem related to a real-world problem (NRC, 2012). The EDP consists of several steps; from the perspective of the study, class time is insufficient for accomplishing these steps. Thus, to implement the EDP effectively, teaching and learning approaches need to be reorganized. By conducting a literature review on science education, we find that the flipped classroom (FC) model requires students to acquire knowledge prior to class by watching instructional videos and completing learning tasks. We propose that applying the EDP using the FC model combined with instructional design to teach physics to engineering students may effectively enhance student learning in physics courses. This study aims to design, develop and implement the EDP based on the FC to teach physics courses to engineering students.

Literature review

Problem-solving is considered to be a central activity of engineering practice (McNeill *et al.*, 2016). The research on science education indicates that learning is promoted when learners are involved in solving real-world problems. Moreover, learning is activated when learners independently construct new knowledge based on prior knowledge and skills. Importantly, new knowledge is integrated into the learner's world (Merrill, 2002). Thus, to implement the EDP effectively, the course needs to be designed carefully.

The EDP is composed of a series of steps, including defining a problem that addresses a need, identifying criteria and constraints, constructing science principles, investigating potential solutions, designing and building a proposed solution, testing the proposed solution and collecting data and evaluating the proposed solution compared with the criteria and constraints (NRC, 2012). Thus, the goal of the EDP is to solve real-world problems with engineer-designed activities (Putra *et al.*, 2021). In addition, the EDP motivates students to apply critical thinking when designing a product (Yu *et al.*, 2020). The EDP facilitates communication and collaboration among students (Hoeg and Bencze, 2017). Using the EDP also provides students with opportunities for communicating with peers to construct a better solution based on concepts in physics (Putra *et al.*, 2021). Once students are involved in the EDP, they endeavor to exchange ideas at the stage of planning a solution, trying their design, testing and deciding on a design (Giri and Paily, 2020).

In this study, we use the analyze, design, develop, implement and evaluate (ADDIE) to approach the EDP through the FC model. The ADDIE consists of five stages, including analysis, design, development, implementation and evaluation (Branch, 2009). In the analysis stage, the teacher should analyze contextual learning, the learning needs of students, engineering problem solving, learning program, learning outcomes and course content. While analyzing learning needs, the teacher should include the profiles of students. In the design stage, the teacher clearly states the learning outcomes to students, plans assessment strategies and elaborates on learning activities. For the development stage, the teacher elaborates on the learning materials, including the learning scenario and guidelines for the cycle of the EDP. Regarding the implementation of the course, dynamic interactive learning is promoted, such as teacher–student, student–content and peer interactions. These types of interactions directly influence learner engagement and achievement. During the EDP, collaboration is key to identifying solutions to complex learning problems (Sulaeman *et al.*, 2021). Lastly, in the evaluation stage, the teacher compares between the academic achievement to the goal and learning outcome of students. At this stage, course assessment is conducted to evaluate the perception of the students of the effectiveness of the course in the learning process.

To help students analyze a problem-situation, identify and define the problem, find solutions and select and implement the best solution to the problem, students need more time to work in collaboration in the community of learning. Regarding this aspect, the FC approach can be used. The FC model is composed of three stages (Kong, 2015). The first is pre-class activities in which students are required to exert effort to study declarative knowledge by watching an instructional video and completing learning tasks on their own before coming to class. During class, the teacher reserves more time for students to practice their problem-solving skills by connecting the learned knowledge to determine a potential solution and design, build and test a product. The last stage pertains to post-class activities in which students are tasked to link the activities during class time to solve a complex problem independently. This study designs the FC model by combining the EDP (NRC, 2012) and the ADDIE model (Branch, 2009). Teaching physics using EDP is established based on NRC (2012; see Table 1).

At the analysis stage, we analyze the learning needs of the students to determine the desired learning outcomes, assessment plans and learning activities (Table 1). In relation to the design stage, assessment strategies and learning activities are planned according to the FC model. The learning material is designed for students to learn outside of class based on the oriented questions and the defined problem. For the development stage, learning materials and assessment plans are fitted together into a module of learning. Moreover, learning activities are elaborated to promote the FC format. With regard to the implementation stage, teacher–student, student–content and student–student interactions were effectuated in the steps of identifying, building and testing the proposed solution. Evaluation occurred during the three phases in class, namely, pre-, in- and post-class.

Research question

- *RQ1.* Is there a significant difference between the experimental and control groups regarding their "perception of physics learning outcomes using the EDP combined with the FC model and the stages of the ADDIE model?
- *RQ2.* How do students perceive their learning outcomes in physics using EDP?

ADDIE model	Steps in the EDP	Flipped classroom model
Analyze	Identifying a problem that addresses a need that reflects the criteria for success and constraints	Pre-class – The teacher analyzes the contextual learning, goal and learning outcomes, assessment plan, teaching and learning activities, content knowledge and learning materials to determine the problem that addresses a need that reflects the criteria and constraints
Design and develop	Constructing relevant knowledge and science principles	Pre-class – Students identify scientific principles that can be related to potential solutions – The teacher provides students with the learning situation, relevant questions and instructional videos to support them in building new knowledge based on previous knowledge and skills – The teacher provides students with multiple-choice questions to help students check for acquiring knowledge after watching the video
	Investigating potential solutions to the problem	In-class – Students brainstorm design ideas and investigate solutions to the problem based on the acquired knowledge
Implement	Designing and constructing a proposed solution	In-class – Students design the proposed solution – Students construct the proposed solution using tools and appropriate materials
	Testing the proposed solution and collecting data	In-class – Students test the proposed solution and collect data
Evaluate	Evaluating the proposed solution in terms of performance	In-class – The teacher evaluates the product using the constraints and criteria for success – Students self-assess the use of acquired knowledge to design and construct a proposed solution
	Identifying potential improvement in the design	– Students redesign the solution based on the results and observations or build and test another design Post-class – Students reinforce classroom activities in class and complete the learning task requirements for the next class session

Source(s): Author's research

Table 1.
Using EDP combined instructional design and flipped classroom models for teaching physics to engineering students

Research method

Sample

The population of this study is all first-year mechanical engineering students at Cao Thang Technical College in Ho Chi Minh, Vietnam, including five classes. Out of the five classes, two are randomly selected and randomly assigned to the treatment or control group.

Research design

The study uses a mixed-method design. First, it applied a quasi-experimental design (pre– post-test control group). Both groups are exposed to the same content except for the intervention method. In the control group, students were taught using the conventional method, while the EDP was applied to the experimental group. The independent variables were two types of instructional approaches, namely, EDP and conventional method. The dependent variable was the perception of the students of their ability to apply the learned physics knowledge to solve the engineering problem. In the experimental research design, each group received pre- and post-tests to measure the dependent variable before and after the intervention. Second, to elucidate the perception of the students about learning physics using the EDP, the study conducted a semi-interview with the experimental group, which was classified into eight subgroups. One student was randomly selected from each subgroup. The selected students are coded S1–S8.

Instrument

Based on NRC (2012), we developed a questionnaire on the perceptions of students about physics learning activities using the EDP as a tool for assessing the problem-solving steps of the respondents. Their perceptions of learning activities were measured using a five-point Likert scale ranging from 1 = Strongly disagree to 5 = Strongly agree. Table 2 presents the questionnaire elaborated under steps of the EDP.

Validity of the instrument. This study used content validity to validate the questionnaire items for the pre- and post-intervention design (Chiwaridzo *et al.*, 2017). Two physics teachers and two engineering teachers reviewed the items, which were modified according to their feedback.

Principles of design	Items	Students' perception of learning physics using the EDP
Identifying and defining the problem	IDP1	Defining engineering problems and addressing the need are meaningful
	IDP2	Engineering problem motivates students to practice science and engineering based on the criteria and constraints
	IDP3	Engineering problem facilitates the learning of physics knowledge
Building knowledge from contextual learning	BK1	Students learn new knowledge related to contextual mechanical engineering
	BK2	Students learn new knowledge for designing solutions to engineering problems
	BK3	Knowledge is built to develop and improve solutions to problems with reference to the constraints and criteria of a product
Applying physics and mechanical engineering to solve problems	AP1	Students obtain the opportunity to design a product based on physics knowledge
	AP2	Students obtain a basic science physics and engineering problem design that exists in their future career in mechanical engineering
	AP3	Students apply physics knowledge and principles of engineering to problem solving
Integrating knowledge	IK1	Knowledge is integrated into the real-life situations
	IK2	Knowledge is connected to solve the engineering problem
	IK3	Students transfer new knowledge to the world of engineering

Source(s): Author's research

Table 2. Principles of instructional design for using engineering design process to teach the physics to engineering student

Reliability of the instrument. The study used Cronbach's alpha test to determine the reliability of the instrument by conducting a pilot study on 50 first-year engineering students who were not part of the sample. After data analysis, we found that the Cronbach's alpha coefficient of the variables IDP, BK, AP and IK are 0.70, 0.72, 0.75 and 0.81, respectively. Therefore, we conclude that the instrument is suitable for the study.

Designing and developing the experimental procedure

Analyzing the context of learning. The author examined the learning outcomes, student profiles, learning need of students, contextual learning, engineering problem-solving, content knowledge and assessment strategy. The author also states a product related to the science and engineering practice (Table 3).

Designing and developing the teaching procedure. First, the instructional videos are designed, developed and elaborated according to the principle of *flipped learning*. Specifically, the learning scenario is explained in detail, including contextual and objective learning, the learning outcome and the problem that the students must solve. The diagnostic assessment is elaborated to evaluate the prior knowledge and skills of the students. Second, they are given learning tasks with the support of the basic theoretical knowledge related to engineering problem-solving. The instructional videos and learning scenarios are uploaded to a learning management system (Table 4).

Implementing the lesson plan. Students in the experimental and control groups were divided into eight subgroups composed of 10 students each. Flipped learning was used in the experimental group, while the traditional method was used in the control group. Table 5 lists the sequence of the lessons.

Data collection

Quantitative data collection. Prior to the intervention study, data were collected using the questionnaire to examine the learning activities of the students in the physics course and to identify the impact of the uses of the EDP in teaching physics to engineering students.

Qualitative data collection. As described in the Research design section, the experimental group was divided into eight subgroups and one student was randomly selected from each

Table 3. Analysis step of the EDP

Aspects of analysis	EDP steps	Contents
Teaching and learning topic		Energy topic
Level of instruction		First-year college students mechanical engineering attending a physics course
Learning needs of students		Students use the EDP to learn science physics
Engineering problem-solving	Define a problem that addresses a need	Designing a machine that lifts objects from the ground up
Learning outcomes		– Applying the law of conservation of energy – Applying the engineering problem-solving method
Content knowledge		Motion, Force, work of force, power, kinetic energy, work-energy theorem, potential energy and conservation of mechanical energy
Assessment strategy		– Diagnostic – Formative – Summative

Source(s): Author's research

Aspect of design and development	EDP steps	Contents
Designing problem-solving scenarios		Children in urban areas need an educational toolkit to discover the sciences, especially the field of engineering (e.g. a lift electric model). The participants play the role of engineering students and design an electric model of an elevator for these children
Building the criteria and constraints of the product	Determining the problem using the criteria and constraints	Designing an electric elevator that carries objects weighing 5 kg from the ground floor to a height of 1 m using wood, metal, plastic and a speed reducer motor with a dimension of 100 × 25 × 20 cm and a power supply of 12 V
Designing questions for determining solutions to the problem		Providing a set of questions for seeking solutions to the problem such as sources of information related to motion, force, work of force, power, energy and the law of conservation of energy. In addition, the teacher also presents students with the engineering problem-solving process
Designing the learning material that helps students select an appropriate solution to the problem		Designing a guideline for engineering design methodology for students to select an appropriate solution to the problem that meets the criteria and constraints
Formulating questions that help students build the protocol for the solution		Designing a guideline for students in building a protocol
Designing an assessment tool for validating the protocol		Designing an assessment tool for validating the protocol for the solution

Source(s): Author's research

Table 4. Design and development of the steps of the EDP

subgroup (S1–S8). After the intervention study, the study conducted semistructured interviews with these students to determine their perception of the uses of the EDP in learning physics using the FC model. This study employed the concept of saturation in the qualitative research to gather data from interviews according to the study objective (Saunders *et al.*, 2018).

Data processing

Quantitative data processing. Data were collected before and after the application of the EDP to teaching science physics with the combined FC and instructional design models. Data were analyzed using SPSS 22. The study used an independent sample Mann–Whitney U test for data analysis due to their non-normal distribution. To identify whether or not significant differences exist between the experimental and control groups in terms of their perception of learning science physics using the EDP, we test a null hypothesis (H0) and an alternative hypothesis (H1) as follows:

H0. No significant differences exist in the two teaching approaches between the experimental and control groups.

H1. Significant differences exist in the two teaching approaches between the experimental and control groups.

Table 5. Steps for learning in the experimental and control groups

	Conventional teaching method	Stage of learning	Flipped teaching method
Weekly schedule			
Week 1	Students read the learning material	Pre-lass	– The teacher provides students with the contextual and learning situations – Students are tasked to identify the problem-solving
	– The teacher explains the learning objective – The teacher introduces the basic theory related to motion and force	In-class	– Students clarify the problem solving through collaboration – Students are tasked to determine the criteria and constraints for the solution to the problem based on previous solutions
	Students do their homework	Post-class	– Students collect information based on the learning activities in class
Week 2	Students read the learning material	Pre-class	– Students explore physics knowledge such as work of force, power, energy, types of energy and the law of conservation of energy – Students watch instructional videos related to the engineering problem-solving method
	The teacher presents the concept of work, power	In-class	– The teacher engages students in the revision of previous knowledge by correcting errors and misconceptions and by adding new information – Students work in groups to select the appropriate solution to the problem based on the criteria and constraints
	Students do their homework	Post-class	– Students improve the selected solution
Week 3	Students read the learning material related to the application of the energy conservation law	Pre-class	– Students are asked to build a prototype
	The teacher presents the law of conservation of energy	In-class	– Students discuss and validate the prototype for the solution to the problem by planning and assigning tasks to each group member – Students test and improve the proposed solution – Students discuss and detail a list of the materials to implement the prototype for the proposed solution
	Students do their homework	Post-class	– Students buy materials to develop the product

(*continued*)

	Conventional teaching method	Stage of learning	Flipped teaching method
Week 4	Students read the learning materials	Pre-class	– Students check the materials corresponding to the prototype established
	– The teacher requires to students conduct a series of exercises related to force and motion, work of force, power and the law of conservation of energy – The teacher checks for student understanding	In-class	– Students set up materials to construct the electric elevator model – Students test the operation of the elevator compared with the criteria and constraints – Students present the product and the teacher evaluates the project
	Students perform these exercises at home	Post-class	– Students write a report about the electric elevator project

Source(s): Author's research

Table 5.

Qualitative data processing. When the researcher intends to understand the viewpoint of interviewees about new topics across a dataset, such as audio data, thematic analysis is used (Braun and Clarke, 2006). Two approaches can be used for thematic analysis, namely, inductive and deductive. This study employed the deductive approach because it aims to understand the opinions of the students based on the EDP during the learning process with some of the themes we expect to find in our collected data. Kiger and Varpio (2020) mentioned that thematic analysis is composed of six steps. First, the author transcribes audio data and immerses in them by reading and checking transcriptions several times. In step 2, the author performs a coding process using the inductive or deductive approach. The third step involves reviewing codes that are categorized into themes. In step 4, the author connects the themes to consider the coherence of these themes. In step 5, the author defines and names these themes. The final step involves writing up the final analysis and description of findings.

Results

Quantitative results session

The data collected in the pre-test were statistically analyzed. Table 6 presents the results.

The study recruited 160 students (experimental group: 80; control group: 80). To determine their perception of learning physics using EDP and to meet the assumption that both groups were equivalent, they were requested to complete the questionnaire on teaching physics using the EDP before the intervention study. Table 6 indicates that the experimental and control groups obtained mean ranks between 72.50 and 85.03 and between 68.50 and 83.93, respectively. The results indicate that the mean rank of the experimental group is

Steps of learning strategies	Items	Group	N	Mean rank	Sum of ranks	Mann–Whitney *U* test	Z	Sig. (Two-tailed)
Identifying and defining the problem	IDP1	Experimental	80	72.50	6620.00	3020.3000	−0.818	0.413
		Control	80	68.50	6260.00			
	IDP2	Experimental	80	77.08	6166.00	2926.000	−1.177	0.239
		Control	80	83.93	6714.00			
	IDP3	Experimental	80	79.63	6370.50	3130.500	−0.310	0.757
		Control	80	81.37	6509.50			
Building knowledge from contextual learning	BK1	Experimental	80	81.01	6481.00	3159.000	−0.169	0.866
		Control	80	79.99	6399.00			
	BK2	Experimental	80	82.66	6612.50	3027.500	−0.950	0.342
		Control	80	78.34	6267.50			
	BK3	Experimental	80	77.75	6220.00	2980.000	−1.308	0.191
		Control	80	83.25	6660.00			
Applying physics and mechanical engineering to problem solving	AP1	Experimental	80	81.51	6521.00	3119.000	−0.332	0.740
		Control	80	79.49	6359.00			
	AP2	Experimental	80	85.03	6802.50	2837.000	−1.371	0.170
		Control	80	75.97	6077.50			
	AP3	Experimental	80	83.26	6661.00	2979.000	−0.825	0.409
		Control	80	77.74	6219.00			
Integrating knowledge	IK1	Experimental	80	80.03	6402.00	3162.000	−0.221	0.825
		Control	80	80.98	6478.00			
	IK2	Experimental	80	78.10	6248.00	3008.000	−0.757	0.449
		Control	80	82.90	6632.00			
	IK3	Experimental	80	83.84	6707.50	2932.500	−1.171	0.242
		Control	80	77.16	6172.50			

Source(s): Author's calculations

Table 6.
Mean score of the pre-test of both groups

higher than that of the control group. However, to determine if a statistically significant difference exists between the two groups, we need to examine the statistical test. All p-values are >0.05 at the 95% confidence interval (95% CI) with Mann–Whitney U- and Z-values (Table 6); thus, H0 is supported. In other words, prior to the intervention study, the experimental and control groups displayed the same achievement level in physics.

After teaching both groups, they were asked to complete the same questionnaire again. Table 7 depicts that the experimental and control groups obtained mean ranks between 87.33 and 107.42 and between 53.58 and 73.68, respectively. In summary, the mean rank of the experimental group was higher than that of the control group.

To verify whether or not a statistically significant difference exists between the two groups, the study examines the results using the Mann–Whitney U test. Table 7 presents the test and U statistics and the p-values of 0.05. First, we find that the p-values for the identification and definition of the problem (IDP1, IDP2 and IDP3) are <0.05, which supports H1. Second, the p-values for building knowledge through contextual learning (BK1, BK2 and BK3) are <0.05, which confirms that contextual learning plays an important role in connecting physics concepts to field of engineering. Third, the p-values for applying physics and mechanical engineering to problem solving (AP1, AP2 and AP3) are <0.05, which suggests that the EDP is effective for the practice of physics and engineering. Finally, the p-values for the integration of knowledge (IK1, IK2 and IK3) are <0.05, which confirms H1 that the EDP facilitates the integration of physics concepts into real-life situations and into the field of engineering. We reject the null hypothesis and conclude that a significant difference exists between the two teaching approaches of the experimental and control

Steps of learning strategies	Items	Group	N	Mean rank	Sum of ranks	Mann–Whitney U test	Z	Sig. (Two-tailed)
Identifying and defining the problem	IDP1	Experimental	80	101.28	8102.50	1537.500	−6.371	0.000
		Control	80	59.72	4777.50			
	IDP2	Experimental	80	94.74	7579.00	2061.000	−4.539	0.000
		Control	80	66.26	5301.00			
	IDP3	Experimental	80	87.33	6986.00	2654.000	−2.406	0.016
		Control	80	73.68	5894.00			
Building knowledge from contextual learning	BK1	Experimental	80	91.00	7280.00	2360.000	−4.296	0.000
		Control	80	70.00	5600.00			
	BK2	Experimental	80	94.27	7541.50	2098.000	−4.488	0.000
		Control	80	66.73	5338.50			
	BK3	Experimental	80	97.95	7836.00	1804.000	−5.873	0.000
		Control	80	63.05	5044.00			
Applying physics and mechanical engineering to problem-solving	AP1	Experimental	80	93.68	7494.00	2146.000	−4.460	0.000
		Control	80	67.33	5386.00			
	AP2	Experimental	80	95.26	7620.50	2019.500	−4.463	0.000
		Control	80	65.74	5259.50			
	AP3	Experimental	80	92.42	7393.50	2246.500	−3.769	0.000
		Control	80	68.58	5486.50			
Integrating knowledge	IK1	Experimental	80	90.79	7263.00	2377.000	−3.208	0.001
		Control	80	70.21	5617.00			
	IK2	Experimental	80	105.71	8457.00	1183.000	−7.783	0.000
		Control	80	55.29	4423.00			
	IK3	Experimental	80	107.42	8593.50	1046.500	−8.348	0.000
		Control	80	53.58	4286.50			

Source(s): Author's calculations

Table 7. Mean score of the post-test of both groups

groups because all p-values are <0.05. In other words, the problem-solving skills of the students in the experimental group (EDP) were higher than those of the control group (conventional method). In summary, the use of EDP in science teaching and learning improved the problem-solving skills of the experimental group, especially their ability to solve physical and engineering problems in terms of the topic of energy. The discussion section elucidates the effectiveness of learning physical science using the EDP.

Qualitative results session

RQ2. What is the perception of the students about using the EDP to teach physics to engineering students?

Table 8 presents the coding of the students' opinions obtained from the interviews according to the results of thematic analysis. Data were analyzed and presented under two categories. The first was classified as the positive effects of the use of the EDP to teach physical science to engineering students and the second category contained the negative effects of EDP. The qualitative data revealed that learning physical science through the EDP exposed a few positive and negative characteristics. Regarding the contextual learning themes, six students mentioned that the engineering problem made the learning experience more relevant and meaningful and provided them with the opportunity to connect physics concepts to engineering problem-solving. They also expressed that the knowledge and skills they gained through the EDP are relevant to the intended profession. However, two students stated that they spent a lot of time discovering the problem or identifying the need for change or improvement to an existing solution. In terms of finding and selecting a technical solution, seven students who commented that learning physics concepts by formulating solutions to problems is an interesting method for learning physics; it encouraged them to motivate and engage in the learning process. Nevertheless, only one student mentioned that building new knowledge through the use of the EDP is difficult because the student was not used to learning in a manner that constructs physics concepts to solve technical problems. Moreover, five students stated that integrating physics concepts into mechanical engineering helped them recognize the significance of physical science in relation to mechanical engineering, while three students pointed out that they need more time to analyze and identify the problem to be solved.

In general, students perceived that learning physical science through the EDP is meaningful for mechanical engineering. Using the EDP to teach physical science is one of the methods for increasing intrinsic learning motivation for engineering students, which leads to academic success.

Discussion

Teaching science physics using the EDP combined with the FC model was likely to promote the effectiveness of learning in the physics course for engineering college students. The EDP is a crucial strategy for engineering students in exploring and learning new knowledge to identify solutions to engineering problems. Moreover, using the EDP to teach first-year physics also increased student motivation and engagement by integrating physics concepts into the context of engineering design. In our opinion, learning physics concepts using the EDP is an effective approach for connecting physics science to engineering. To facilitate the effectiveness of the exploration and construction of physics concepts, defining the problem and the need to create a product based on the criteria and constraints of the product are a means for instilling the desire to learn in students. Moreover, based on the acquired physics

Table 8. Results of treatment of qualitative data

Theme	Code	Number of students	Advantage of using the EDP Students 'opinions	Number of students	Disadvantage of using the EDP Students' views
Contextual learning	Engineering problem	6	Students identifying as S1, S3, S4, S6, S7 and S8 mentioned that the engineering problem could be used to enhance the learning process. They also stated that the engineering problem makes the learning experience more relevant and meaningful	2	S2 and S5 mentioned that they spend more time on studying the engineering problem
	Learning situation	8	All students mentioned that the learning situation is related to their learning need	0	
	Science and engineering practice	8	All students mentioned that problem solving motivated and engaged them in the practice of science and engineering	0	
Finding and selecting the appropriate solution	Previous knowledge	8	All students mentioned that previous knowledge helped them complete the learning tasks	0	
	New knowledge	7	S1, S3, S4, S5, S6, S7 and S8 mentioned that building knowledge by identifying solutions to the problem is an interesting way to learn physics	1	S2 mentioned that building new knowledge by finding solutions to the problem is difficult
Applying knowledge to solve the problem	Applying learned knowledge to building the prototype	8	All students mentioned that applying the learned knowledge to solve the engineering problem is essential	0	
	Explaining the operation of a machine	6	S3, S4, S5, S6, S7 and S8 mentioned that using the EDP helped them understand and explain the operation of an elevator based on the principles of physics	2	S1 and S2 stated that they could not explain the operation of the machine, because most of the time was reserved for researching information and finding solutions to the problem

(*continued*)

Table 8.

		Advantage of using the EDP		Disadvantage of using the EDP	
Theme	Code	Number of students	Students 'opinions	Number of students	Students' views
Integrating physics knowledge into mechanical engineering	Developing skills in the steps of the EDP	8	All students cited that the EDP helped them acquire their skills in engineering problem solving	0	
	Linking physics concepts to the engineering problem	5	S3, S4, S5, S6, S7 and S8 expressed that using the EDP helped them integrate physics into the engineering problem	3	S1, S2 and S8 stated that they still did not establish the relationship between the physics concepts and mechanical engineering due to the lack of time
	Orienting students into engineering careers	8	The students mentioned that using the EDP helped them acquire an in-depth insight into engineering in the future	0	

Source(s): Author's research

concepts and engineering design, students investigated and selected the best solution, improved and built the proposed solution, and tested the operation of the product on the basis of its criteria and constraints. Thus, learning the physical sciences using the EDP enhances the ability of engineering students to solve real-world problems. Furthermore, using the EDP to learn the physical sciences is useful for studying physics in the context of mechanical engineering, because it helps them integrate physics concepts into the field of engineering. In addition, the EDP requires students to become proactive in the learning process, such that they no longer need to absorb information from only the teacher. In other words, using the EDP improved the academic performance of students. Indeed, after the intervention study, the experimental group obtained better results than did the control group (Table 7).

This study elucidated the use of the EDP combined with the FC model, which was designed under the stages of the ADDIE model. Before the class, the experimental group was given contextual learning and engineering problem solving; they then identified and defined the problem that addresses the learning needs and determined the criteria as well as constraints of a successful solution. When the criteria for success and constraints are examined in advance, the practice session can be devoted to exploring and learning new knowledge to determine the potential solutions to the problem. From the perspective of the study, when teaching and learning physics in the context of the EDP, identifying and defining the problem and establishing the criteria for the technical solution or product are important aspects, such that students develop the concepts or principles of physics. These criteria help students engage in crosscutting concepts and disciplinary core ideas, as defined by the NRC (2012). During class, the teacher spends less time teaching the concepts to the students; therefore, the majority of the class time can be spent on finding solutions to the problem based on the concepts, criteria and constraints. Moreover, the prototype can be built and improved, the proposed solution can be implemented and tested and the product of the project can be communicated. In the post-class phase, the students reviewed and improved the learning task during class and prepared learning tasks for the next lesson.

Using the EDP to teach physics to engineering students is an effective strategy for motivating and inspiring students to practice science and engineering. Science teaching and learning is necessary for acquiring the fundamental skills in engineering for the future careers of students. Linking the learned knowledge using the traditional method for teaching physics courses is difficult, because scientific teaching and learning differ from contextual learning. In contrast, using the EDP to teach physics helps students use science to solve engineering problems. The finding is consistent with that of Brand (2020) who emphasized the importance of science and engineering practice. The author mentioned that using the EDP to learn science enables students to build essential skills. This teaching method provides students with an opportunity for developing an understanding of engineering as a discipline and as a potential career path. Moreover, the finding aligns with that of the NRC (2012), that is, the objective of using the EDP is to reinforce science and engineering practice. Moreover, according to the NRC, the EDP is limited to K–12; thus, the current study implemented the EDP on first-year engineering students. The study provides a significant contribution toward the improvement of the teaching of physical science to engineering students using the EDP.

The qualitative data revealed that the majority of the students stated that using the EDP encouraged them to learn physical science, but a few students met difficulties when learning physics concepts through the EDP. The students who commented on the negative aspects of EDP stated that they spent a considerable amount of time searching for information and finding solutions to the problem. Thus, they lacked sufficient time for establishing the relationship between physics concepts and mechanical engineering. To eliminate this problem, creating digital learning materials then uploading them to a learning management system is necessary to help them reduce the time spent searching for information related to solutions.

Conclusion

This study implemented the EDP in teaching physics to first-year engineering students in the Department of Mechanical Engineering using the combined FC and instructional design models. The results revealed that a difference exists in the perception of the students in terms of integrating the EDP into learning physics between the experimental and control groups. The experimental group, who underwent the EDP, obtained better results than did the control group, which used the conventional method. The results demonstrated that the EDP encouraged the students to explore and learn new content knowledge by selecting the appropriate solution to the problem. The EDP also helped them integrate new knowledge and engineering skills into mechanical engineering. This research also introduced a new perspective on physics teaching and learning using the EDP to engineering college students.

Research implication

Teaching science physics using the EDP to engineering college students exerted a positive effect on the engineering problem-solving skills of the students. This teaching and learning strategy improved academic performance and helped them connect physics concepts to engineering. The findings are important for physics teaching and learning using the EDP in the context of engineering education. Thus, educators can integrate physics teaching and learning into the EDP to motivate and engage students in learning. However, the study was limited to a single product on the topic of energy. Therefore, future studies could use more learning products and examine the application of the results across topics. Second, assessment strategies, tools and technical assessments of the EDP need to be implemented. Finally, this study is limited by its sample size, such that the findings can be considered generalizable only if the results are obtained from a larger sample size.

References

Branch, R.M. (2009), *Instructional Design: the ADDIE Approach*, Springer Business Media, New York.

Brand, B.R. (2020), “Integrating science and engineering practices: outcomes from a collaborative professional development”, *International Journal of STEM Education*, Vol. 7 No. 1, pp. 1-13, doi: 10.1186/s40594-020-00210-x.

Braun, V. and Clarke, V. (2006), “Using thematic analysis in psychology”, *Qualitative Research in Psychology*, Vol. 3 No. 2, pp. 77-101, doi: 10.1191/1478088706qp063oa.

Chiwaridzo, M., Chikasha, T.N., Naidoo, N., Dambi, J.M., Tadyanemhandu, C., Munambah, N. and Chizanga, P.T. (2017), “Content validity and test-retest reliability of a low back pain questionnaire in Zimbabwean adolescents”, *Archives of Physiotherapy*, Vol. 7 No. 1, p. 3, doi: 10.1186/s40945-017-0031-y.

Giri, V. and Paily, M.U. (2020), “Effect of scientific argumentation on the development of critical thinking”, *Science and Education*, Vol. 29 No. 3, pp. 673-690, doi: 10.1007/s11191-020-00120-y.

Hoeg, D.G. and Bencze, J.L. (2017), “Values underpinning STEM education in the USA: an analysis of the next generation science standards”, *Science Education*, Vol. 101 No. 2, pp. 278-301, doi: 10.1002/sce.21260.

Kiger, M.E. and Varpio, L. (2020), “Thematic analysis of qualitative data: AMEE Guide No. 131: AMEE Guide No. 131”, *Medical Teacher*, Vol. 42 No. 8, pp. 846-854, doi: 10.1080/0142159x.2020.1755030.

Kong, S.C. (2015), “An experience of a three-year study on the development of critical thinking skills in flipped secondary classrooms with pedagogical and technological support”, *Computers and Education*, Vol. 89, pp. 16-31, doi: 10.1016/j.compedu.2015.08.017.

McNeill, N.J., Douglas, E.P., Koro-Ljungberg, M., Therriault, D.J. and Krause, I. (2016), "Undergraduate students' beliefs about engineering problem solving", *Journal of Engineering Education*, Vol. 105 No. 4, pp. 560-584, doi: 10.1002/jee.20150.

Merrill, M.D. (2002), "First principles of instruction", *Educational Technology Research and Development*, Vol. 50 No. 3, pp. 43-59, doi: 10.1007/bf02505024.

National Research Council (2012), *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, The National Academies Press, Washington, DC.

Putra, P.D.A., Sulaeman, N.F. and Wahyuni, S. (2021), "Exploring students' critical thinking skills using the engineering design process in a physics classroom", *The Asia-Pacific Education Researcher*, pp. 1-9.

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H. and Jinks, C. (2018), "Saturation in qualitative research: exploring its conceptualization and operationalization", *Quality and Quantity*, Vol. 52 No. 4, pp. 1893-1907, doi: 10.1007/s11135-017-0574-8.

Sulaeman, N.F., Putra, P.D.A., Mineta, I., Hakamada, H., Takahashi, M., Ide, Y. and Kumano, Y. (2021), "Exploring student engagement in STEM education through the engineering design process", *Jurnal Penelitian dan Pembelajaran IPA*, Vol. 7 No. 1, pp. 1-16, doi: 10.30870/jppi.v7i1.10455.

Yu, K.-C., Wu, P.-H. and Fan, S.-C. (2020), "Structural relationships among high school students' scientific knowledge, critical thinking, engineering design process, and design product", *International Journal of Science and Mathematics Education*, Vol. 18 No. 6, pp. 1001-1022, doi: 10.1007/s10763-019-10007-2.

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