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A comparison of three stem approaches to the teaching and learning of science topics: Students' knowledge and scientific creativity

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ABSTRACT

The main objective of this study was to compare the effectiveness of three STEM approaches in implementing STEM activities in lower secondary school students based on knowledge and scientific creativity. A pre-posttest experimental design was adapted. Six classes with almost similar learning conditions were randomly selected and each class was assigned as a group, in which two groups followed the Stand–alone engineering design approach, two adopted the 5E-EDP approach, and two classes used the Jigsaw learning approach. The data were collected from the tests before and after the experiments and were statistically analyzed. The findings revealed that these three approaches enhanced the students' gains in both knowledge and scientific creativity. Despite the overall progress, there existed a statistical difference among these models in their effects on the students' knowledge and scientific creativity. While 5E-EDP and Jigsaw learning approach were proven to make substantial progress in these factors, the Stand-alone engineering design scored less significance. The study also showed that there was a statistical difference between the Stand-alone engineering design approach and Jigsaw learning approach. The respective second approach formed a foundation for better performance of the students' knowledge and scientific creativity compared to the first one. Each approachhas its own value in enhancing students' knowledge and scientific creativity. The result of this study could be a hint for STEM educators to apply appropriate methods in similar contexts to boost achievements.

Contribution/Originality: The research demonstrates the importance of using appropriate methods to achieve better performance in STEM education. By providing empirical evidence on the effectiveness of different approaches, this study contributes to the development of evidence-based STEM education practices. Overall, the conclusion of this research offers valuable insights for STEM educators and policymakers to improve STEM education in lower secondary schools.

1. INTRODUCTION

The Industrial Revolution 4.0 is taking place at an exponential growth rate, spreading widely with the combination of multiple technologies leading to unprecedented changes and impacts on countries and the whole society. The humanity is on the verge of a revolution that will fundamentally change the way people think, live and work (Philbeck & Davis, 2018). The development of the fourth industrial revolution urgently requires new human resources in the world. Human skills in the new era need to change. Finding and building a suitable educational model is the need of the hour STEM education is promoted and applied as an appropriate model for this context (Martín-Páez, Aguilera, Perales-Palacios, & Vílchez-González, 2019; Wells, 2019). Around the world, STEM education has received tremendous attention in education reform efforts and in the mass media. Science, Technology, Engineering and Mathematics (STEM) plays an important role in the development of each country, determining the sustainable development of humanity in the face of the challenges of climate change and hunger. STEM creates the competitive strength of the economy (Rotermund & Burke, 2021).

The implementation of STEM education in developing countries like Vietnam has contributed to the increase in the number of skilled workers, as well as a whole generation of the young Vietnamese who adapt to the digital age through learning practical skills (Ho et al., 2020; Vuong & Trung, 2021). A practical question is how STEM education should be implemented to suit the context in each different country as each country chooses different implementation methods to suit its convenience (Jenlink, 2022; Lee & Lee, 2022). Vietnam ranks high in the Program for International Student Assessment (PISA) where the Vietnamese students did well, especially in the science test. It is a positive result however there are reasons to be cautious about the interpretation of Vietnam's PISA results. A few factors must be taken into account such as participants were not randomly selected, therefore, many subjects were excluded, and the structure of the test and the construction of the exercise format were similar across the organization. Teaching methods in Vietnam also suited the examination purposes. For this reason, many schools have adopted PISA-based student assessment, and, moreover, Vietnamese students are inherently smart in detecting and solving problems already learned (McAleavy & Fitzpatrick, 2021). Vietnam often achieves positive results of tests like PISA, according to statistics of the Intellectual Property Office of Vietnam under the Ministry of Science and Technology of Vietnam. Besides, the number of patent applications in Vietnam since 2010-2020 has also increased significantly, though up to 90% of applicants are foreign organizations and individuals, while Vietnamese applicants only account for a very modest number - around 10% (Department of Intellectual Property, 2020). In comparison with some countries in the Association of South East Asian Nations (ASEAN)+ 3 region about the number of patents, Vietnam is at the bottom and is quite far from Thailand and Singapore. According to the Global Innovation Index (GII), Vietnam's GII ranks 44/132 countries in the GII 2021 Report. However, in the ASEAN region, Vietnam ranks 4th, after Singapore (8/132), Malaysia (36/132) and Thailand (43/132).

Unlike developed countries such as the US, UK, China, France and like, STEM education introduced to Vietnam in 2014 did not originate from educational scientific research or from macro-policy on human resources, but from Robot competitions for high school students, implemented by technology companies in Vietnam together with foreign organizations. Since then, STEM education has begun to spread with many different forms, different implementation methods, and many different supporting organizations (Nguyen & Dang, 2019). However, the development of approaches to implementing STEM education in Vietnam needs to be studied and evaluated.

The main objective of this study was to compare the effectiveness of three STEM approaches (Stand – alone engineering design approach, 5E-EDP approach and Jigsaw learning approach) in implementing STEM activities in lower secondary school students based on students' knowledge and scientific creativity.

2. LITERATURE REVIEW

In the past, Vietnamese education was heavily focused on knowledge transmission, but the 2018 curriculum changed it from content access to learner's competence development (Ministry of Education and Training, 2018). This is an opportunity to apply STEM education to the 2018 curriculum. From the perspective of educational research, there have been a number of contemporary domestic researchers who conducted studies on the approaches to STEM education for Vietnamese curriculum. For example, a survey of teachers' attitudes on STEM education measured teachers' perceptions to maintain the development of STEM education. The study showed that teachers had a positive perception of STEM education, especially young teachers, who however found it very difficult to implement STEM education (Nguyen, Van Bien, Lin, Lin, & Chang, 2020). Moreover, how STEM pedagogy is being used to directly teach math and science concepts while there are obstacles to exam pressure and achievement is expressed as STEM teachers' concerns.

Currently, the approach to implementing STEM education in Vietnam's schools is mainly through extracurricular activities, clubs and science festivals (Nguyen & Dang, 2019) which uses mainly an independent engineering design approach model (EDP). There are some studies on implementing STEM education in mainstream curricula introduced by Vietnamese authors, most of these mainly use the EDP model and proposed to apply EDP to teach the applied content of knowledge (Nguyen et al., 2020; Thanh, Phuong, & Hai, 2018; Thi, Xuan, & Xuan, 2018).This model gave some positive results such as student's learning result still met the expected outcome of the curriculum while developing STEM skills as a kind of 21st century skills. This is consistent with a number of studies (Long, Yen, & Van Hanh, 2020; Nurtanto, Pardjono, Widarto, & Ramdani, 2020; Winarno, 2020).

However, the results of these reviewed studies are currently relatively fragment with the main approach focusing on survey assessment of knowledge requirements, assessment of students' competence and awareness development at the qualitative level. There has not been any evaluation and comparison of many EDP modeling approaches in different ways and at different stages of STEM education with respect to a content-oriented curriculum framework. Meanwhile, studies have made an effective assessment of its impact on students' perceptions and confidence in STEM knowledge, as well as their interest in STEM careers.

The steps of the EDP used in science education differ from one study to another study of Lin, Hsiao, Chang, Chien, and Wu (2018); Nurtanto, Pardjono, Widarto, and Ramdani (2020); Winarno et al. (2020). Although the steps of the EDP used in each study are different, the steps of the EDP have several common phases. There were additional or reduced periods in the EDP presented as the difference between studies. However, most phases of EDP include problem identification, construction, testing, evaluation, and redesign (Winarno et al., 2020). However, the approach of the EDP model to different learning phases also needs to be considered and clarified.

2.1. Content-Oriented Lesson Approach Combined with Stand – Alone Engineering Design

Content-oriented lesson approach, combined with Stand – alone engineering design approach, is an activity applied mostly in Vietnamese schools. In traditional classes, the students learn through a content-oriented curriculum, mainly by the method of presentation, wherein it is the teacher who provides the knowledge. After lessons, the students are trained to practice solving quizzes on their understanding of knowledge. The advantage of content – oriented method is that the students know the knowledge quite well, but they have few opportunities to practice discussing and solving real-life problems (Ministry of Education and Training, 2018).

The approach to STEM education is that engineering design is held for less than 3 hours after schooling, it can be viewed as an extracurricular activity. This is how STEM was initially approached in Vietnam, with the participation of private companies and later deployed in a number of general schools in the form of clubs or experiential festivals (Nguyen & Dang, 2019). These activities are often separated from mainstream classes and national standards with the aim of fostering passion and soft skills in learners (Gök & Sürmeli, 2022; Long et al., 2020). Students are provided with materials and asked to design products with certain criteria and they are guided to apply previously learned knowledge to solve design building problems (Pisanpanumas & Yasri, 2018). Figure 1 is an example of a stand – alone engineering design for a nail suction cart.

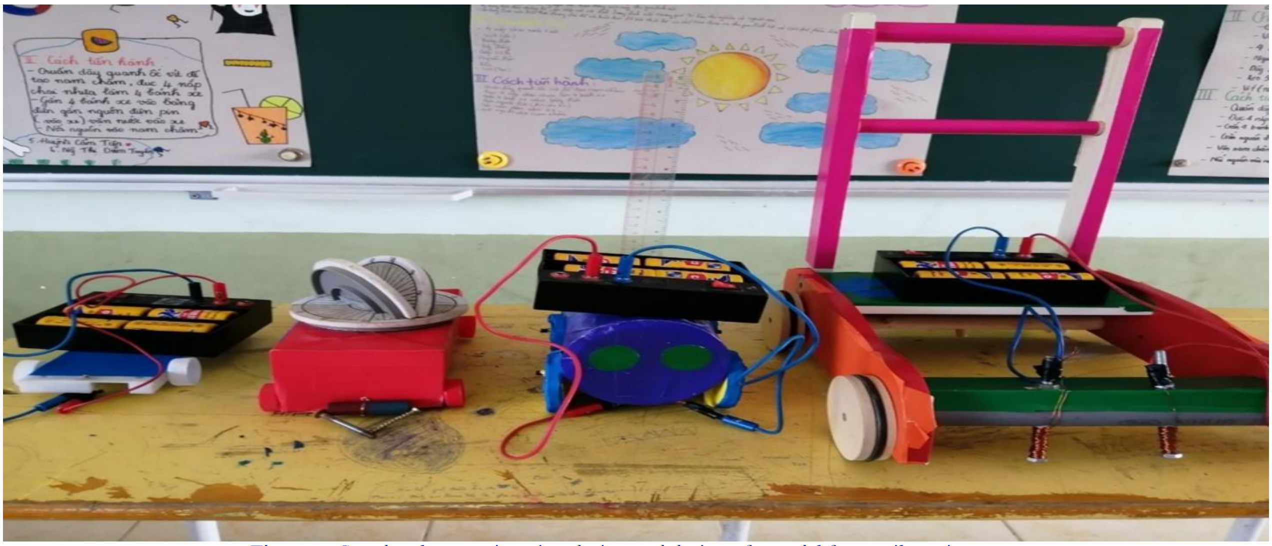

Figure 1. Stand – alone engineering design and design of a model for a nail suction cart.
Source: Developed by Phu An Secondary School students in Binh Duong province, Vietnam.

The implementation process is an engineering design process that includes a few steps like asking questions; imagining the solution; making a plan; making product design; and improvement (Nanang Winarno et al., 2020). Of course, at the end of the process there is always a group sharing about developed products, receiving feedback from other groups and teachers. Studies have also found that engineering design activities can help the students become interested in STEM and develop skills such as creativity, critical thinking, collaboration, and communication as well as attracting STEM-related career choices (Peterson, 2020). However, this form of implementation has disadvantages in linking the learning phase of scientific concepts and applications, which can reduce learners' motivation to learn and orient the academic knowledge application into practice.

2.2. Combined 5E-EDP Design Methodology

Different from the Stand – alone engineering design, the combined 5E-EDPapproach begins with a science and math inquiry and ends with design activity. By developing a sequence of learning activities in accordance with national science education standards, this approach uses a systematic curriculum that arranges themes in a one-way fashion, starting from basic concepts to more sophisticated and from theoretical to more practical elements (Pittayapiboolpong & Yasri, 2018). To be more explicit, the 5E-EDP approach establishes the necessary mathematical and scientific underpinnings to handle engineering design before allowing the students to engage in engineering design. This model helped students make more complex decisions based on their background knowledge instead of relying on intuition.

5E-EDP strategy is student-centered learning approach. The learning process becomes more meaningful and authentic. The student experience activities have more priority which can make students become more active when participating in lessons. It also stimulates student's critical thinking skills and creativity. The phases of the 5E-EDP approach consist of engagement, exploration, explanation, elaboration, and evaluation, Putra, Nur Kholifah, Subali, and Rusilowati (2018). The Engineering Design Process (EDP) could fall under the 5E framework, replacing the Elaboration-specific implementation phase with an EDP phase which proposes to focus on creating an environment for students to put what they have learned into practice. In the Evaluation step, teachers can proceed through the Exploration, Explanation processes of the 5E model, and in the steps of the EDP phase (Norwood, 2019).

A solid foundation of scientific knowledge can derive a 5E model, which can then lead to insightful decision making when undertaking an engineering design activity. The students who participate in an engineering design activity present a higher conceptual understanding and show a more complex level of understanding where different concepts can be integrated (Pittayapiboolpong & Yasri, 2018). However, one can realize that this STEM approach is time consuming. If one considers an engineering design activity to be a "peak", linear design goes from part to part to achieve this step. Therefore, taking a lot of time to prepare can make it impossible for many people to do it.

2.3. Jigsaw Learning Approach

The application of combined 5E-EDP design method could help students have better understanding of scientific concepts, help them to make informed decisions when doing an engineering design activity, but they have to spend much more time. The study which combines collaborative learning in content exploration of scientific concepts for undergraduate students shows that in general, the students in the Jigsaw learning group appreciate working with others and receiving help in a better way, discussing and sharing information and teaching others more comfortably, and enjoyed this model very much (Thi, 2022). Experimental implementation of cooperative learning through Jigsaw approach with high school students has also shown that students' problem solving and concept exploration are improved, and the students find it interesting to do experiments to solve problems and apply concepts (Maison, Kurniawan, Sukarni, Erika, & Hoyi, 2021).

In this approach, the teacher divides students into groups of four to six and asks those groups to rejoin at a later stage. The content is also divided into four to six equal parts. Students are divided up so that one person from each puzzle group moves on to the expert group. These students become "experts" in that piece of content. They read the information provided and/or search for information, discuss ambiguities, perhaps perform a task, then the students return to their original jigsaw groups. At this stage, the students present content on which they have become "experts" (Blajvaz, Bogdanović, Jovanović, Stanisavljević, & Pavkov-Hrvojević, 2022). Once their share is over, they are allowed to work on the engineering design of the challenge. This approach helps to reduce costs significantly in terms of time. In essence, it is still the foundation of the 5E-EDP approach, but Jigsaw learning approach is applied in the Exploration and Explanation steps.

Approach models of Stand – alone engineering design or a combination of 5E-EDP, or Jigsaw learning have the advantages and disadvantages that have been fully presented. With the educational innovation strategy from content-oriented education model to competence development, approaching STEM education with separate 5E or EDP models is more effective than traditional lectures in Vietnam (Linh & Huong, 2021; Thanh et al., 2018; Thi et al., 2018). However, due to lack of study about the combined application of 5E-EDP and Jigsaw learning, its effectiveness on conceptual understanding still remains subtle. With that perspective, the descending performance rankings in STEM activities could be hypothesized by the researchers to be Stand-alone engineering design 5E-EDP, Jigsaw learning, respectively.

3. METHODS

3.1. Data Collection and Sampling

The data were collected from 240 students of 7th grade who had never been introduced to any STEM activities or physics lesson related to electricity and magnets. It could be, thus, confirmed that their conceptual and skill enhancements were remarkably dependent on the STEM activities emerging from the three mentioned approaches. These students were selected according to convenience sampling method consisting of three steps. The first step was to obtain approval of the school leaders, and secondly to select teachers. These teachers, in the third step, attended a 4-week training course in STEM education and developed their teaching plans with the support of the research members. To enable data collection to be successful, two-week work duration was required during the semester. Interestingly, among lower secondary school classes, those 7th graders showed more flexibility when participating in the research. Therefore, based on the accessibility, flexibility and willingness of both participants and the school, a convenience sampling method was selected.

3.2. Semi-Empirical Research

This study randomly selected 06 classes from schools with almost similar learning conditions. The participating students had never been exposed to the three instructional approaches of STEM education. Two groups followed the stand – alone engineering design model, two classes adopted the 5E-EDP approach, and the last two classes used the Jigsaw learning approach. There were no set priorities or criteria in place when assigning each class to a particular STEM approach. In summary, while the students joined a Stand-alone engineering design group, design activities were organized outside of the mainstream curriculum. The students participated in the 5E-EDP approach and Jigsaw learning approach starting with the process of learning basic science concepts in an exploratory learning method. Finally, they were exposed to an operational challenge making the whole process a part of the mainstream curriculum with regulatory constraints.

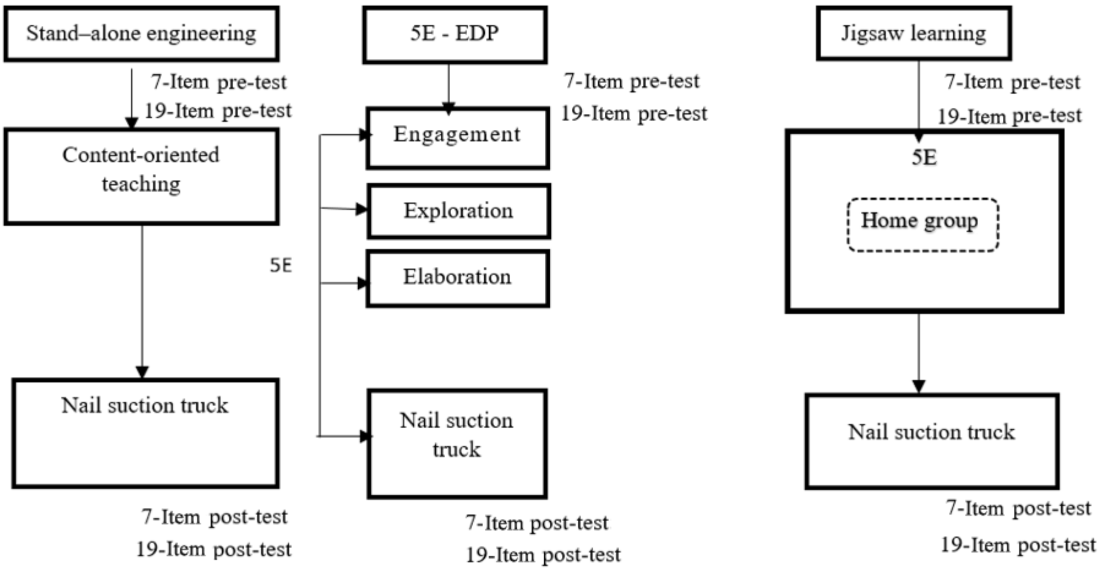

Figure 2. Diagram of three approaches to implement STEM activities.

3.3. Content-Oriented Teaching Approach Combined with Stand -Alone Engineering Design

The selected students were allowed to participate in regular classes according to the current curriculum in Vietnam. The main testing method was the application of the learned knowledge in which teachers made presentations and gave questions and answers while students solved given exercises. During the whole process, the teacher was the central person who coordinated as well as provided basic knowledge for the students. After the regular classes, students participated in designing and manufacturing nail suction carts (Figure 2). To participate in this independent activity, the students were divided into small groups formed by four to five members. This activity was carried out independently from the main programs.

Within 2 hours, the students had to use their learned science knowledge and skills to build a nail sucker that involved the concept of electric circuits, the effects of current, using of electric current to solve the problem of nail thieves. Furthermore, they were expected to use their circuit design and vehicle design skills to help the vehicle move and absorb the nails as much as possible on the obstacle course. Eventually, to complete the mission, each group tested their racing car performance and competed against other groups. Performance criteria included the number of nails sucked by the built race car, the maximum load carried by the car, speed of execution and efficient use of the materials provided.

There were 80 students who participated in this engineering design activity, which lasted 2 hours in total. They were asked to take two pre- and post-experiment tests on their knowledge of electrical circuits, the effects of current, their applications, and a well-established survey was also performed before and after the experiment (Figure 2). The knowledge test was designed similarly to a normal test currently used for assessment in Vietnamese schools, with the goal of assessing students' knowledge and understanding. To accomplish this, the core curriculum was unchanged (180 minutes according to the current curriculum distribution) and 120 minutes for the design activity.

3.4. 5E-EDP Linear Approach

The 5E-EDP approach is an instructional approach that starts scientific question with basic concepts, and then links these concepts to more complex concepts in a linear manner, where a model is required to be properly understood before moving on to the next concept. The students were encouraged to discover on their own the scientific knowledge related to electrical circuits, the effects of electric current and electric practical applications. The students conducted a survey and performed related experiments. These steps were carried out in the first three phases of the 5E model. Here students were led to explore scientific knowledge and conduct experiments. In the specific application phase of the 5E-EDP approach, the students were asked to solve the problem of nail thieves on highways.

There were 80 students participating in the 5E-EDP approach group. They conducted activities to explore scientific concepts; it took them 3 sessions (135 minutes) to complete the whole activity of exploring scientific concepts without practice lessons like traditional teaching methods. The students were facilitated to explore concepts, conduct the experiments, and given 2 hours to perform the design activity. The first three sessions focused respectively on electrical circuits, effects of electric current and electrical current applications. The fourth session was a 2-hour race car engineering design activity. The students were required to take the same tests as a Stand-alone engineering design approach.

3.5. Jigsaw Learning Approach

When joining in a Jigsaw learning class, the joiners were divided into three different groups as experts; each group was responsible for learning the content about electrical circuits, the effect of current, and the application of electric current. Each of such expert group was divided into sub-groups with seven members in maximum. After finishing the given tasks, the experts were assigned to home groups with members from other expert groups. Therefore, each family group consisted of members who had learned different scientific concepts, where they were going to share what they had learned to each other.

There were 80 students participating in the Jigsaw learning group. They were given the same tests as the one in the first STEM approach described above. This was followed by three parallel sessions, where each group of experts learned the assigned topic and where each of home group members shared what they had learned with others. These parallel sessions ran for 2 hours. The students then took 2 more hours to participate in the engineering design of the designated suction truck as described in Figure 2.

3.6. Measurement Tools

The students were required to take 02 tests before and after the experiment which included a test with knowledge related to electrical circuits, the effects of electric current, its applications and a test of scientific creativity. The test with knowledge of measurement tools appeared as four options. Firstly, it was a set of concept tests for small units of electrical circuits, current effects and applications, and a survey that measured STEM competence and career intention. The conceptual test which aimed to measure the development of the students' conceptual understanding, memorization and comprehension was designed with 19 items being divided into 3 subsections of electrical circuits, effects of electric current, and electric current applications with the number of 7, 6, and 6, respectively. To finish the test, the students were supposed to perform high-order thinking to critically assess the options with 3 distracting answers and choose the correct one (Sam et al., 2018).

The reliability and content validity of the test were also considered. The reliability, calculated by Kuder-Richardson Formula 20 (KR-20), was at acceptable level with the coefficient value of 0.76 (Kumar, Jaipurkar, Shekhar, Sikri, & Srinivas, 2021). Meanwhile, the index of Item-Objective Congruence (IOC) for content validity was employed to verify the teachers in this research (Ismail & Zubairi, 2022). All of them had more than 10-year experience of teaching physics in middle schools. From the IOC scores, the questions were then classified into 2 groups in which the first including questions with the score above 0.75 remained original, and the second with questions of below 0.75 would be revised for improvement.

Along with the test above, a scientific creativity with 7 open-ended questions using the Scientific Creativity Structure Model (SCSM) (Eroglu & Bektas, 2022) was developed. This test focused on the levels of fluency, flexibility, and originality and provided a comprehensive result of the students' scientific creativity competence. To guarantee the content, validity, language and clarity, 6 middle school teachers independently and objectively made their evaluation of the test instrument and questionnaires. The IOC score was then used to group the items of over 0.75 and below 0.75 as the previous test. The latter group would be revised or modified as suggested. A KR-20 of this test had the index of 07.1 which was equivalent to the acceptable level of reliability (Ekolu & Quainoo, 2019).

4. RESULTS AND DISCUSSION

The students' improvement in knowledge and scientific creativity was identified by two tests before and after the experiment. Specifically, for achievement in knowledge, the mean scores of the pre-test ranged from 3.09 of 5E-EDP approach to 3.63 of Jigsaw learning approach while the corresponding figures of the post-test approximately doubled, from 6.61 of stand-alone engineering to 7.73 of Jigsaw learning. Such apparent difference resulted in the noticeable gap in the average mean of the pre-test and the post-test, at 3.35 and 7.19, respectively (see Table 1).

The similar difference could be observed in scientific creativity when means of the post-tests outnumbered those of the pre-tests. Jigsaw learning approach gained the highest mean before and after the experiment, at 4.63 and 7.97, respectively. Although the design independent engineering method had almost equivalent mean with the 5E-EDP approach in the pre-tests, these learning approaches could be concluded to create distinguished influence on the learning outcomes with large variation recorded in the post-tests. The mean score of the 5E-EDP approach was initially the lowest, at 4.29, it then reached the second top score, at 7.47 in recognition of the experiment, which was higher than the corresponding value of the design independent engineering method, at 6.54.

Table 1. Descriptive of pre-test and post-test (N=239).

Students' gains	Test	Model	N	Mean	Std. deviation	Std. error
Knowledge	Pre-test	1	83	3.33	2.11	0.23
		2	78	3.09	1.70	0.19
		3	78	3.63	1.67	0.19
	Post-test	1	83	6.61	2.16	0.24
		2	78	7.27	1.41	0.16
		3	78	7.73	1.64	0.19
Scientific creativity	Pre-test	1	83	4.33	2.11	0.23
		2	78	4.29	1.70	0.19
		3	78	4.63	1.67	0.19
	Post-test	1	83	6.54	2.06	0.23
		2	78	7.47	1.25	0.14
		3	78	7.97	1.28	0.15

Note: Model 1: Stand – alone engineering design model; Model 2: 5E-EDP model; Model 3: Jigsaw learning model.

From the findings, the three approaches were proven to be effective in developing the students' knowledge and scientific creativity. It could be noted that this progress could be classified into two groups in which the first group just included the Stand-alone engineering approach. According to the results, this learning approach could be reported to make less academic influence on the students compared to 5E-EDP and Jigsaw approaches in the second group. Both learning models in this group assisted the students to gain comparatively higher performance in knowledge acquisition as well as scientific creativity development. These findings are partly in line with the study of Maison et al. (2021) when the authors proved that Jigsaw learning approach could enhance students' interests to find concepts. As experimental interest is possibly regarded as a fundamental element of knowledge acquisition in a way that it consciously energizes the learning process, it can be inferred that the mentioned-above model is likely to boost the students' knowledge through intensive learning. Additionally, the results of this study somehow reinforce the conclusion of Pisanpanumas and Yasri (2018) about the 5E-EDP learning approach in which students, in use of this approach, showed a higher and deeper conceptual understanding. In other words, it played a significant role in building up scientific knowledge of the students.

Table 2. In-group comparison of pre-test and post-test means of the three approaches.

Students' gains	Comparison		Pre-test		Post- test		Differences	Sig. (*p*)
			Mean	Standard deviation	Mean	Standard deviation		
Knowledge	Model	1	3.3	2.1	6.6	2.2	3.3	0.00
		2	3.1	1.7	7.3	1.4	4.2	0.00
		3	3.6	1.7	7.7	1.6	4.1	0.00
Scientific creativity	Model	1	4.3	2.13	6.5	2.1	2.2	0.00
		2	4.3	1.70	7.5	1.2	3.2	0.00
		3	4.6	1.67	8.0	1.3	3.4	0.00

Note: Model 1: Stand – alone engineering design model; Model 2:5E-EDP model; Model 3: Jigsaw learning model.

Table 2 showed that the outcome of the experiment was significant when the post-test mean of each model was statistically higher than that of the pre-test (Sig.=0.00). On the other hand, the SD was almost identical between the tests.

In terms of knowledge, the lowest mean score of the pre-tests belonged to the 5E-EDP approach, at 3.1 (SD=1.7) while the highest was seen in the Jigsaw learning approach, at 3.6 (SD=1.7). After the experiment, there was a significant increase in values when they all reached almost twice as much as those of the pre-test scores. The most noticeable difference was exhibited in the 5E-EDP model with mean at 7.3 (SD=1.4) which was almost similar to the Jigsaw learning model (Mean=7.7, SD=1.6). The stand-alone engineering approach showed less difference when the mean before and after the experiment were 3.3 (SD=2.1) and 6.6 (SD=2.2), respectively. It could be inferred that 5E-EDP and Jigsaw learning approaches, in this study context, outperformed the first numbered one in increasing the students' knowledge.

Regarding the scientific creativity, it could be said that the students in this study had better creativity than knowledge. The pre-test means of this factor recorded 1 point higher than that of knowledge, at around 4.5 compared to the average of 3.5 of knowledge. After the experiment, the scientific creativity of the students had substantial growth. Among the 3 learning approaches, Jigsaw had the most impressive change as its mean in the post-tests reached the top of 8.0 (SD=1.3) compared to only 4.6 (SD=1.67) in the pre-tests. In the second position was the 5E-EDP approach with a rise from 4.3 (SD=1.7) to 7.5 (SD=1.2) after the experiment. In contrast to the previous significant rise, the stand-alone engineering approach was reported to not to make equivalent development of the students' scientific creativity. Its values of mean before and after the test were 4.3 (SD=2.1) and 6.5 (SD=2.1), respectively.

Table 3. Between-group comparison of pre-test and post-test means of the three approaches.

Students' gains	Comparison		Sum of squares	Degree of freedom	Mean square	F	Sig.
Knowledge	Pre-test	Between groups	11.54	2.00	5.77	1.70	0.19
		Within groups	801.71	236.00	3.40	0.00	0.00
		Total	813.26	238.00	0.00	0.00	0.00
	Post-test	Between groups	50.82	2.00	25.41	8.08	0.00
		Within groups	742.12	236.00	3.15	0.00	0.00
Scientific creativity	Pre-test	Between groups	5.59	2.00	2.79	0.82	0.44
		Within groups	801.71	236.00	3.40	0.00	0.00
	Post-test	Between groups	84.73	2.00	42.37	16.83	0.00
		Within groups	593.96	236.00	2.52	0.00	0.00
		Total	678.69	238.00	0.00	0.00	0.00

For the correlation between the three approaches in the pre-tests and post-tests, a comparison analysis was performed (Table 3). The results indicated that while the pre-tests showed no statistical difference among the three models in the students' knowledge (sig=0.19) and their scientific creativity (sig=0.44), both factors had statistical difference in the post-tests (sig=0.00). In other words, these three approaches, after the experiment, made different levels of improvements in the students' knowledge and scientific creativity. The above results imply the impact of teaching approaches in STEM education. In fact, each method has its own distinctive influences on the learners' progress. Although that influence of a learning model may vary from others, it is apparent that all approaches, to some extent, develop the learners' knowledge and scientific creativity by using a variety of activities to help learners reach the expected academic targets.

It is interesting to note that the three learning approaches were implemented in similar contexts with the students from the same school and same learning conditions. After the experiment, the performance of these students varied according to each method. It, therefore, indicates that an appropriate choice of teaching and learning approach that fits the education context possibly brings best outcomes. In STEM education, this matter turns out to be much more critical since these subjects requires a long process with many activities to help the students not only understand relevant scientific concepts and, consequently, develop their knowledge but also improve their scientific creativity that may motivate productive learning process and original STEM products.

Table 4. Multiple comparisons.

Dunnett t (2-Sided)a								
Students' gains	Dependent variable	(I) Three models	(J) Three models	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
							Lower bound	Upper bound
Knowledge	Pre-test	1	3	-0.31	0.29	0.46	-0.96	0.34
		2	3	-0.54	0.30	0.12	-1.20	0.11
	Post-test	1	3	-1.12*	0.28	0.00	-1.74	-0.49
		2	3	-0.46	0.28	0.19	-1.09	0.17
Scientific creativity	Pre-test	1	3	-0.31	0.29	0.46	-0.96	0.34
		2	3	-0.34	0.30	0.40	-1.00	0.31
	Post-test	1	3	-1.43*	0.25	0.00	-1.98	-0.87
		2	3	-0.50	0.25	0.09	-1.06	0.07

Note: *. The mean difference is significant at the 0.05 level.
a. Dunnett t-tests treat one group as a control, and compare all other groups against it.

To discover the paired difference of these models, a Dunnett test was performed. According to Table 4, there was no statistical difference between each pair of models in the pre-tests. After the experiment, the post-tests also indicated no statistical difference between the 5E-EDP and the Jigsaw learning approach in knowledge and scientific creativity (sig=0.18 and sig=0.09, respectively). However, between the Stand – alone engineering design and Jigsaw learning approach, there existed a statistical difference (sig=0.00) in both factors. Specifically, the students who applied Jigsaw approach performed better in the post-test compared to those with the Stand-alone engineering approach. The results from this table obviously lead to a conclusion that Jigsaw learning approach worked more efficiently than the other in improving the students' knowledge and scientific creativity.

The outperformance of the students in Jigsaw learning approach in comparison with the Stand-alone engineering approach regarding knowledge and scientific creativity could be explained by the fundamental coherence of learning stages. While the latter model may possess some weaknesses in linking the scientific concepts and practices that are likely to reduce the students' motivation, the former approach, to some extent, shows a more positive scenario in this issue. The results are significantly in line with the study of Maison et al. (2021) in which learning this subject, using Jigsaw learning approach, would be more enjoyable with the emphasis on the students' collaboration. Such motivational anticipations undoubtedly inspire the active and natural development of knowledge and scientific creativity.

5. CONCLUSION

This study aimed to explore the effects of the STEM activities designed with 3 learning approaches, i.e., Stand – alone engineering design, 5E-EDP , and Jigsaw learning on the students' knowledge and scientific creativity. Moreover, it investigated the level of impact of each approach on these factors to provide insights of STEM education in the context of a lower secondary school. The data were collected from the tests before and after the experiments and were statistically analyzed. The findings revealed that these three approaches enhanced the students' gains in both knowledge and scientific creativity. The improvement was remarkably significant when it was reported to achieve double levels. Despite the overall progress, there existed a statistical difference among these models in their effects on the students' knowledge and scientific creativity. While 5E-EDP and Jigsaw learning approaches were proven to make substantial progress in these factors, the Stand-alone engineering design scored less significance. The study also showed that there was a statistical difference between the Stand-alone engineering design and Jigsaw learning model. The respective second approach formed a foundation for better performance of the students' knowledge and scientific creativity compared to the first one. This could be a hint for STEM educators to apply appropriate methods in similar contexts to boost achievements.

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REFERENCES

Blajvaz, B. K., Bogdanović, I. Z., Jovanović, T. S., Stanisavljević, J. D., & Pavkov-Hrvojević, M. V. (2022). The Jigsaw technique in lower secondary physics education: Students' achievement, metacognition and motivation. *Journal of Baltic Science Education, 21*(4), 545-557. https://doi.org/10.33225/jbse/22.21.545

Department of Intellectual Property. (2020). *Annual report on intellectual property activities 2020.* Vietnam: ANLIS IP CO., LTD.

Ekolu, S. O., & Quainoo, H. (2019). Reliability of assessments in engineering education using Cronbach's alpha, KR and split-half methods. *Global Journal of Engineering Education, 21*(1), 24-29.

Eroglu, S., & Bektas, O. (2022). The effect of STEM applications on the scientific creativity of 9th-grade students. *Journal of Education in Science, Environment and Health, 8*(1), 17-36. https://doi.org/10.21891/jeseh.1059124

Gök, B., & Sürmeli, H. (2022). The effect of scientific toy design activities based on the engineering design process on secondary school students' scientific creativity. *Asian Journal of University Education, 18*(3), 692-709. https://doi.org/10.24191/ajue.v18i2.17987

Ho, M.-T., La, V.-P., Nguyen, M.-H., Pham, T.-H., Vuong, T.-T., Vuong, H.-M., . . . Vuong, Q.-H. (2020). An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam. *Children and Youth Services Review, 119*, 105650. https://doi.org/10.1016/j.childyouth.2020.105650

Ismail, F. K. M., & Zubairi, A. M. B. (2022). Item objective congruence analysis for multidimensional items: Content validation of a reading test in Sri Lankan University. *English Language Teaching, 15*(1), 106-117. https://doi.org/10.5539/elt.v15n1p106

Jenlink, P. M. (2022). *A global reimagining of stem teacher preparation and practice. STEM teacher preparation and practice for the 21st Century: Research-based insights*. Charlotte, NC: State University Information Age Publishing, Inc.

Kumar, D., Jaipurkar, R., Shekhar, A., Sikri, G., & Srinivas, V. (2021). Item analysis of multiple choice questions: A quality assurance test for an assessment tool. *Medical Journal Armed Forces India, 77*, S85-S89. https://doi.org/10.1016/j.mjafi.2020.11.007

Lee, Y.-F., & Lee, L.-S. (2022). Status and trends of STEM education in highly competitive countries: Country reports and international comparison. *Online Submission*.

Lin, K.-Y., Hsiao, H.-S., Chang, Y.-S., Chien, Y.-H., & Wu, Y.-T. (2018). The effectiveness of using 3D printing technology in STEM project-based learning activities. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(12), em1633. https://doi.org/10.29333/ejmste/97189

Linh, N. Q., & Huong, L. T. T. (2021). Engineering design process in STEM education: An illustration with the topic "wind energy engineers". *Journal of Physics: Conference Series, 1835*(1), 012051. https://doi.org/10.1088/1742-6596/1835/1/012051

Long, N. T., Yen, N. T. H., & Van Hanh, N. (2020). The role of experiential learning and engineering design process in k-12 STEM Education. *International Journal of Education and Practice, 8*(4), 720-732. https://doi.org/10.18488/journal.61.2020.84.720.732

Maison, T. T., Kurniawan, D. A., Sukarni, W., Erika, & Hoyi, R. (2021). Assessing students' attitudes towards physics through the application of inquiry and jigsaw cooperative learning models in high schools. *International Journal of Instruction, 14*(4), 439–450. https://doi.org/10.29333/iji.2021.14426a

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799-822. https://doi.org/10.1002/sce.21522

McAleavy, T., & Fitzpatrick, R. (2021). Promising practice in government schools in Vietnam. In C. McLaughlin & A. Ruby (Eds.), Implementing Educational Reform: Cases and Challenges (Cambridge Education Research). In (pp. 127-148). Cambridge: Cambridge University Press.

Ministry of Education and Training. (2018). *General education program – Master program. Circular No. 32/2018/TT-BGDĐT, 52*. Retrieved from https://data.moet.gov.vn/index.php/s/LETzPhj5sGGnDii#pdfviewer

Nguyen, C. T., & Dang, V. S. (2019). *STEM education in Vietnam: tools and methods. In Hdll.Vn*. Retrieved from http://hdll.vn/vi/thong-tin-ly-luan/giao-duc-stem-tai-viet-nam-cong-cu-va-phuong-thuc.html

Nguyen, T. T. K., Van Bien, N., Lin, P.-L., Lin, J., & Chang, C.-Y. (2020). Measuring teachers' perceptions to sustain STEM education development. *Sustainability, 12*(4), 1-15. https://doi.org/10.3390/su12041531

Norwood, M. (2019). *The impact of the biological sciences curriculum study (BSCS) 5E model on middle-level students' content knowledge*. Doctoral Dissertation, University of South Carolina.

Nurtanto, M., Pardjono, P., Widarto, W., & Ramdani, S. D. (2020). The effect of STEM-EDP in professional learning on automotive engineering competence in vocational high school. *Journal for the Education of Gifted Young Scientists, 8*(2), 633–649. https://doi.org/10.17478/JEGYS.645047

Peterson, B. (2020). Building STEM career interest through curriculum treatments. *Journal of STEM Education: Innovations and Research, 21*(1), 64-73.

Philbeck, T., & Davis, N. (2018). The fourth industrial revolution. *Journal of International Affairs, 72*(1), 17-22.

Pisanpanumas, P., & Yasri, P. (2018). Taxonomy: Increased complexity of conceptual understanding about the interconnection between convection and natural disasters using hands-on activities. *PSAKU International Journal of Interdisciplinary Research, 7*(2), 91-103. https://doi.org/10.2139/ssrn.3262589

Pittayapiboolpong, T., & Yasri, P. (2018). Development of an integrative learning unit to enhance students' conceptual understanding of dissolution and their reasoning sophistication. *Journal of Research in Science, Mathematics and Technology Education, 1*(3), 283–309. https://doi.org/10.31756/jrsmte.133

Putra, F., Nur Kholifah, I. Y., Subali, B., & Rusilowati, A. (2018). 5E-learning cycle strategy: Increasing conceptual understanding and learning motivation. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 7*(2), 171-181. https://doi.org/10.24042/jipfalbiruni.v7i2.2898

Rotermund, S., & Burke, A. (2021). *Elementary and secondary STEM education.* Retrieved from Science & Engineering Indicators 2022. NSB-2021-1: National Science Foundation, USA.

Sam, A. H., Field, S. M., Collares, C. F., van der Vleuten, C. P., Wass, V. J., Melville, C., . . . Meeran, K. (2018). Very-short-answer questions: Reliability, discrimination and acceptability. *Medical Education, 52*(4), 447-455. https://doi.org/10.1111/medu.13504

Thanh, N. N., Phuong, H., & Hai, M. N. L. (2018). Organization of STEM education-oriented teaching some Physical knowledge 10 through simple toy manufacturing. *Journal of Social Sciences. Journal of Social Sciences, Humanities and Education, 8*(3B), 66-73. https://doi.org/10.47393/jshe.v8i3B.725

Thi, K. C. N., Xuan, D. H., & Xuan, H. D. (2018). Application of STEM education model in some main classes of characteristics in high school. *Journal of Social Sciences, Humanities and Education, 8*(3A), 13-16.

Thi, T. T. N. (2022). Integrated teaching in the direction of STEM education for primary students using the "EDP-5E" model. *Education Magazine, 22*(12), 1-6.

Vuong, Q. H., & Trung, T. (2021). *Academic contributions to the UNESCO 2019 forum on education for sustainable development and global citizenship.* Basel, Switzerland: MDPI.

Wells, J. G. (2019). STEM education: The potential of technology education. In. Ctete, St. Louis: Council on Technology and Engineering Teacher Education.

Winarno, N. (2020). The steps of the engineering design process (EDP) in science education: A meta-analysis. *Journal for the Education of Gifted Young Scientists.* https://doi.org/10.17478/jegys.766201

Winarno, N., Rusdiana, D., Samsudin, A., Susilowati, E., Ahmad, N., & Afifah, R. M. A. (2020). The steps of the engineering design process (EDP) in science education: A systematic literature review. *Journal for the Education of Gifted Young Scientists, 8*(4), 1345-1360. https://doi.org/10.17478/jegys.766201

Winarno, N., Rusdiana, D., Samsudin, A., Susilowati, E., Ahmad, N. J., & Afifah, R. M. A. (2020). Synthesizing results from empirical research on engineering design process in science education: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(12), 1–18. https://doi.org/10.29333/ejmste/9129