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Approaches for Implementing STEM (Science, Technology, Engineering & Mathematics) Activities among Middle School Students in Thailand

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Abstract: STEM education is a pedagogical philosophy which aims to draw the interrelationship between science, technology, engineering and mathematics to solve complex problems in real life situations. In order to use STEM education to foster students' learning, the researchers designed STEM activities for middle school students related to the concept of force and motion in three different approaches: a linear model, a jigsaw learning and a stand-alone engineering design activity. To compare the effectiveness of the three approaches, the researchers analysed students' reasoning and problem-solving scores gained before and after doing the activities. The result showed students participating in the linear model and in the jigsaw learning significantly outperformed those in the stand-alone engineering design activity. In addition, when comparing conceptual development between those attending the linear model and jigsaw learning, the result showed that the former significantly outperformed the latter. It is therefore suggested that to maximise the effectiveness of STEM activities in promoting conceptual understanding as well as reasoning and problem-solving skills, teachers should adopt the linear model. However, when instructional time is limited, the jigsaw learning can be considered as an alternative approach. The stand-alone engineering design activity although can promote students' enthusiasm to learn, it may not sufficiently lead to the development of reasoning and problem-solving skills as expected.

Keywords: *STEM education, linear model, jigsaw learning, engineering design.*

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Introduction

During the 1980s, Thailand used to be one of the leading countries in Asia in terms of economy, known as The Five Tigers (Muscat, 1994). However, since then the country has remained in the middle-income trap, while the other four Tigers (Singapore, Taiwan, Hong Kong & South Korea) became economically developed nations (Paldam, 2003). As a result, recent national policies of Thailand have emphasised more on promoting creative and innovative economy through the campaign of Thailand 4.0 (Puncreobutr, 2016). It aims to cultivate the entrepreneurial mind-set to the people to make them aware of the importance of science, technology and innovation which are believed to be vital causes for economic development (Vares et al., 2011).

To move towards an innovation-driven economy, it is important to reform educational policies of the country so that future generations of Thai citizens can become more capable of developing new technologies. STEM education is believed to be a promising way to make the expectation come true. Since 2014, educational movements on promoting STEM education have been implemented (Srikoom et al., 2017). As a result, educational trainings have been delivered across the country by both public and private organisations to assist school teachers to be ready to run STEM activities in classrooms.

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STEM education

STEM education is perceived as an educational philosophy in which science, technology, engineering and mathematics are used as integrative means to solve real-life problems (Priemer et al., 2019) and through the application of the four disciplines innovations emerge (Vasquez et al., 2013).

It has become a topic of interest among the international community. The US government uses it as a way to increase the number of workforces in science and technology whose contributions can give rise to the development of technological advancement which can in turn prosper the country (Hira, 2010). In addition, this educational viewpoint has been spread throughout Europe where learning of science is no longer considered as the study of separate subjects of physics, chemistry and biology, but integrative knowledge that can be used to understand natural phenomena and to apply to solve complex problems and to innovate new developments (Kudenko & Gras-Velazquez, 2016). Likewise, across Asian countries including Japan, Singapore, and China STEM education is believed to be a key promoting factor of the development of stronger innovative economy as learners can experience the application of the four disciplines which can promote their interest in STEM-related careers (Han & Appelbaum, 2018).

STEM education is viewed as a tool used for understanding the ever-changing, natural world in daily life (Srikoom et al., 2017). Science is generally perceived as foundational understanding to explain how things work in nature. Then, it is the use of technology that can give rise to humans' convenience by modifying some aspects of the natural world to meet our daily needs. In addition, to arrive at such innovative development, learners are prone to use the engineering process to design, create and redevelop innovative products or processes using both hard-skills and soft-skills. Ultimately, learners can use mathematical skills including calculation and decision making to solve problems (Reeve, 2013).

Although different practices regarding STEM activities can be seen from countries to countries, it is likely that in addition to conceptual understanding of science and mathematics, they all aim to cultivate 21st century learning skills including problem solving, creativity, collaboration, communication and critical thinking for learners (Ostler, 2012). Therefore, it is commonly seen that active learning of science in the forms of project-based learning, problem-based learning, inquiry-based learning, engineering design process, and many others, have been utilised (Bell, 2010; Christiansen et al., 2013; Andrini, 2016; Mangold & Robinson, 2013). This is due to the fact that active learning involves group work where communication and collaboration are intrinsic (Frykedal & Chiriac, 2017). In addition, through solving problems or designing products, creativity and critical thinking can be sufficiently promoted (Stollberger et al., 2017). Based on this factual information, science teaching that focuses more on the traditional learning which often starts with teachers teaching the content directly to students for them to memorize will be sooner or later replaced with active learning (Ghavifekr & Rosdy, 2015; Setiawan et al., 2019).

While there is no doubt about the importance of STEM education and its growing attraction for promoting countries' development, a practical issue has emerged and that is the question on how STEM education should be implemented. Based on STEM education movements in Thailand, two main directions of STEM trainings have been implemented. One is the delivery of engineering design activities done by the Institute for the Promotion of Teaching Science and Technology (IPST) which is a government agency whose responsibilities include the development of national science and mathematics curricula. The other is a linear design of STEM activities done by Chevron's Enjoy Science Project which is a national collaboration between private organisations and public universities to strengthen Thailand's competitiveness and innovation by improving STEM and vocational education across the country.

A stand-alone engineering design approach

Engineering design activities are normally stand-alone events which can be done within 2-3 hours as an extracurricular activity. In addition, they can be detached from formal classes and national standards so that teachers can use them for promoting enthusiasm in learning science and cultivating soft-skills among learners (Hathcock et al., 2015). In its regular practices, students are provided with a set of materials which can be used to build up a prototype that can solve the mission of engineering design challenge (Park, Park, & Bates, 2018). Known examples include racing cars, catapult challenge, robot arms, roller coasters, to name a few (Yilmaz et al., 2017). To give one specific example, students are provided with wooden sticks, rubber bands, and a sticky tape. Using these materials, they are given a mission to build a catapult that can project an object from a starting point to a finishing line (see Figure 1).



Figure 1: An example of engineering design activity (catapult challenge)

According to the IPST guidelines, each engineering design activity contains six stages. The first step begins with the teacher presenting a real life situation related to the activity to students in order to engage them to the activity. Before moving to the next step, the teacher clarifies the purposes and checks prior knowledge of students after that divides them in small groups. In the second step, each small group is informed about materials that are available for the activity and allowed to search for more information related to the problem, followed by group discussions. In the third step, the teacher allows each group to draw a model of prototype, and to explain how it works. In the fourth step, each group carries out the proposed plan and builds up a prototype using materials provided. Fifth, when the prototype is successfully created, each group is allowed to test if it works as expected before having some extra time for redesign and further development. Once the final product is fully built, every group assembles for a competition to find the winner. Finally, the teacher leads a class discussion about their development as well as problem solving strategies (IPST, 2013).

Research has shown that engineering design activities can help promote students' interest in STEM education and cultivate various forms of soft skills such as creativity, critical thinking, collaboration, and communication (Hathcock et al., 2015). Many have been inspired by the activities to carry on their further education in STEM-related degrees (Ostler, 2012). However, this STEM approach is not without critiques. While its effectiveness on engagement attracts no doubts, its capability of building conceptual understanding of science concepts is questionable. This is due to the fact that this STEM approach emphasises more on soft skills that lead students to build a product, and thus little attention is given to scientific concepts behind the engineering design activity (Pisanpanumas & Yasri, 2018). As can be seen from the six stages, no room is provided for discussing about the science behind the design of the product.

Linear design approach

Turning to the linear design, instead of portraying STEM activities as single events of engineering design activities, this STEM approach starts with a series of inquiry-based investigations of science and mathematics activities, before reaching an engineering design activity in the end (Pisanpanumas & Yasri, 2018). The linear design employs a systematic curriculum that arranges topics in a unidirectional fashion, starting from simple to more advanced concepts, and from theoretical to more practical aspects by creating a sequence of learning activities that are consistent with the national science education standards (Pittayapiboolpong & Yasri, 2018). To be more precise, before allowing students to experience an engineering design activity, the linear model lays scientific and mathematical foundations that are relevant for solving the engineering design activity. It believes that the background knowledge can help students make more sophisticated decision making rather than relying on intuition.

For example, instead of jumping to make a catapult, students may need to learn about a projectile motion and carry out a simple activity related to this. Then they may need to learn about the concept of the lever and the moment through an inquiry-based activity. Once their conceptual understanding is fully formed, they are then allowed to do the engineering design activity of catapult challenge. It is expected that to design the model of the catapult, students can consider different possibilities of the lever classes of the catapult and perhaps they can critically think about the angle of projection that can make the catapult function more effectively. Therefore, based on the linear model, students are encouraged to learn relevant science concepts through an inquiry-based method which is normally hands-on, before drawing this background knowledge to construct a product to accomplish engineering design challenges (Pisanpanumas & Yasri, 2018).

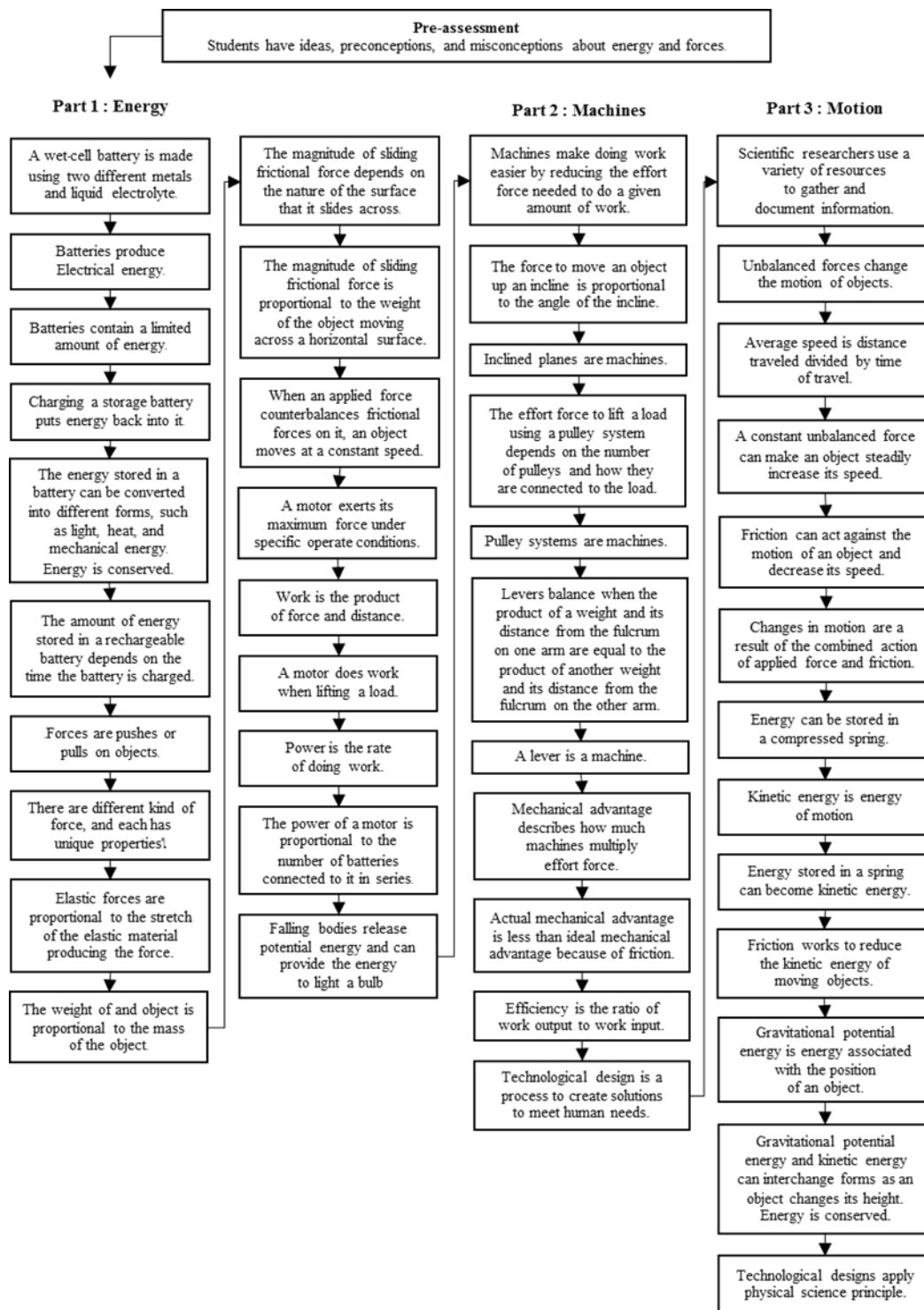


Figure 2: An example of activities developed after the linear model

Figure 2 represents how the linear design works developed by Chevron’s Enjoy Science Project. The whole set of activities compose of three modules: energy, machines and motion. Each box shows an inquiry-based activity that builds on one scientific concept. Towards the end of each module, students have a chance to do a technological design activity (which is an engineering design activity referred to in this study). It is important to note that in this linear design, each module is not in isolation. Knowledge from the energy model can be used to form understanding of the machine module. Likewise, scientific concepts learned in the machine module can be used in the energy module accordingly.

It appears that firm foundation of scientific knowledge can be gained from the linear design which can then lead to profound decision making when doing an engineering design activity. Research has shown that students participating in a linear design activity related to natural disasters exhibited greater conceptual understanding and showed more complex levels of understanding where different concepted can be integrated (Pisanpanumas & Yasri, 2018). However, one may realise that this STEM approach is time-consuming. If one considers an engineering design activity as a

“climax”, the linear design takes session after session to reach this step. Thus, excessive time for preparation may put many off.

Jigsaw learning approach

The existence of challenges of the linear design leads to the review of the third STEM approach which has never been done in Thailand, but is theoretically valid to solve the issue of time while remaining the essence of laying foundation of scientific understanding before reaching engineering design. Overall, this approach is called jigsaw learning in which multiple scientific concepts can be delivered within a condensed period of time through collaborative learning (Tran & Lewis, 2012).

In the jigsaw learning, each student is viewed as a piece of the jigsaw and the whole picture represents the whole learning process taking place in class. Each student is required to be responsible for a particular task which is different from others. Then each would contribute his/her own learning experience to the rest in order to form a holistic idea of the whole lesson (Grasha & Yangarber-Hicks, 2000; Tran & Lewis, 2012). One may consider this approach as a structured peer coaching where different students learn different concepts and they all share what they learn to each other so that others can receive second-knowledge from the one who experiences it first-hand.

To put it into practice, in the jigsaw learning class, a small group of students is formed which is called a “home group”. Basically, the number of group members is supposed to be equal to the number of concepts or activities to be delivered in the class. Once a home group is formed, each member is assigned to be responsible for learning about a particular topic. Those members who are assigned to do the same activity are considered the same “expert group” as the term implies that they experience the learning of this particular concept first-hand (Doymus et al., 2004; Slavin, 1991).

To elaborate this, taking the idea of the linear design of the catapult challenge into consideration, the jigsaw approach would divide students into three expert groups to study about the concepts of projectile motion, the lever classes, and the moment; all of which occur simultaneously. Instead of having three sessions in a row, the whole period is condensed into one session. When each expert group completes the assigned task, three members from each of the expert groups would return to their home group so that three people who experience the different activities can assemble to share what they learn to the rest of the group. Once their sharing session ends, they are allowed to do the engineering design activity of catapult challenge. Therefore, while the essence of the linear design in terms of laying sufficient scientific foundations remains intact, time can be substantially safe in this jigsaw learning (Colosi & Zales, 1998).

Theoretical framework

While the pros and cons of the engineering design and the linear design approaches have been well informed by the literature, it is little known about the effectiveness of the jigsaw learning. Each has its own strengths and weaknesses. However, it is believed that the three approaches can promote students’ reasoning and problem-solving skills in some way. This is due to the fact that activities designed according to these STEM approaches allow students to experience hands-on learning which has been proven effective compared to traditional lectures. However, to compare their effectiveness in terms of conceptual understanding development, it is believed that both the linear design and the jigsaw learning can lead to comparable results, although in the jigsaw learning, this depends on how well students in the expert groups can communicate what they learn to the rest of the group members. Therefore, the researchers hypothesised that students participating in STEM activities designed according to the linear model can show the highest performance, followed by those in the linear design and the engineering design, respectively.

In order arrive at a conclusion, three research questions are set as follows.

1. How do students’ achievement scores and reasoning skills differ between before and after doing the developed STEM activities which are designed based on the principle of each of the proposed approaches?
2. How do students’ learning gains and reasoning skills differ among students exposed to the three different approaches for STEM activities?
3. Is there a statistical difference in students’ conceptual understanding between students exposed to the linear design and the jigsaw learning?

Methodology

Research Goals

1. To design STEM activities based on the linear model, the jigsaw learning, and the stand-alone engineering design and investigate their effectiveness on students’ reasoning and problem-solving skills compared between before and after doing the activities
2. To compare the effectiveness of the three STEM approaches for implementing STEM activities among middle school students based on reasoning and problem-solving skills

3. To compare the effectiveness of the linear model and the jigsaw learning in terms of conceptual understanding development

Sample and Data Collection

Participants in this research were 115 grade nine students in Northern Thailand. The inclusion criteria to involve them in the data collection stage were that the students had no prior experience about STEM activities and they had no formal exposure to the concept of electric circuit, motor force, and frictional force. Therefore, their conceptual and skills development could be sufficiently attributed to the proposed STEM activities using the three approaches. This recruitment process was done based on the convenience sampling method as the first author received formal permission from school leaders who acknowledged the importance of STEM education and would like to contribute to the development of STEM education in Thailand. To allow the data collection to proceed successfully, five working days during the term were required, meaning that the student participants had to devote their time to participate in the STEM activities, as well as formal teaching by school teachers had to be replaced by the process of data collection. Among middle school grades, those ninth graders appeared to be more flexible to take part in the research. Therefore, based on the accessibility, the flexibility, and the willingness from both the participants and the school, a convenience sampling method was chosen.

Quasi-experimentation

Although the school allowed the data collection to proceed as planned, it was their request that all student participants could experience in at least one STEM activity. Therefore, having a control group where students do not expose to any form of the proposed STEM activities was not appropriate. In addition, for practical reasons, the school would like the data collection to take place in one class at a time, making random assignment of participants impractical. As a result, the researchers conducted a quasi-experimental study (Campbell & Stanley, 2015) where student participants were divided into 3 groups randomly according to their actual class. Each of which was exposed to one set of STEM activities designed according to the three instructional approaches of STEM education, composing of the stand-alone engineering design activity, the linear model, and the jigsaw learning. No preference or certain criterion was made when assigning each class to one particular STEM approach. In sum, while students joining the stand-alone engineering design group started the activity straightaway, those participating in the linear model, and the jigsaw learning had previous sessions where they learned concepts foundational to the engineering design activity prior to their final exposure to the challenge activity. However, it should be noted that a lack of random assignment remains a weakness of the quasi-experimentation which may limit the ability to conclude a causal association between an intervention and an outcome to some extent (Harris et al., 2006).

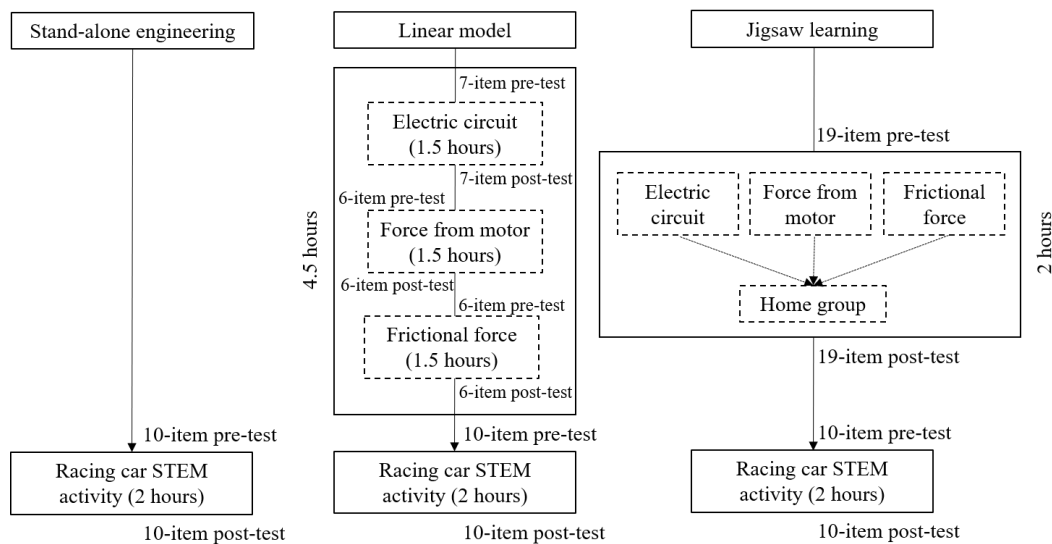


Figure 2: A diagram of the three approaches for implementing STEM activities

Engineering design activity

In this research, the developed engineering design activity is called Racing Car (see Figure 3). To participate in this stand-alone activity, the students were divided into small groups. Each group was formed by at least four members. Within 2 hours, they were supposed to use their prior scientific knowledge and skills that they learned from schools or elsewhere to construct a racing car which involves the concept of electric circuits, force from motor and frictional force. Moreover, they were expected to use design skills in electric circuit and vehicle design to make the car move safely in every condition such as slope, curves, or a rough surface. Then to complete the mission, each group tested the efficiency

of their racing car and competed with other groups. The efficiency criteria included the number of rounds that racing car can run, the maximum load it can carry, the speed it performs, and the effective use of provided materials.

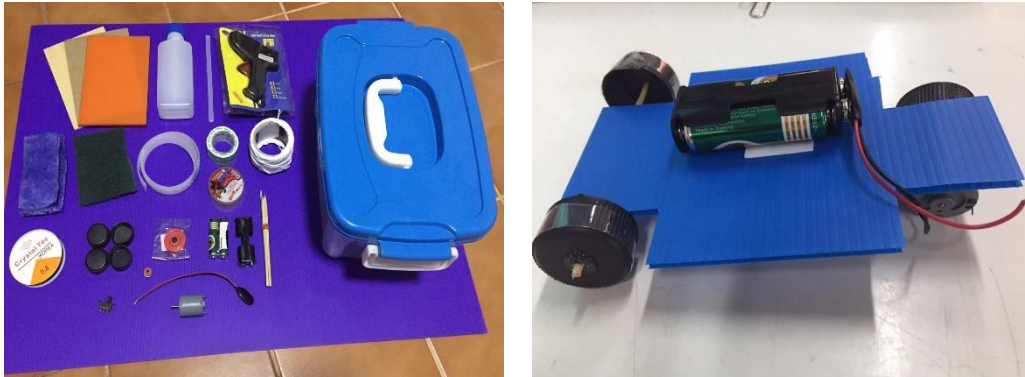


Figure 3: An engineering design activity of racing car challenge

There were 38 students participating in this engineering design activity which took 2 hours in total. They were asked to do a 10-item pre-test measuring their reasoning and problem-solving skills related to the challenge in the racing car activity. After that, they completed the whole activity, followed by a 10-item post-test.

Linear model

A linear model is an instructional approach that begins with fundamental concepts then links these to more complex ones in a linear manner in which one is required to be properly understood before proceeding to the next one. For the racing car STEM activity, electric circuit was the first unit which students needed to understand how to apply appropriate electric circuit to make a motor work. Then the students were expected to link this concept to the next unit which was force from motor. Theoretically, the students should acquire some understanding about factors that make motor produce force to let racing cars' wheels move. The last unit was about frictional force in which students experienced how different surfaces could affect the efficiency of racing cars. Once students made their racing car move using motor, they were expected to make it move with the highest efficiency by considering the surface. In addition, they were expected to understand the effects of different types of surface on the speed of racing car.

There were 38 students participating in this group. It took four sessions for them to complete the whole activity, which lasted 6.5 hours in total. The first three sessions were electric circuit, force from motor, and frictional force, respectively. Each lasted 1.5 hours. The final session was the engineering design activity of racing car which lasted 2 hours. In each session, the students were given a pre-test, followed by the assigned activity and a post-test. The three conceptual tests related to electric circuit (7 items), force from motor (6 items), and frictional force (6 items) were used. The 10-item test for reasoning and problem-solving skills in the engineering design activity was the same as those in the first STEM approach described above.

Jigsaw learning

In the jigsaw learning, the participants were divided into three expert groups, each of which was responsible for learning either electric circuit, force from motor, or frictional force, separately. However, the three activities were run simultaneously in the same class. In each expert group, sub-groups were formed with the number of group members not exceeding four. Once the expert groups finished their tasks, they were assigned to home groups with two other members who were from different expert groups. Therefore, each home group consisted of members who had learned each of the three scientific concepts where they shared what they learned to the other members (Doymus, 2008). Figure 4 shows an example of the formation of expert groups and home groups after the completion of the tasks.

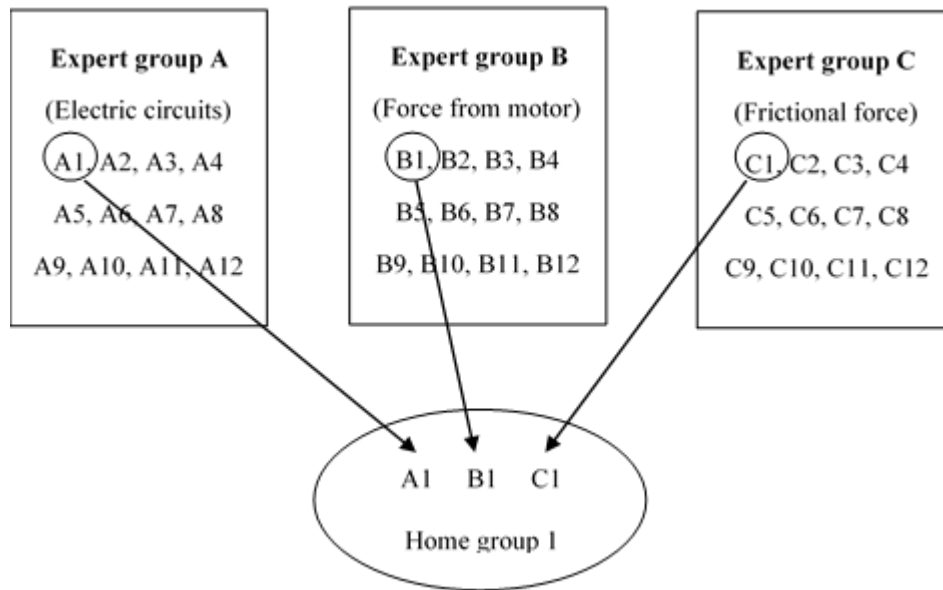


Figure 4: The formation of Expert and Home groups based on jigsaw learning

There were 39 students participating in the jigsaw learning group. First of all, they were asked to complete a conceptual pre-test consisting of 19 items (the same conceptual test used with those in the linear model group, but delivered all at once). This was followed by the three parallel sessions where each expert group learned about their assigned topic and where members of each home group shared what they learned to the others. These parallel sessions lasted 2 hours. Then the students spent additional 2 hours to participate in the engineering design activity of racing car as described above.

The measuring tools

As described above, there were two main sets of measuring tools which appeared in a 4-choice form. One was a set of conceptual tests for the small units of electric circuits, force from motor and frictional force, and the other was a reasoning and problem-solving test for the engineering design activity of racing car. The 19-item conceptual test consisted of 7 items for electric circuits, 6 items for force from motor, and 6 items for frictional force. The design of the tests concerned conceptual understanding rather than memorisation so that students can analyse provided choices composing of one correct answer and three distractors using higher ordered thinking (McCoubrie, 2004). A reliability test based on Kuder-Richardson Formula 20 (KR-20) showed a coefficient value of 0.76 which indicated an acceptable level of reliability (Tan, 2009). Also, a content validity was assessed by the index of Item-Objective Congruence (IOC) verified by five experienced science teachers who have taught middle school physics for more than ten years (Turner, 2003). Questions that were given the IOC score above 0.75 were kept in their original form. However, those questions with the score below 0.75 were subject to change. Their suggestion for improvement was incorporated in the process of revision.

In addition, the 10-item test for assessing reasoning and problem-solving skills in the engineering design activity was also evaluated its validity and reliability. Like above, items that were given the IOC score over 0.75 were unchanged, those lower than this were modified as suggested by the same group of experience science teachers. A KR-20 of this test showed an acceptable level of reliability as the index was 0.71 (Tan, 2009).

Data analysis

In-group comparison

The students' mean scores from the 10-item reasoning and problem-solving test gained in the pre-test and the post-test were compared a paired t-test (Little, 2013). This analysis was done to show how the three STEM approaches can help the students develop their reasoning and problem-solving skills which can answer the first research question.

Between-group comparison

In addition, the post-test means gained by those participating in three STEM approaches from the 10-item test were compared to determine the effectiveness of each approach against the others using the one-way analysis of variance (ANOVA). This analysis was done to respond to the second research question. Furthermore, to broaden current understanding, the comparison of students' means gained from the three small units of electric circuits, force from motor and frictional force between those in the linear model and the jigsaw learning was carried out by ANOVA to determine the effectiveness on conceptual improvement. The final part was to respond to the third research question.

Ethical Consideration

To take part in this research project, the recruitment of the participants was based fully on a voluntary basis. All research tools and essential processes of data collection were approved by The Institutional Review Board (IRB) of Institute for Population and Social Research. The student participants were fully informed about the research protocol and their participation. They were made fully aware that they could withdraw their participation at any time if they wished. Raw data including participant personal information was kept securely. It was coded and given pseudonyms to prevent direct identification. Since student participants were under 18, prior to data collection, the participants were asked to sign a written assent form, while their guardians were asked to sign a written consent form.

Results

In-group comparison

To explore students' improvement of reasoning and problem-solving skills, students were tested using the 10-item test both before and after doing the engineering design activity of racing car. A paired t-test (Table 1) showed that the post-test mean gained in each of the STEM approaches was statistically higher than the pre-test mean ($p=.000$). The students in both linear model and jigsaw learning exhibited a good mean score in the post-test which is 6.66 and 6.36 out of 10, respectively. It should be noted that those in the engineering design activity had 2.8 as their average score which is relatively lower. Although there is an apparent difference in terms of the effectiveness of the three STEM approaches, this analysis specifically pointed out that they all can promote students' reasoning and problem-solving skills.

Table 1. A paired t-test of pre-test and post-test means of the three approaches

Design	Pre-test			Post-test		Differences	Sig. (<i>p</i>)
	n	Mean	SD	Mean	SD		
Linear	38	4.84	1.81	6.66	1.47	1.82	.000*
Jigsaw	39	4.19	1.20	6.36	1.19	2.17	.000*
Engineering	38	2.00	0.80	2.80	1.28	0.80	.000*

* The mean difference is significant at the .05 level

Between-group comparison (reasoning and problem-solving test)

Since it is obvious that those participating in the engineering design activity alone had a lower mean in the pre-test, using the post-test means to compare the effectiveness of the activity might be unfair. Therefore, instead of using the post-test mean, this analysis used a learning gain (the difference between post-test and pre-test means) to compare. The result from ANOVA (Table 2) revealed that the learning gain of participants in the linear model and the jigsaw learning were not statistically different ($p=.429$). However, it showed that the learning gain of students participating in the engineering design activity alone was statistically lower compared to those in the linear model ($p=.002$) and the jigsaw learning ($p=.000$).

Table 2. Learning gains from linear model, jigsaw learning & engineering design

Design (I)	Comparison (J)	Mean Difference (I-J)	Sig. (<i>p</i>)
Linear	Jigsaw	-.351	.429
	Engineering	1.013	.002*
Jigsaw	Linear	.351	.429
	Engineering	1.364	.000*
Engineering	Linear	-1.013	.002*
	Engineering	-1.364	.000*

* The mean difference is significant at the .05 level

In sum, the results from Tables 1 and 2 concluded that although the linear model, the jigsaw learning, and the stand-alone engineering design activity can help promote students' reasoning and problem-solving skills after their participation, development of the skills of those in the linear model and the jigsaw learning was statistically greater than those in the stand-alone engineering design activity.

Between-group comparison (conceptual understanding test)

Focusing on the development of conceptual understanding, the result showed that there was a statistical difference in the post-test means between those participating in the linear model and in the jigsaw learning ($p=.000$). Those in the linear model significantly outperformed those in the jigsaw learning (Table 3). The analysis revealed that while

students participating in the jigsaw model gained a statistically higher post-test means in the topic of electric circuits ($p=.007$) and force from motor ($p=.000$), no statistical change was found in the topic of frictional force ($p=.193$).

Table 3. The comparison of post-test means between the linear model and the jigsaw learning divided by topics

	Group	N	Mean	SD	SE	Sig. (p)
Electric (7)	Linear	38	4.69	.977	.157	.007*
	Jigsaw	39	3.95	1.356	.217	
Motor (6)	Linear	38	5.44	.718	.115	.000*
	Jigsaw	39	4.46	.942	.151	
Friction (6)	Linear	38	4.67	1.177	.189	.193
	Jigsaw	39	4.33	1.060	.170	
Total (19)	Linear	38	14.85	1.647	.264	.000*
	Jigsaw	39	12.74	2.336	.374	

* The mean difference is significant at the .05 level

Learning phenomena within the jigsaw learning

An additional analysis was performed to understand learning phenomena among those participating in the jigsaw learning. The rationale for doing this analysis was to investigate possible factors that may contribute to the lower post-test means compared to those attending the linear model in the previous test. An assumption was made that the lower means may be attributed to the nature of cooperative learning where students who experienced first-hand activities share their knowledge to others who received it second-hand. However, according to Table 4 based on ANOVA, the result revealed that statistical differences in post-test means among the three expert groups did not exist, meaning that those experiencing a particular topic first-hand performed equally well compared to those received second-hand knowledge.

Table 4. A comparison of post-test means among expert groups

Topic	Comparison	Mean	SD	Sig. (p)
Electric circuit	Expert-Motor	3.62	1.325	.491
	Expert-Frictional forces	3.92	1.656	
	Expert-Motor	3.62	1.325	.260
	Expert-Electric circuit	4.31	1.032	
	Expert-Frictional forces	3.92	1.656	.107
	Expert-Electric circuit	4.31	1.032	
Force from motor	Expert-Motor	4.31	1.032	.706
	Expert-Frictional forces	4.46	1.127	
	Expert-Motor	4.31	1.032	.242
	Expert-Electric circuit	4.62	.650	
	Expert-Frictional forces	4.46	1.127	.113
	Expert-Electric circuit	4.62	.650	
Frictional force	Expert-Motor	4.38	.961	.747
	Expert-Frictional forces	4.46	1.127	
	Expert-Motor	4.38	.961	.574
	Expert-Electric circuit	4.15	1.144	
	Expert-Frictional forces	4.46	1.127	.848
	Expert-Electric circuit	4.15	1.144	

Discussion

This study proposes the different approaches for implementing STEM activities in classroom: an engineering design, a linear model and a jigsaw learning. These approaches are believed to transform the image of science education from traditional lectures to active learning where students cognitively and emotionally engage in the activity. Research has shown that students' learning behaviours have changed in the fashion that various approaches should be integrated and multidisciplinary instruction should be emphasised (Ucak, 2019). Therefore, this study suggests how to implement integrative activities where science, technology, engineering and mathematics are made interrelated. Also, it points out practical suggestions to use these approaches in various contexts.

According to the findings, it is clear that in order to develop students' conceptual understanding of scientific concepts and scientific reasoning skills based on STEM activities, using an engineering design activity alone was proven ineffective compared to the counterparts. Two statistical results verified this claim. One is the fact that those participating in the stand-alone engineering design gained a statistically lower mean in the pre-test of the 10-item test

compared to the other two groups (as shown in Table 1). In fact, the student participants involved in this study performed equally well in school as they all were classified in the same academic performance level by the school. However, the pre-test means in this study based on the reasoning and problem-solving test pointed out that their skills were underperformed. To explain this result, it may be caused by the lack of exposure to the three conceptual modules of scientific inquiry related to the engineering challenge. Although the three modules may not directly lead to the ability to perform the test, skills including reasoning and problem-solving can be enhanced through those foundational activities.

The other is the fact that although those in the stand-alone engineering design activity could gain a statistically higher post-test mean, their learning gain was significantly lower than the other two groups (according to Table 2). This raises awareness among STEM teachers that if their aim for implementing STEM education is to also build conceptual understanding as well as reasoning and problem-solving skills, in addition to engage students to learn emotionally, using the engineering design activity which stands alone might not be appropriate.

Roberts et al. (2018) claimed that participating in this form of activities, learners tend to enjoy the hands-on tasks with less cognitive engagement. It is therefore more suitable for promoting positive attitudes towards learning science, but does not effectively serve to develop problem-solving and reasoning skills, not to mention conceptual understanding. Therefore, a voice is raised here that if one aims to cultivate deeper learning among learners where scientific understanding and soft skills are sufficiently nurtured through STEM activities, it is important to take a great deal of time and a series of scientific inquiry activities that help promote different aspects of concepts which are essential for solving complex problems in engineering design activities. Of course, engineering design activities are engaging in nature (Cunningham & Lachapelle, 2016). However, if done without proper strategies, learners may end up using their intuition to solve problems in the assigned tasks, rather than relying on scientific concepts and scientific methods (Nelissen, 2013). A lack of scientific content leads students to rely on common sense when solving problems. In contrast, more sophisticated reasoning, problem-solving and creativity are expressed when students hold a good ground of scientifically accurate understanding (Pittayapiboolpong & Yasri, 2018).

Therefore, more pedagogically appropriate approaches for STEM activities among secondary school students include the linear model and the jigsaw learning. In other words, before reaching an engineering design activity, it is crucial for students to lay good scientific foundation through a series of scientific inquiry which can be done sequentially where every single learner experience first-hand knowledge (the linear model) or done simultaneously where cooperative learning takes place (the jigsaw learning). Both appeared to be able to equally promote scientific understanding as well as reasoning and problem-solving related to the engineering design activity as no statistical difference was found in the comparison of students' learning gains (according to Table 2). It is important to note that this positive result could be gained during a short period of time (4.5 hours for the linear model and 2 hours for the jigsaw learning) because the conceptual test was designed to be relevant to the activities. Understanding main parts of the activities can naturally help students respond to the conceptual test appropriately. Also, the nature of scientific inquiry allows students to construct knowledge by themselves through experimentations and discussion. Therefore, completing the provided activities would lead to effective conceptual development (Pittayapiboolpong & Yasri, 2018).

However, considering in particular which approach is more effective in promoting conceptual understanding, the result showed that those participating in the linear model outperformed those in the jigsaw learning significantly. This is due to the fact that experiencing first-hand knowledge allows learners to gain and retain information and develop profound understanding compared to those experiencing second hand knowledge (Pittayapiboolpong & Yasri, 2018). However, such profound understanding requires a great deal of time. In this study, the whole set of scientific inquiry activities lasted 4.5 hours in the linear model; whereas only 2 hours were spent in the jigsaw learning.

Therefore, which one is considered more effective depends on practical issues. More specifically, if time allows and the teacher would like to build on students' scientific understanding in a sequential manner before reaching the point where they integrate all learned concepts to solve a STEM-related problem, the linear model is highly recommended. In this approach, all students learn the same concept at a time altogether, making classroom management and material preparations more convenient for the teacher to manage. However, a major concern would be that since it takes a longer period of time until the final engineering design activity is reached, it might be boring to some students who may want to proceed with the lessons more quickly. So, once again, it all depends on the practical issues in the classroom which the teacher knows the best which approach suits his/her students.

Turning to the jigsaw learning, this instructional approach for STEM activities is time effective as it reduces a great deal of time spent for the learning of each scientific content by dividing learners into the expert groups and home groups. Therefore, if time is the issue of concern in any classrooms, the learning through the jigsaw model is highly recommended. Aside the effective allocation of time, this learning model can also promote effective cooperative learning where each student contributes a significant part in the group and each knows his/her role so that no one in the group is left alone, but all work together. The only concern would be that it is rather challenging to implement in a large classroom where one teacher is responsible for the whole class. To divide students into small groups and let them work in the expert and home groups, the teacher has to pay extra attention for the progress of the class activities

(Lynch & Pappas, 2017). On top of this, since multiple activities are run in parallel, it can be difficult for the teacher to manage all at once. Therefore, facilitators may be required for promoting effective jigsaw learning (Grasha & Yangerber-Hicks, 2000; Tran & Lewis, 2012).

Conclusion

In sum, this study compares the effectiveness of three different approaches for implementing STEM activities among secondary school students. The first approach can be done within 4-5 hours, called a stand-alone engineering design, where an engineering design process is involved in the STEM activities to let students build a product from a set of provided materials. The second approach is called a linear model in which a series of scientific investigations are carried out in a sequential manner to build on scientific understanding from fundamental to advanced ones before reaching the engineering design activities. The last approach utilises the usefulness of jigsaw learning where the same set of activities in the linear model is used in parallel so that learners have to be split into the expert groups and assembled as home groups in order for each member responsible for a particular concept to share what he/she learned. This study compared the effectiveness of the three STEM approaches using a reasoning and problem-solving test. The results showed that student participants exposed to the three STEM instructional approaches grew their reasoning and problem-solving statistically. However, the results revealed that students in both the linear model and jigsaw learning outperformed those in the stand-alone engineering design activity significantly, while both did not show statistically different results in this respect. However, in terms of the development of conceptual understanding, those participating in the linear model exhibited a statistically higher mean compared to those in the jigsaw learning. Therefore, it is recommended STEM teachers to adopt either the linear model or the jigsaw learning, or both where appropriate. To choose one over the other, it does not depend on the result, but practical issues in the classroom such as time allowed, materials to be prepared, and the number of students.

Suggestions

In terms of educational implications, it is suggested STEM teachers to layout their scientific and mathematics content to see how they can form a linear fashion of the lessons. Once the lessons are carefully aligned, the teachers can then decide whether the activities will be implemented sequentially according to the linear model or they have to be delivered through the jigsaw learning approach. Both share the same set of content backgrounds and activities. However, the linear model holds an advantage of strong conceptual development; whereas the jigsaw learning can help minimise time spent for covering the whole set of scientific inquiry activities.

In terms of research implications, this study relies heavily on physical science content related to force and motion. It is considered important to extend the current understanding to other scientific concepts in order to be certain that the recommendation made in the article is valid. Although it is convincing that both linear and jigsaw approaches are more pedagogically appropriate, more results from various aspects are of crucial to verify this current claim. In addition, this study relies exclusively on statistical data. It is important to deepen the current understanding using a qualitative perspective to explore students' as well as teachers' view on the three different approaches.

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