Original Research Article
Integrated Science, Technology, Engineering and Mathematics (STEM) education through active experience of designing technical toys in the Vietnam schools
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ABSTRACT
Aim: STEM has attracted great consideration. The purpose of research is: (i) study STEM education; (ii) explore STEM education with the creative and experiential activity; (iii) suggest applying STEM education by designing technical toys for the middle school student.

Study design: This study used a qualitative approach to carry out teaching integration for STEM education.

Place and duration of the study: The study applied to teaching the technological field in Vietnam middle schools. The design performed at the Faculty of Technology Education, Hanoi National University of Education (HNUE), Vietnam in April 2015.

Method: This study used the integrated approach to design subjects for STEM education.

Result: Two procedures for integration undertook with analysis. A sample of producing technical toy was consistent with developing students’ competencies.

Conclusion: Integrated approach to STEM education through designing technical toys is possible. By applying knowledge to the real world problems and settings, students can experience the benefits of a concrete and useful learning. The multidisciplinary and interdisciplinary integration approaches are consistent with developing students’ competencies.

Keywords: STEM, STEM education, technical toy's design, experiential activity, active learning

1. INTRODUCTION
Since the terminology developed, STEM has attracted great consideration. STEM is an acronym of Science, Technology, Engineering, and Mathematics. Studying eight journals, Brown (2012) found over 1,100 articles published from January 1st, 2007 until October 1st, 2010 related to STEM. The primary focus of the STEM education is to prepare the students’ competencies for the 21st century workforce (Obama, 2009). The workers need complex technology and engineering skills to perform in the high-tech knowledge-based economy. Since the shortage of STEM workers to create a threat to US competitiveness (William, 2011), STEM educational reform started in the US, and it soon extended to many other countries. National reports for performing STEM educational reform has published in several countries as Australia, England, Scotland, the US… (Marginson, 2013; NGA, 2007; Pitt, 2009; SEEAG, 2012). The K-12 STEM curriculum developed as integrative cross-disciplinary approaches within each of the STEM subjects. The connections of learners between their STEM educational experiences and future careers have created in many curricular (ASEE, 2011; Kim,

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2011; OCS, 2013; PLTW, 2014; Pitt, 2009; Ritz, 2011). Other opportunities for young learners to interest in STEM careers, as extra-curricular activities, contests, have organised (ASEE, 2011; Sasol Inzalo Foundation, 2012). However, the approaches to STEM are different in countries because of the political, social and technological history (William, 2011).

The effectiveness of STEM education has proved that increase participants’ skill levels and awareness of science and engineering concepts and experiential methods (Dementry & Nicoletti 1997; Anderson & Gilbride 2003; Madihally & Maase 2006). The interdisciplinary promotes the middle and early secondary school student learning and STEM activities (Barrett, 2014).

The wide range research on STEM education included methods, results, subjects, faculty working, for example, has been studying and up-to-date (Brown, 2012). Nevertheless, the caution about curriculum, clarity, vocational and general education, alignment, epistemology, and goals still need to explore (William, 2011).

In Vietnam, the authority and scholars have paid attention to STEM (MOET, 2014), but the great issue exists. Follow the curriculum, the integration applied to several subjects in the primary education, but not realised in the middle and high school. Teachers have a focus on the content knowledge than developing students’ competencies. The shortage experience in learning causes the problem for Vietnamese students. They have troubles with solving the reality, the creativeness, the flexibility, and the other technical skills as information technology (ICT), for example. Thus, the deficient preparation for students as the future workforce is clear.

Middle school is an important time for students as thinking about future careers. They might enter STEM fields if they liked. Many studies show the students’ feeling related to what they do with toys. Having studied Hong Kong students' attitudes toward technology (PATT) in the middle school, Volk (2003) found that students showed more positive attitudes when they had technical toys. Other works confirmed this result despite the differences in countries and students’ ages (Bame, 1993; Becker, 2002). Students’ learning is effective when they take part into the toy design (Sirinterlikci, 2009; Thomas, 2009). The toys can come from various types as handmade, machine-made or robotics. The students’ learning experience with such toys brings about the efficiency (Hertz, 2013; Karp, 2013).

The aim of this research is to: (i) study STEM education; (ii) explore STEM education with the creative and experiential activity; (iii) suggest STEM education with designing technical toys for the middle school student.

2. MATERIAL AND METHODS

2.1. Understanding STEM education

There are many different definitions of STEM education as different approaches as a silo, embedded and integrated one.

*The silo approach*

In the silo approach, the teacher coaches individual STEM subject separately (Gerlach, 2012). The content knowledge is important. Students are deep understanding of the course content because of concentration on the individual subject. The teacher plays an important role. He/she presents quality instructions for students. Students learn to know but not experience learning by doing (Morrison, 2006).

Having discussed the silos’ shortage. Dickstein (2010) supposes the lack of STEM contributes to the field because of the students’ passive in learning. Therefore, it is likely that student misunderstand the integration, which naturally occurs between STEM subjects in the real world (Breiner, 2012). Students
also feel little motivation because teachers rely on lecture-based method rather than a hands-on approach as they wished (Dickstein, 2010).

The embedded approach

The embedded approach highlights on the real world and problem-solving techniques within social, cultural, and contexts of domain knowledge (Chen, 2001). The instruction is effective because the students reinforce what they learned in other classes (ITEEA, 2007). Contrary to the silo approach, the embedded approach encourages the learning through various contexts (Rossouw, 2010).

However, the embedded approach has weaknesses as the missing design in evaluation and assessment (Chen, 2001), and the learning fragmentation (Hmelo & Narayanan, 1995). A learning disruption will happen if the teacher has to pause on the embedded knowledge for correcting (Novack, 2002). Students cannot associate the set-in content of the lesson and lose the whole lesson.

The integrated approach

In the integrated approach, the STEM content areas mix and learning as one subject (Breiner et al., 2012; Morrison & Bartlett, 2009). Students must use multidisciplinary STEM concepts to solve real world problems (Wang, Moore, Roehrig, & Park, 2011). These increased the interest in STEM content areas, especially at young age student (Barlex, 2009; Laboy-Rush, 2010).

According to Wang (2011), there are two kinds of integrative instructions as multidisciplinary and interdisciplinary. While the multidisciplinary develops students’ ability to link content from specific subjects, the interdisciplinary incorporates content and skills from various fields. Therefore, the interdisciplinary incorporates cross content with critical thinking, problem-solving skills, and knowledge to finish as it begins with a real world problem. Nevertheless, the multidisciplinary creates a connection with various subjects in numerous classrooms at a different time as faculties’ corroborations.

The best approach to STEM instruction is the integration in accordance with many above works. However, the integration of the STEM subjects may detract from the integrity of any individual STEM subject because of the different epistemological assumptions of the individual STEM disciplines (Williams, 2011). Besides, the lack of general structure within the lesson may limit students’ comprehension referred as potpourri effect (Jacobs, 1989). In this case, teachers fail to create one common objective despite incorporating material from each discipline.

Each approach has strengths and weakness that need consideration in completing. Teachers should evaluate the content and choose the best teaching through each approach (Roberts & Cantu, 2012).

2.2. STEM education with the creative and experiential activity

Torrance (1962) defined the creativity as the process of sensing gaps or disturbing, missing elements; forming ideas or hypotheses concerning them; testing these hypotheses; and communicating the results, possibly modifying and retesting the hypotheses. To promote creativity in science classrooms, Dass (2004) cited the strategies as visualisation, divergent thinking, open-ended questioning, consideration of alternative viewpoints, generation of unusual ideas and metaphors, novelty, solving problems and puzzles, designing devices and machines, and multiple modes of communicating results.

Studies show the creativity, problem-solve and design as essential skills in students’ STEM development (Baine, 2009; NAE, 2008). While science is a process of investigation and inquiry, engineering is a process of design that requires a blend of knowledge and creativity (Katehi, 2009). Those skills developed conveniently with the experiential activity because these create an environment of active learning for students.
Active learning is an instructional method that engages students in the learning to improve the results of the process (Bruner, 1961). Through the environment, knowledge is directly experienced, constructed, acted on, tested, or revised by the learner (Holzer, 1994) and interactions between stakeholders (for example: Teacher, students, materials...) improved. Students developed many skills by active learning as communication, higher-level thinking, collaboration, problem-solving, creativeness, for example, with a positive attitude and motivation as well. Problem-based, experiential, and inquiry-based learning are the most often cited forms of active learning. However, the formal and structured methods needed early to set up a strong basis or background within any given area for students, then the effectiveness can be strengthened by the active learning (Kirschner, Sweller, & Clark, 2006).

With the activities as extra-curricular, contests, for instance, the students’ interest and motivation in STEM careers improve (ASEE, 2011; Sasol Inzalo Foundation, 2012). In fact, the annual creative, experiential contest held by Vietnam Ministry of Education draws much attention and attendance of students, as well stakeholders (parents, teachers, companies, society, for example). Students experience activities as designing, studying and producing many materials applied to learning, working... Therefore, they find out the interest and meaning of the experiential activity and the supplementary concern in studying STEM.

2.3. STEM education with the technical toy design

Studying the TOY challenge for student teams from grades 5-8 and its application, Sirinterlikci (2009) argues the hands-on learning as means of promoting the scientific method with young learners. Students had positive attitudes toward the engineering. By doing that, students explored a set of ideas and used high-level thinking in deciding and solving problems, repeating the process of scientific inquiry used by experts in STEM fields. Having applied knowledge to the real world problems and settings, the students could experience the real useful learning (Edelson, 1998).

The findings of the study are consistent with other work about African-American 4-6th grade girl students’ attitude toward STEM by activities included toy design (Thomas, 2009). The students’ enthusiasm for learning, confidence, ability in science, and the interest in STEM careers increased.

Designing with technical toys is proper to students’ psychology and ability to help them make acquaintance with the features of the engineering design. However, the teacher should concern the students’ difference between habits of thought and action. According to the NAGB (2010), engineering design is a systematic, creative, and iterative for addressing challenges while in school, students take on to solve problems by trying the first solution that comes to mind. That suggests students need take the time to do the procedure as defining the problem, making several solutions, and testing, evaluating, revising and testing again during the engineering design.

Design and exploiting the top, Worch (2009) agued the students’ competencies in maths and physics increased. He suggested three phases as engaging, exploring and extending to utilise the top for the STEM education. The consumable materials for the top were inexpensive and easily obtainable at any discount or craft store. Thus, making a technical toy with cheap materials is possible.

2.4. Procedure for Technical Toys Design with STEM education

As the difficulty pointed out by William (2009), the school curriculum hardly changes. The integrated approach is radical in the primary school but a real problem in the secondary school. Teachers teach all subjects in the primary but separately in the secondary. At the current time, it is not practical to combine all the STEM subjects into a whole for an individual teacher in the secondary school. Therefore, teachers should find out the intersection of subjects to integrate. Teachers can choose an embedded or an integrated approach to carrying out. This work studies the integrated approach.

The procedure proposes as 5 steps for teachers as follows:
Step 1: Teachers must study subjects and contents of subjects related to STEM (Technology, Maths, Physics...).

Step 2: Teachers identify the intersection between content subjects and learning outputs (knowledge, skill and attitude for students) related to STEM and the possibility of integration. They study materials, including textbooks and others, both formal and informal, for example: From the Internet to concrete an intersection subject for integration.

Step 3: Teachers decide types of technical toys for applying the most knowledge from subjects. Questions should rise as finding the linking between content knowledge and technical toys, proving the connection.

Step 4: Teachers design technical toys and evaluate the possible application of the toys for STEM education. After testing and judging, teachers change or redesign those toys to increase benefits for STEM education.

Step 5: Teachers organise classroom to suggest students making technical toys. This is a form of the creative and experiential activity. Many teaching methods can apply as problem-based, project-based, inquiry-based...

The procedure for teachers suggests briefly as Figure 1 bellows:

**Figure 1. Procedure for technical toy’s design for teachers**

- Study subjects and contents related to STEM (e.g.: Technology, Math, Physics...)
- Identify the intersection of content subjects with learning outputs (e.g.: knowledge, skill, attitude for students) related to STEM and the possibility of integration
- Determine types of technical toys
- Design, test and modify
- Instruct students to make technical toys

**The needs for technical toy design**

To optimise technical toys, the design must meet the following needs:

- Multi-functions and multi-choices: The multi-functions of the technical toy are a possibility to work several demands. The multi-choices are a flexibility in designing, producing, for example, as a detail depicted in several ways; a product built with different procedures.
- Integration: technical toys related to various subjects, but it presented as a whole. The content knowledge of technical toys associated with subjects as science, maths, technology...

With features, teachers analyse the scientific basis of design and the applicable possibility.

A technical toy must satisfy other specifications as follows:

- Educational features: Matching curriculum and being consistent with students’ ability
• Economical features: Being produced from common materials which are simple, easy to find and being made with simple tools
• Technical features: Meeting essential strength and exact
• Safe features: Conforming to students psychology and health

In the classroom, teachers guide students to the procedure as follows:

**Figure 2. Procedure for technical toy’s design for students**

1. Understand the requirements of technical toys
2. Discuss to find out solution and make a design with graphics
3. Determine materials to make technical toys
4. Create, test and modify
5. Disclose products

Step 1: Students must understand the needs of the technical toys they will make (for example: Tasks, features, styles...). They watch the samples made by the teacher as a suggestion.

Step 1: Students discuss in a group to find out the solution: what they like best and what the best. They make a model design with graphics. To have a good design, students do the active as applying learned knowledge, imagining themselves or searching suggested information from other as textbooks, the Internet, or recommendations of the teacher.

Step 3: Students settle materials to make technical toys. They choose suitable materials for the technical toys and tools to produce.

Step 4: Students create technical toys with the design and materials. They test and modify the product to meet the requirements with the teacher’s suggestion. In this phase, students do as hands-on, practising and performing. They can apply the knowledge learned from the previous lessons and their lives. The teacher should encourage students to experience with their ideas which make them excited.

Step 5: Students disclose products in class. They may feel proud of their products, interest in STEM education despite advice or crises.

**3. RESULTS AND DISCUSSION**

Based on the procedure of technical toy’s design, the authors offer the experiential activity for the 8th grade student in designing a mini-racing car.

According to the Vietnamese curriculum, the needs for students at 8th grade integrate in activities of designing a mini-racing car as in the Table 1.
Table 1. Competencies in designing a technical toy “a mini-racing car”

<table>
<thead>
<tr>
<th>Competencies</th>
<th>Technology 8</th>
<th>Maths 8</th>
<th>Physics 8</th>
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<tbody>
<tr>
<td>- Competencies in design:</td>
<td>applying the engineering draw to design car style</td>
<td>- Competencies in algebra: measuring the long wheelbase, calculating the transmission ratio, the length between details</td>
<td>- Competencies in mechanics: understanding the kinds of motion, friction; analysing and evaluating the factors affected by the speed of the car, e.g.: Friction, weight of the car</td>
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<tr>
<td>- Competencies in technical activities: using simple tools as pliers, hammer, scissors...; understanding the engineering details and assembly...; applying the transmission knowledge to choose the transmission drives as a belt drive, gear drive...; applying the wire connector to turn on/off and operating the motor in proper turn</td>
<td>- Competencies in geometry: analysing and cutting the polygons with simple tools, e.g. Compass, calculating area and evaluating properly for the components</td>
<td>- Competencies in electrics: understanding the transmission energy from the electrical energy to the mechanical energy, evaluating the engineering power</td>
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The teacher introduces the sample of mini-racing car with the task of running on the straight way and going over the ramp with minimum passing time.

The minimum requirement for construction is attaching the car to the essential model (The car has a backbone chassis, actuator). Students can change or attach the extra details to optimise tasks. They operate individual and group.

Materials are supplied to each group, including 01 plywood, wheels, spindles, mini motor, bevel wheels, belt, battery, switch, screws...; tools include a small saw, scissors, pliers, screwdriver, glue...

The multidisciplinary and interdisciplinary integration approaches can be determined as follows:

Table 2. The integrated approach to design a technical toy “a mini-racing car”

<table>
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<tr>
<th>Competencies from subjects</th>
<th>Figure</th>
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<tr>
<td>Applying knowledge of the technical draw and the technological subjects to design backbone chassis, including size, styles.</td>
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Applying knowledge of the geometry from the maths subjects to cut polygon and calculate the area of chassis. Students use the simple tools as compass... and evaluate properly parts.

Applying knowledge of turning from the technological subjects to produce the detail. Students learn using tools and revise understanding from the previous lessons to complete in practice.

Applying understanding of the machine details and attachment from technological subjects to link parts. By revising and understanding learning information, students carry out experientially.
Applying knowledge of transmission and transformation, the motion of the technological subjects to choose transmission instance, for example: Using a belt transmission.

Applying knowledge of the technological subjects to calculate speed and evaluate instances to speed up. Students also calculate the power and the force from several physics lessons. They estimate reasons affected by the speed of the car.

While students do the project, the teacher plays a role as an instructor. He or she need covering the groups in class, suggest or questions to promote critical thinking and doing. Students should be encouraged to exchange ideas and improve the sample design. The teacher can use various tactics to have the best achievements (Dass, 2004; Nam, 2014a, 2014b). The concern is that students constrained a strong basis or background within any given area for the experiential to strengthen the learning effectiveness (Kirschner, Sweller, & Clark, 2006).

With the framework, the integrated approach can be undertaken for other technical toys, for example: rowing robot, mini-fan, lift, for example. With such toy, students can work out several possible solutions, for example: Power for the car from battery or the wind... The materials for such toys are from second-hand or low cost, obtainable and familiar as another study of hands-on product (Hertz, 2013). They must be safe for the students’ health. Exploiting the technical toys in the proper context could develop the STEM skills as the proof of other works (Worch, 2009; Hertz, 2013; Karp, 2013).

4. CONCLUSION

In conclusion, the integrated approach for STEM education with technical toy design is possible because applying knowledge to the real world problems and settings, students can experience the benefits of a concrete and useful learning. Students are not only glued to the static knowledge in school, but dynamic understanding. The multidisciplinary and interdisciplinary integration approaches with subjects are consistent with the development of students’ competencies that the Vietnam Ministry of Education is carrying. However, the achievement will be better if the curriculum changes to promote a strong integration subjects as a whole, and that need study.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS’ CONTRIBUTIONS
Le Xuan Quang contributed to the design of the research project, and drafted the manuscript. Nguyen Thi Tu Anh, Vu Thi Hong Nhung designed and made technical toys; Le Huy Hoang and Vu Dinh Chuan contributed to the content of the draft manuscript. Nguyen Hoai Nam contributed to the framing and final writing of the article. All authors read and approved the final manuscript.

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