Teacher Reflection on Practice: Teaching Engineering Design Modules in High Schools of Taiwan

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BACKGROUND

During the 2012-2013 school year, the researchers worked with two high school technology teachers to develop and implement two different engineering design modules, which included STEM engineering module and mechanical history module. In the pilot study, it showed that the two modules could aid students in increasing conceptual and procedural knowledge effectively. However, it is more important to know the reflection from teachers who participated in developing and teaching these engineering design curricula. Thus, it will help other technology teacher better understanding of how engineering design can be taught in Taiwan.

PURPOSE

This study sought to examine the implementation of engineering design modules by two high school technology teachers in Taiwan. The researchers focused on understanding the teachers' reflection in curriculum development and instruction progress, and also to find out the potential problems in implementing engineering education in Taiwan's high schools.

DESIGN/METHOD

This study employed a semi-structured interview method to obtain the opinions from the two participant teachers. The content of interview outline included: (1) the primary problems in developing and teaching engineering design module, (2) the key factors that affect students' learning, and (3) the feasible instructional strategies to improve the teaching of engineering design. A grounded theory study approach was adopted for exploring and understanding the interview data.

RESULTS

Both teachers indicated that the primary problems in developing and preparing engineering design modules were: (1) the selection of engineering knowledge content, (2) the integration of science and mathematics knowledge, and (3) the limitation of external conditions in classroom.

Second, the teachers pointed out the key factors that affected students' learning performance were: (1) observation ability, (2) predictive analysis ability, (3) spatial ability, (3) hands-on skills, (4) prior knowledge, (5) problem-solving experience, (6) metacognition, (7) attitude, and (8) subject learning aptitude.

As the feasible instructional strategies in the future, both teachers agree that the history of technology can promote students' learning motivation, interest, and provide diversified concepts of technology development which can be transformed into design ideas. On the other hand, the STEM engineering curriculum can aid student in organizing interdisciplinary conceptual knowledge between science, technology, engineering, and mathematics. This will help students focusing on the connecting between knowledge and practical application of problem-solving process.

CONCLUSIONS

Both the participant teachers agree that engineering design curriculum can help Taiwanese students connecting of conceptual knowledge and problem solving. However, there are still many problems need to be solved in practice. In addition, several factors that affect students' learning during engineering design also need to be in-depth studied to examine the interaction and relation among these factors. Teachers, school administrators, and teacher educators all need to invest more time and efforts in designing engineering curriculum to ameliorate engineering instructional modules and curriculum in Taiwan.

KEYWORDS

Engineering design, STEM curriculum.

INTRODUCTION

In the last two decades, engineering design becomes an important instructional approach in K-12 engineering and technology education (Carr, Bennett, Strobel, 2012; NGSS Lead States, 2013). There has been a shift in attention from a focus on technology literacy to an emphasis of reinforcing it with integrative science and mathematics concepts through engineering-oriented activities (Dearing & Daugherty, 2004; Kelley & Kellam, 2009). Many engineering design curricula had been developed by science and technology education professionals (Bayer Corporation, 2010; Brophy, Klein, Portsmore, & Rogers, 2008; Engelbrecht, Bergsten, & KÅgesten, 2012; PLTW, 2014). Most of these engineering design curriculum aim to help students to emphasize conceptual and procedural knowledge, as well as to develop capabilities in solving complex problems in real-world situation.

In technology education, the development of engineering design curriculum module often emphasizes in curriculum design approach, instructional practices/strategies, and curriculum contents. Most engineering design curriculum modules are designed as project-based learning activities and take engineering design process as implementing steps. These engineering design steps can be generally identified as following process: (1) define and delimit the engineering problems, constraints, and limitations; (2) plan and carry out investigations and data collection; (3) Use information to design possible solutions; (4) Use mathematics and computational thinking to analyze and predict the potential solutions; (5) create the prototype; (6) test and modify the prototype systematically; (7) evaluate the results; (8) Optimize and redesign the solutions (NGSS Lead States, 2013; National Research Council [NRC], 2009). During the design process, the engineering design curricula focus on integrating and applying scientific knowledge, technological knowledge, and mathematical principles to solve ill-structured problems. Generally speaking, an effective engineering design curriculum module should be constructed through an open-ending, meaningful context which can provide highly iterative problem-solving process for applying scientific, mathematical, and technological concepts (NGSS Lead States, 2013; NRC, 2009). Therefore, how to design and present an appropriate project context is a key task in developing engineering design curriculum.

Many researches have confirmed that using engineering design approach could improve students' learning in knowledge and high-order thinking, especially in increasing the application of science and mathematics conceptual knowledge (Brophy et al., 2008; Hernandez et al., 2013; Merrill, Custer, Daugherty, Westrick, & Zeng, 2008). For example, Project Lead the Way (PLTW), one of the best known middle and high school engineering programs in USA, was designed to prepare students in pre-engineering learning through project- and problem-based learning, and has been proven of its benefit in learning science and mathematics (Brophy et al., 2008). Merrill et al. (2008) developed four instruction units to aid students gaining core engineering concepts. They found that most students could have positive learning effectiveness from the units. However, to better integrate engineering concepts within technology education, teachers need to focus on having students apply mathematical and scientific knowledge when working on the engineering design. Steif, Lobue, Kara and Fay (2010) also designed a questioning strategy that could effectively help student focusing their attention on the core conceptual knowledge of statics question and thinking about the bodies present in the problems. Meanwhile, Hernandez et al. (2013) designed an interdisciplinary team-based approach to implement designed engineering design project. Their result showed that a successful engineering design practice depends upon well-designed instructional strategies as well as effective teaching and learning practices. More specifically, some instructional practices which focus on the application of scientific and mathematics knowledge are required. As McCormick (2004) noted that the instruction of engineering design curriculum may fail if teachers only go through the design process without well explain the application of science and mathematics knowledge.

Teachers need to pay a lot of efforts to help students connecting the theoretical knowledge and practical problem-solving. The design of instructional practices also become a key task.

Many researches have showed that many teachers still faced difficulties to aid their students understanding how to integrate and apply interdisciplinary knowledge during their engineering design process (Brophy, et al., 2008; Crismond & Adams, 2012; Kelley, Brenner, & Pieper, 2010; Sanders, 2009; Taraban et al., 2007). Without appropriate teaching and guiding, students usually use trial-and-error aimlessly in their engineering design project, which cause the overall design process contributing nothing to students' learning and problem-solving ability. For example, Taraban et al. (2007) noted that many novice engineering students lack of the experiences, knowledge, and metacognitive to apply conceptual knowledge and high-order thinking. They are not yet cognitively prepared to find connections among the problem, the information, and related subject knowledge, therefore, only very limited knowledge was used to solve problems during their design process. Kelley et al. (2010) found that when high school students participated in pre-engineering programs, very little mathematics was employed to describe and analyze the problem, or used to predict the potential of possible solutions. Meanwhile, Crismond and Adams (2012) found out that many ineffective designs were highly related to designers' problem prediction and problem analysis abilities; most of them happened due to lack of appropriate integrative knowledge and high-order thinking skills. Therefore, to promote teaching and learning of engineering design, teacher should notice behaviors of students and find out the key factors that affect students' learning performance. Teachers need to select realistic learning practices and strategies that aim to improve particular inefficient design behaviors, create viable formative assessments to assess students' growing, thus guide students to gain meaningful learning experiences (Crismond & Adams, 2012).

In Taiwan, engineering design is gradually becoming an important approach to implement integrative STEM curriculum in high school technology education. However, many technology teachers still lack of confidence to teach their students how to apply interdisciplinary knowledge during their engineering design process. Therefore, during the 2012-2013 school year, the researchers worked with two high school technology teachers to develop and implement two engineering design modules in Taiwan. In the pilot study, it showed that the modules could aid students in increasing conceptual and procedural knowledge effectively. However, it is more important to know the reflection from the teachers who participated in developing and teaching these integrative STEM curricula. Thus, it will help other technology teacher better understanding of how engineering design can be taught.

PURPOSE

The purpose of this study was to gain understanding about the teachers' reflections and opinions of curriculum development and instruction progress, thus to find out the potential problems in implementing engineering education in Taiwan high schools. The specific research objectives to be addressed in this study are as follows:

1. Investigate the primary problems in developing and teaching engineering design module in Taiwan high schools.
2. Identify the key factors that affect on students' learning in integrative STEM curricula.
3. Propose the feasible instructional strategies to improve the teaching of engineering design module in Taiwan high schools.

METHODOLOGY

This study employed a semi-structured interview to obtain the reflections and opinions from the participants. The interview was directed by an interview outline which developed from literature review and aligned the research objectives. The content of interview outline included: (1) the primary problems in developing and teaching engineering design module,

(2) the key factors that affect students' learning performance, and (3) the feasible instructional strategies to improve the teaching of engineering design. A grounded theory study approach was adopted for exploring and understanding the interview data.

Participants

The participants of this study were two technology teachers teaching in different high schools in Taiwan. Both the participant teachers had a master degree and were certified to teach technology education at the secondary level. Meanwhile, they all had more than ten years teaching experience in technology education and participated in professional development studies regularly. Both teachers worked with the researchers throughout the curricula development process. During the teaching experiments, the STEM engineering module were taught to 171 tenth-grade students by one teacher and the mechanical history module were taught to 155 eleventh-grade students by the other teacher. Both teachers gained extensive teaching experiences and had in-depth understanding of students' learning situations.

Instructional Modules

Two engineering design modules were developed by the participant teachers and the researchers during the 2012-2013 school year. These two modules were: "STEM engineering module" and "mechanical history module". In both modules, teacher would teach instructional units aligned with specific engineering knowledge contents regarding mechanism. Then students were asked to complete a mechanism toy design project with a multifunctional mechanical structure via LEGO parts and other materials provided in the classrooms. The mechanism toy design project would follow the engineering design process which guided from the design portfolio.

The STEM engineering module aimed to help students to apply science principle and mathematics knowledge in analyzing, predicting, and solving complex problems during their design process. This module used virtual simulation and computer aid design to aid students learning the connections among science, technology, engineering, and mathematics contents. Meanwhile, these modules also applied many physical practices to increase students' hands-on skills and troubleshooting experiences through the design process.

The mechanical history module was designed to help students to realize the principle and application of different mechanisms via the history of technological products (from the original simple idea to complex design and products). From the historical point of view, students can learn the relationship between engineering design and societal development, thus developing better knowledge connection among engineering concepts and their daily life experiences.

Data Analysis

The participant teachers were interviewed individually by the researcher with about 90 minutes. The interview data were recorded and translated into interview transcripts. The data were coded and analyzed via grounded theory. The analysis was made to summarize, categorize, and analyze the teachers' reflections, opinions, and suggestions to identify some general trends and significant patterns. In keeping with the trustworthiness of a qualitative research, this study employed triangulation of multiple analysis methods, data sources, and viewpoints during data analysis process.

Limitations of the study

Although this study yielded findings that have pedagogical implications in the area of technology education, its design did have some flaws. The first limitation concerns the research design. This study was an extensional study from two experimental studies, which focused on understanding the participant teachers' opinions of implementing engineering design modules. Although both of the teachers could provide meaningful reflections, the small samples still limit the generalizability of our results. Second, some findings which came from teachers' observations lacked of the corroboration of quantitative data in the present studies. Thus, these findings can become the basis of future researches, but require more precise experimental studies.

FINDINGS AND DISCUSSIONS

The primary problems in developing and teaching engineering design module in Taiwan.

From the responses of teachers, the primary problems in developing and preparing engineering design modules include: (1) the selection of engineering knowledge content, (2) the integration of science and mathematics knowledge, and (3) the limitation of external conditions in classroom. First of all, the teachers indicated that some of the engineering contents taught in the instructional units were not adopted by most students in their design projects. For example, most students tended to adopt little specific mechanism (e.g. planar linkage, crank shaft, cam mechanism, and gear set) which could be assembled easily in their projects, but seldom designed their projects with complex mechanism. As a result, teachers were facing the dilemma of whether to teach a complete set of curricular or only teach fragmented knowledge which might be frequently used in student's design.

Second, how to integrate science and mathematics knowledge into engineering curriculum is also a difficult task, especially in mathematics. Kelley et al. (2010) indicated that students seldom used mathematics to solve engineering problem, even they have learned a lots of mathematics in schools. In this study, both teachers also found similar situation. Although mathematics and science were taught at middle school level (e.g. basic measurement and computation, force and torque, speed and gear ratio, and etc.), most students still could not find the connections between science and mathematics concept and the engineering problems. As Taraban et al. (2007) noted, most of our students were not yet cognitively prepared for solving problems in their design process. In this study, it was found that some engineering mathematics concepts are too difficult for students. Thus, it is hard to match up the current high school mathematics curriculum and integrate them into engineering curriculum.

Third, the teachers also highlighted that some external conditions which may restrict teachers from implementing engineering curriculum. These restricted conditions include: (1) lack of instruction times, (2) heavy workload of teaching job, (3) lack of appropriate tools and equipment, and (4) insufficient material resources. Because most high schools only allocate 36 hours to implement technology course in Taiwan, the time limitation made it difficult to design a project-based engineering design curriculum. In addition, a large classroom size also results in a heavy workload and difficulties to teach engineering design curriculum. Other difficulties include the shortage of tools, equipment, and material resources.

The key factors that affect students' learning performance.

The teachers pointed out the key factors that affected students' learning performance include: (1) observation ability, (2) predictive analysis ability, (3) spatial ability, (3) hands-on skills, (4) prior knowledge, (5) problem-solving experience, (6) metacognition, (7) attitude, and (8) subject learning aptitude. During the instruction period, both teachers found that the observation ability and the spatial ability might be two major factors that affect students' comprehension on the connections between mechanism and science and mathematics knowledge. As Clark and Ernst (2008) pointed out that the virtual modeling and physical hands-on activity could effectively help students' learning. In this study, both teachers found that computer simulation and practical examples would help students to better observe the motion of different mechanisms. This would also assist students to solve problems even without sufficient prior knowledge and engineering problem-solving experiences.

During the project design process, the predictive analysis ability to analyze the feasibility of different solutions was a key factor that affected students' problem solving performance. Both teachers found that the predictive analysis ability was also highly related to students' observation ability and their spatial ability. The spatial ability would affect students' performance in making computer 3D graphics as well as in building their physical mechanism toy. Meanwhile, the observation ability would affect students' performance of problem finding and troubleshooting during the design process. Therefore, if students had a predictive analysis ability, they could shorten the production time from the beginning of idea generation to the completing the final product. Simply to say, students could better predict the feasibility before building the prototype, and could more effectively analyze and find out the problems during the testing and revising period. Furthermore, both teachers indicated that the metacognition, the comprehensive performance of conceptual and procedural knowledge and high-order think abilities might be a key factor that affect students' engineering design performance. The finding was similar to the researches of Taraban et al. (2007) and Steif et al. (2010). Therefore, to further understanding students' learning in engineering design curriculum, more researches regarding the metacognition in engineering design are required.

In addition, the learning aptitude toward subjects becomes clear in individual students at high school level. For non-science aptitude students, their learning motivation in engineering design activities and self-efficacy are relatively lower than those with science aptitude. While some of them showed less interested in science and mathematics regarding engineering design. It becomes a major challenge for teachers to strengthen those students' motivation and help them developing meaningful learning experience. As Tawfik, Trueman and Lorz (2014) noted that the negative attitudes (e.g. lack of confidence and interesting) in these non-science aptitude students was the most critical problem that hindered their success in STEM course. Therefore, the STEM course needs to be designed with meaningful social context to better engaging non-scientists students in connecting integrative STEM curriculum with real-world problems.

The feasible instructional strategies to improve the teaching of engineering design module.

Currently, most high school students in Taiwan still lack of sufficient prior knowledge, technological hands-on skills and problem-solving experiences in engineering design activities. Therefore, more targeted teaching strategies regarding the application of scientific and mathematics knowledge are essential. Practices to enhance the proficiency of materials selection and tool skills are also required. As Merrill et al. (2008) indicated that to improve the teaching of engineering design, the development of sound curriculum, activities, and assessments that target engineering design concepts are needed. Both teachers agreed that these two modules are useful for teachers as a reference to develop and implement engineering design curriculum. However, as Crismond and Adams (2012) highlighted, to further improve engineering design curriculum, strategies that focusing on students' design behavior and intuitive learning experience are critical when to establish appropriate knowledge and foster problem-solving ability.

In the mechanical history module, we found that it can be used to promote students' learning motivation, and to provide diversified concepts that can be transformed into design ideas. However, when using the technology history materials, teacher should pay more attention on explaining the connections between history product and modern technology product. More physical models and hands-on practices which present the concepts of history products are needed. Thus, it would help student better understanding the relationship among the engineering contents and their daily experiences.

On the other hand, the STEM engineering module can aid student in organizing interdisciplinary conceptual knowledge between science, technology, engineering, and mathematics. It can help students to focus on the connecting between knowledge and practical application of problem-solving. In this study, the virtual modeling and physical hands-on activity are effective teaching strategies for those students who lack of prior knowledge and experience. A virtual modeling can be used to explain the science and mathematics conceptual knowledge regarding engineering contents. Furthermore, when building the physical models through hands-on practices, teacher can design experimental challenges to guide students in exploring and solving different design problems through related subject knowledge. In brief, the design of instruction unit should be targeted on specific science and mathematics knowledge. Also, the instruction should connect to the engineering process through following steps: (1) introducing the engineering topic, (2) imitating virtual and physical models, (3) explaining related science and mathematics knowledge, (4) solving assigned problem-solving tasks, (5) testing and experimenting, (6) revising solution. Following the above steps, students can be guided to learn how to complete a project design.

CONCLUSIONS

Engineering design curriculum could help students strengthen the connecting of conceptual knowledge and problem solving ability. The participant teachers believed that engineering design should be an important approach in Taiwan high school technology education. However, several factors that affect students' learning during their design (e.g. observation ability, predictive analysis ability, spatial ability, and metacognition) also need to be in-depth studied to examine the interaction and relation among these factors. Teachers, school administrators, and teacher educators all need to invest more time and efforts in designing engineering curriculum to ameliorate engineering instructional modules and curriculum in Taiwan.

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