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Enhancing STEM Knowledge and Skills by Making Electronic Sound Synthesizer based on TPACK Model

Chih-Chien Hu[abc], Hui-Chin Yeh[ac] & Nian-Shing Chen [ac*]

[a]*Research Center for Smart Learning, National Yunlin University of Science and Technology, Taiwan R.O.C.*

[b]*Bachelor Program in Interdisciplinary Studies, College of Future, National Yunlin University of Science and Technology, Taiwan, R.O.C.*

[c]*Department of Applied Foreign Languages, National Yunlin University of Science and Technology, Taiwan R.O.C.*

hucc@yuntech.edu.tw, hyeh@gemail.yuntech.edu.tw, *nianshing@gmail.com

Abstract: STEM education has received increasing attention in recent years. Thus, this study proposes a knowledge and skill enhancement framework by integrating TPACK for enhancing learners' STEM knowledge and skills. The main idea of the proposed approach was to conduct a workshop for learners to make an electronic sound synthesizer. Related data were collected along the whole process, the results revealed that the proposed approach significantly helps learners improve their learning performance and fosters their positive attitudes toward STEM.

Keywords: STEM knowledge, STEM skill, hands-on activity, learning attitude, TPACK

1. Introduction

In the science and technology-rich society, it is important to develop student awareness about the connections of science, technology, engineering, and mathematics (STEM) and to leverage the connections in ways that improve learning (Honey, Pearson, & Schweingruber, 2014). Integrated STEM education is a new way to make learning more connected and relevant for students (Falloon, 2019) and emphasize learning activities that focuses on hands-on inquiry (Kalaani, Haddad, & Guha, 2015; Wahono, & Chang, 2019). Several studies argue that STEM learning should be more connected to the context of real-world problems, so that the designed STEM activities would be more relevant to leaners (Kelley, & Knowles, 2016; Honey, Pearson, & Schweingruber, 2014). As shown in Figure 1, the key components of STEM learning include STEM knowledge and STEM skills (Benek & Akcay, 2019).

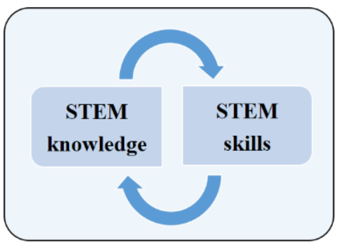

Figure 1. STEM learning.

Several studies have explored the effect of how to help students understand the theory and concept of hands-on projects, and equip them with the necessary technical skills (Lo, Lau, Chan, & Ngai, 2017). The findings showed that there are no significant differences exist between their varied backgrounds, and they also showed the multidisciplinary hands-on projects benefit these students. Some hands-on activities are intended for learners to solve some real-world problems. Thus, they were designed to integrate both STEM training activity and hands-on activity as an effective way to provide learners the opportunity to apply their theoretical knowledge to solve the real-world problems (Kalaani, Haddad, & Guha, 2015; Lo, Lau, Chan, & Ngai, 2017). Technological pedagogical and content knowledge (TPACK) is critical to effective teaching with technology (Koehler, & Mishra, 2009). Therefore, TPACK cannot assist teachers to follow an instructional design framework for improving learners' STEM knowledge and skills.

The goal of this study is to investigate how the proposed knowledge and skills enhancement framework can affect student learning in a STEM workshop. The proposed framework includes TPACK; and the designed activities also include training activity, hands-on activity, and creative activity. Two research questions are then formulated:

RQ1: What is the effect of the proposed knowledge and skills enhancement framework on learners' learning outcomes?

RQ2: What are learners' attitudes toward using the proposed knowledge and skills enhancement framework for cultivating STEM learning outcomes?

2. Related Works

STEM education evolves into an interdisciplinary, which is often used to indicate the integration among science, technology, engineering, mathematic and real-world applications in teaching and learning process (Kelley, & Knowles, 2016). Some pedagogical knowledge practice frameworks were used to explain links to learning outcomes in STEM education (Hudson, English, Dawes, King, & Baker, 2015; Kelley, & Knowles, 2016; Christ, Arya, & Liu, 2019). Technological pedagogical and content knowledge (TPACK) combines content knowledge, pedagogical knowledge, and technological knowledge that interactively synthesizes knowledge among technology, pedagogic, and content (Mishra, & Koehler, 2006). The TPACK frameworks (Mishra, & Koehler, 2006; Akyuz, 2018; Christ, Arya, & Liu, 2019) were designed to evaluate how much the teacher's capability to use integrated technology in teaching; it can only be used as input for the development of the teacher's capability to use technology. Their frameworks cannot assist teachers to identify an instructional design framework for improving learners' STEM learning outcomes and fostering their STEM attitudes.

Recently, some training activities and hands-on activities have been developed to allow learners to build and exercise STEM projects (Hudson, English, Dawes, King, & Baker, 2015; Lau, Lo, Chan, & Ngai, 2016; Lo, Lau, Chan, & Ngai, 2017). However, learners may not always inquire or start with lower order knowledge for each STEM topic (Hu, & Li, 2017). Moreover, there was not designed to apply specifically to enhancing STEM knowledge and skills of learners, so it did not provide a ready-made categorization of instructional design for learners.

Therefore, it is important to follow an instructional design framework based on TPACK model to facilitate the learning context from specific content and various STEM topics through technology and pedagogy approach.

3. Knowledge and Skill Enhancement Framework

3.1 The proposed knowledge and skills enhancement framework

Here we introduce how to establish a framework (Fig. 2), knowledge and skills enhancement framework, to enhance learners' STEM knowledge and skill by integrating varied state-of-the-art tactics to cultivate learners' STEM learning. Particularly, facilitating training activities and hands-on activities in the STEM workshop by the framework is proposed.

The proposed framework contains three dimensions, which are (i) content knowledge (CK), (ii) technological knowledge (TK), and (iii) pedagogical knowledge (PK). CK is the subject matter such as the contents of science, technology, engineering, mathematics and so on. In this study we introduced the concept and theatrical knowledge of electrical components and electronic sound synthesizer to learners. TK is the studies about how to operate devices and relevant systems, or how to construct an electronic object by using particular knowledge. Teachers transferred their knowledge and experiences of using information technology to students throughout the workshop. Technological content knowledge (TCK) is knowledge studied about how the CK (i.e., training content) can be examined or interacted with TK. For instance, using hands-on activity enhances learners' skills and engagements in learning environment. PK is the ability in teaching and learning management. To help manage learners' progress of content knowledge, the teacher established training activities for enhancing the students to deepen their STEM knowledge at the beginning of the workshop. The teacher also provided guidelines of hand-on activities, depicted some examples to hint learners. In this stage, the most important issues are how to represent and formulate STEM content and how technology can facilitate pedagogical approaches that make knowledge understandable by learners. Pedagogical content knowledge (PCK) and technological pedagogical knowledge (TPK) are interacted as technological pedagogical and content knowledge (TPACK). A knowledge management platform (http://km.mis.nsysu.edu.tw/) was adopted the exchange of knowledge and information between teacher and learner for tracking and archiving the learning progress.

TPACK in the proposed knowledge and skills enhancement framework can be used to support and assist learners in identifying what they need to know about the use of STEM in learning, help learners develop varied learning methods, improve knowledge and skill learning, and make learning environment more interesting (Mishra, & Koehler, 2006). Using the proposed framework, learners can effectively organize objectives and create learning plans with appropriate content and instruction to lead learners up the pyramid of learning.

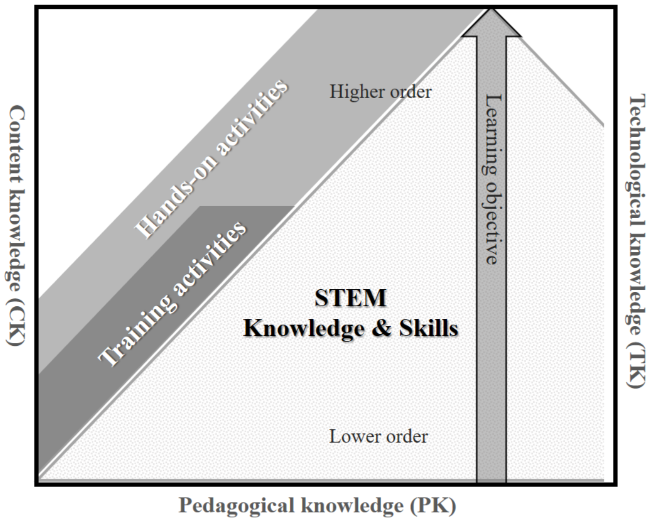

Figure 2. Knowledge and skills enhancement framework.

3.2 The design learning activity based on knowledge and skills enhancement framework

The instructional design based on knowledge and skills enhancement framework is consisted of three components: the training activity, the hands-on activity, and the creative activity, as shown in Figure 3. In this study, the procedure of applying the knowledge and skills enhancement framework was sequentially deploying the learning activities of training activity, hands-on activity, and creative activity.

Training activity: The training activities are categorized as lecturing instructions, slides, video lectures, and so on. Learners can learn the foundational theories and concepts in the activities.

Hands-on activity: To facilitate hands-on activities for completing hands-on tasks; it is more practical to adopt prior knowledge learned in training activities. Using hands-on activity enhances learners' skills and engagements in learning environment.

Creative activity: It's important that how technology can facilitate pedagogical approaches that makes it understood by learners. Learners can comprehend the knowledge about how to facilitate learning from the content through pedagogical and technological approaches by the creative activities. The objective of creative activity is to stimulate learners to develop their skills of self-learning and critical-think, and raise learners' knowledge level higher.

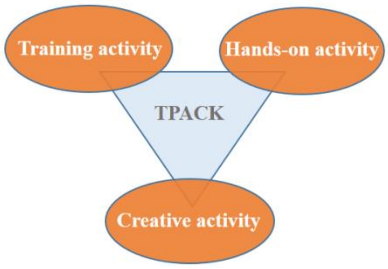

Figure 3. Instructional designs of the integrated knowledge and skills learning framework.

4. Method

4.1 Participants

To accomplish this research we examined student projects in a workshop. The present study involved 22 students. The participants interactively learned the concepts and theory of the electronic sound synthesizer used the training activities and the hands-on activities. The introductory workshop was delivered over 6 weeks.

4.2 Experimental procedure

Learners have never worked the similar tasks before. Each of the training activity and hands-on activity was allocated for 2 hours per week. A pre-test was conducted to compare the participants' prior knowledge of the course content in week 1. We then provided learners with training activities in week 2 and 3, hands-on activities in week 4 and 5. Finally, the post-test was administrated in week 6.

Figure 4 shows some of the electronic sound synthesizers created by the learners in the workshop based on the proposed framework.

Figure 4. Workshop for making electronic sound synthesizers.

4.3 Instruments

The research tools in this study included a pre-test and a post-test for measuring the learners' STEM learning outcomes. The evaluation of learning outcomes consists of twelve single-choice questions, designed by an expert with electronic engineering background. A questionnaire of STEM attitude scale was modified from the measure developed by Benek & Akcay (2019) to measure learners' attitudes.

5. Results and Discussion

Results are based on the STEM learning outcome tests. A total of 22 learners' learning outcomes were assessed. The Shapiro–Wilk test is used to test these samples of normality in frequentist statistics (Shapiro, & Wilk, 1965). Wilcoxon signed-rank test (Pratt, 1959; Chan, 2003) is a nonparametric test that can be used to determine whether data are paired and come from the same population having the same distribution between pre-test and post-test ($p < 0.05$).

5.1 Learning outcomes of the training activity and hands-on activity

The results of the outcome tests for training activities (Test A) obtained from the descriptive statistics are summarized in Table 1. The outcomes of knowledge learning were significantly improved based on Wilcoxon signed-rank test. For instance, the median, mean, and standard deviation of the overall scores were 4, 4.36, and 2.13 for the pre-test (Test-A), and 9, 8.77, and 2.31 for the post-test (Test-A). The overall gain score is 4.41 for the Pre-Post (Test A) comparison. The finding reveals that the learners' learning outcomes increased since the learners learned knowledge by the training activities. The lecturing training activities significantly affected the learning outcomes of STEM knowledge.

The test result of hands-on activity (Test B) as shown in Table 1, there was a significant difference ($p < 0.05$) based on Wilcoxon signed-rank test in learning effectiveness favoring the hands-on activity participants. The learners' learning outcomes were improved since they experienced hands-on learning activities. The outcomes of STEM knowledge were significantly improved. For instance, the median, mean, and standard deviation of the overall score were 12, 11.73, and 3.03, respectively, for the pre-test, and 19, 18.41, and 1.50 for the post-test. The overall gain score is 6.68 (mean) for the Pre-Post (Test B) comparison. The proposed approach may support the constructive cumulative, goal oriented acquisition processes in all learners. The hands-on activities foster in learners the knowledge and skills to apply STEM learning efficiently. It is highly recommended that teachers should enhance their instructional designs of hands-on activities for learners to learn the STEM domain knowledge and skills effectively based on the proposed knowledge and skills enhancement framework.

Table 1

Learning outcomes analysis for the training activity and hands-on activity

Learning activities	**Pre-test**				**Post-test**				**Comparison** (Wilcoxon signed-rank test)
	N	Median	Mean	SD	N	Median	Mean	SD	*p*
Training activity (Test A)	22	4.00	4.36	2.13	22	9.00	8.77	2.31	0.000041
Hands-on activity (Test B)	22	12.00	11.73	3.03	22	19.00	18.41	1.50	0.000042

5.2 Learners' attitudes toward STEM workshop

For evaluating changes in the learners' STEM attitudes, the responses to the survey of STEM attitude scales show the median, mean, and standard deviation in Table 2. The perfect score is 5. Pre-post STEM attitude score increased for the overall score: pre-test Mean = 3.32 to post-test Mean = 3.59. The gain score of the overall attitude was 0.27.

As depicted, there is a significant improvement ($p < 0.05$) on the overall positive attitude while learning with the proposed approach. The dramatical improvement on the overall attitudes toward STEM since the learners were engaged in the problem-based learning with the proposed learning framework. According to the research finding, the learners' attitudes toward STEM toward using the proposed framework for cultivating STEM competence were positively improved.

Table 2

STEM attitude measurement

STEM attitude									
Pre-test				**Post-test**				**Comparison** (paired t-test)	
N	Median	Mean	SD	N	Median	Mean	SD	Gain score	*p*
22	3.25	3.32	0.89	22	3.75	3.59	0.82	0.27	0.002915

6. Conclusions

This study investigates that how the effects of the knowledge and skills enhancement framework based on TPACK to foster learners' STEM attitudes and learning outcomes. Several major findings are summarized. First, the learners' learning performance were improved significantly since they learned knowledge and skills based on the proposed approach. Moreover, the proposed learning framework affects knowledge acquisition. The training activity helped learners significantly acquire their STEM knowledge, and then the hands-on activity fosters learners on not only STEM knowledge, but also real-world skills. Hence, the proposed knowledge and skills enhancement framework helped learners have ability to solve problems and generate ideas. Additionally, the learners' attitudes toward STEM were positively improved. Further studies may be conducted by varied STEM projects based on the proposed knowledge and skills enhancement framework to analyze the difference.

Acknowledgements

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