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Effectiveness of On-line STEM Project-Based Learning for Female Senior High School Students*

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This study aimed to develop an interdisciplinary on-line learning project for female senior high school students and to explore their participation process and its learning effectiveness. The topic for the project was 'The creative design of a cup speaker'. The five-stage model comprised preparation, implementation, presentation, evaluation and revision (PIPER). The model was used for the integrated learning of science, technology, engineering, and mathematics (STEM). Throughout the project, the students were able to discuss and share knowledge about their projects via the STEM on-line platform. The study involved 40 volunteers from a girl's senior high school in Taiwan, grouped into ten teams of six students. Textual analyses, survey questionnaires, and interviews were used to collect data. The findings of the study show that the female students were engaged in the project and were able to combine theory with practice effectively to create cup-speakers according to the five stages of PIPER. In addition, this project created a new opportunity for female Taiwanese senior high school students to experience the joy of engineering design as well as to enhance the effectiveness of the STEM knowledge application. Therefore, the design of interdisciplinary and hands-on projects is seen as an important issue for future curriculum design.

Keywords: female senior higher school student; learning effectiveness; project-based learning (PBL); STEM

1. Introduction

Science and engineering have traditionally been male-dominated. According to 2006 OECD (Organization for Economic Co-operation and Development) statistics, the percentage of female graduates in the fields of science in some countries was 38.02% with 24.2% in engineering and 47.79% in agriculture. Thus, men tend to dominate the population of science graduates, with the gap between men and women in the engineering fields being the most conspicuous [1]. In Taiwan, university- and academy-level female students are predominantly found in three fields: social science, technology and engineering. By 2008, female graduates from technology fields had fallen to 31.65% from the 1998 level of 34.04% [2]. In addition, the percentage of women in engineering departments fell by 33.51% (from 17.28% in 1998 to 11.49% by 2008) [2]. Thus, the total number of female college students in Taiwan has been constantly falling. To increase the percentage of female students in engineering departments, we must encourage students' interests in engineering or scientific research by their senior year of high school. Therefore, it is critical to include technology and engineering in the learning processes of female high school students. Modern educational reform has emphasized that teachers must combine their knowledge of theory and practice in a student-centred learning process. To achieve this objective, project-based learning (PBL), with its emphasis on content and systemization, may offer a good learning model that is applicable (and integral) to the learning of engineering and technology [3, 4].

John Dewey, the mid-20th century philosopher of education, proposed the concept of 'practical intelligence' and argued that the acquisition of knowledge must also be a process of practice. Only through practical activities can genuine learning take place. Following Dewey's now ubiquitous aphorism, this practice is essentially 'learning by doing'. PBL is a systematic teaching method that integrates curricular content. Students can raise genuine questions and conduct surveys associated

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with real-life issues. Because PBL integrates content from different subjects, students engaged in PBL stand to develop a comprehensive knowledge or mastery of a subject. Students successfully gain knowledge and skills through in-depth exploration of complicated issues and engagement with carefully planned tasks [5, 6]. We see PBL as ultimately benefiting the learning processes of female students in engineering fields.

PBL itself is derived from pragmatism. From the perspective of pragmatism, Dewey stressed that 'life is learning . . . learning by doing' [7, 8]. He argued that teachers should guide students' own explorations as they give free reign to their creative instincts. The starting points for learning would be the student's own life experiences, with the teacher adjusting the curriculum according to the student's interests, thus ensuring that the students will actively participate in their own learning processes [9]. PBL learning differs from traditional classroom teaching in that it consists of interactive, long-term, project-centred teaching activities that integrate ideas from many disciplines [10, 11]. In addition, PBL provides learners with a highly complex and project-oriented learning process, which enables students to present their work and to complete project-based exploring processes through the construction of topics, designing, planning, collecting data, and exploring special issues [12, 13].

PBL was developed as a teaching and learning method, based on constructionist theory and supplemented with concepts from cognitive psychology and situational learning [14]. Social constructionists argue that the formation of an individual's knowledge is constructed within the context of interactions between social groups. Consequently, it seems reasonable that Internet learning groups could provide virtual environments for cooperative learning by facilitating interaction between groups in the construction of knowledge. In light of the highly developed state of information technology, PBL could be combined with Internet platform-based learning so that teachers and students could interact and access the latest information across classrooms and campuses without restrictions on time or place. In addition to offering learners a new model, this approach has the potential to use various communication methods (simultaneous and non-simultaneous one-on-one dialogues, one-to-many broadcasts and many-to-many discussions) along with a diversity of content types (text, graphics, audio, video, and other multi-media) [15]. This approach and its reliance upon the Internet facilitate students' interactions and their ability to share and discuss. Finally, it helps students to construct their own knowledge and points of view without depending on 'accurate answers' from their teacher.

In addition, the theory of PBL is in accordance with situational learning theory, which emphasizes that the problems that students explore must reflect real situations or problems that occur in everyday life. In addition, PBL should provide students with the tools used in the real community. Thus, the students will be able to apply what they have learned to daily life and their learning motivation can be improved. PBL also emphasizes the linkages between learning and context and the usability of knowledge. It accelerates dynamic learning and encourages the teacher to allow learners to choose projects by themselves; learning is thus reshaped into a purposeful activity [16, 17]. Shy presented a five-stage model for on-line PBL implementation [12] that might be suitable for project-based learning by Taiwanese high school students. The five stages are: preparation, implementation, presentation, evaluation and revision (PIPER). The details of each stage are as follows:

1. *Preparation*: cover subject content, confirm teaching goals, access resources and prerequisite knowledge, develop evaluation methods, ensure progress, organize teams, and train teachers
2. *Implementation*: create special topic plans, arrange division of labour and team responsibilities, generate hypotheses, collect, analyse and verify information, organize teamwork, create progress reports, and integrate and analyse results
3. *Presentation*: present oral presentations, and complete written reports
4. *Evaluation*: conduct expert-, peer- and self-evaluations
5. *Revision*: conclusion, revision and review.

Previous research suggests that students engaged in PBL enhance their capacity to collect, analyse, organize and apply information. In addition, the students develop their interpersonal skills, learning to respect the thoughts of others, to accept others' criticisms, and to solve problems by giving free reign to their creativity and critical thinking abilities [18, 19]. PBL also has many positive implications for learning outcomes with respect to motivation, attitude, achievement, problem-solving ability and the development of creativity. Meanwhile, due to the development of Internet technology, PBL itself has changed. However, research on this rapidly growing domain concentrates on elementary school subjects or on junior high school students. In addition, research shows a strong focus on PBL 'teaching design and implementation' as well the 'effects of PBL on students' academic achievement' [11, 20–25]. There are very few studies on how well female students learn technology and engineering. Therefore, this study aimed to explore technology and engineering learning by female senior high school students by employing the PIPER five-stage model using a special project activity combined with the topic of 'cup-speakers', which are related to the context of students' lives. We also adopted the STEM (science, technology, engineering, and mathematics) approach to designing the project activity and to investigating the effectiveness of the project-activity learning process.

The main subjects in this study included the knowledge content of STEM with respect to science, electromagnetism and sound science; technology, applied-production technology, tool use and equipment operation; engineering, applied creative thinking and design; and for mathematics, applied exponents and logarithms. STEM was employed to analyse the features of the students' work and the application of the students' knowledge, skills, and decision-making. Thus, the students were able to discuss and explore the solutions on-line in order to complete their projects. Thus, the purposes of this study were as follows:

1. to explore the PBL process;
2. to explore the content of the STEM project; and
3. to analyse factors associated with PBL application.

2. Research design

This research consisted of an interdisciplinary project activity with female senior high school students as the subjects. It entailed holding a contest for the creative design of a 'cup-speaker' and provided an on-line STEM learning website to help students to learn. The researchers collected data relating to the students' progress through the STEM website. Textual analysis was used to analyse these data. In conjunction with the STEM survey questionnaire, we also conducted interviews with three representative teams.

2.1 Research subjects

The research subjects for this study were 40 students from a public girl's senior high school in Taiwan. Although the school announced the objectives for the various activities, the students were free to organize the teams within which they would participate. Each team included four students. Six teams were made up of freshman students (24 students), and four teams were made up of sophomore students (16 students) for a total of 40 students.

2.2 Members of the research team

The roles and tasks of the research team members were as follows.

1. *Experts and scholars*: A university professor led the research and was the expert and scholar for these activities. His task was to plan the research, provide on-line STEM platforms, and supervise progress.
2. *Schoolteachers*: Two teachers participated in the research. Both teachers had many years of teaching experience. Their tasks were to provide students with support and consultation about the computers and other equipment.
3. *Researchers (on-line teaching assistants (TAs))*: There were two researchers whose primary tasks were centred on the design and implementation of the research and the implementation of the methodology. During the research period, they also acted as network assistants for the STEM on-line platform and provided students with constant in-depth consultation and guidance throughout the process.

2.3 The cup-speaker activity process

This study was based on the STEM interdisciplinary course-centred project combining the PIPER five-stage learning model with on-line project activity learning, which emphasized finding solutions to real problems [12]. Because they are easy to make, are low cost, and result in a production process involving STEM principles, the researchers decided to choose 'cup speakers' as the topic for the activity. Each task revolved around the completion of the PBL process (Fig. 1). In addition, the researchers provided TAs to guide the students via the STEM website. Each experiment entailed completing the goals of various tasks and establishing the best solution before completing the production, presentation and evaluation of the 'Cup-Speaker Project'.

2.4 Research tools

2.4.1 The STEM on-line platform

The frequencies and interaction content of PIPER,

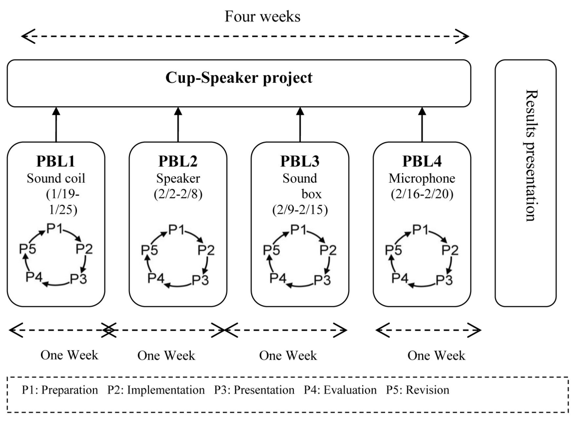


Fig. 1. Implementation of the Cup-Speaker Project.

Fig. 2. The Webpage introducing the STEM courses on the cup speaker.

the discussion content within the STEM on-line platform, and the features of the students' work were collected by the two internet-based teaching assistants while the students simultaneously and non-simultaneously engaged in the project activities. The interface of the platform (Fig. 2) consisted of the following primary contents: (1) STEM and KM (knowledge management) (http://stem.nknu.edu.tw/moodle/z), (2) descriptions of the activities, (3) a supplementary knowledge station, (4) project descriptions, (5) a bulletin board, (6) four-stage tasks, (7) a forum, (8) a chat room, (9) a results-presentation area, and (10) statistical data.

2.4.2 The PBL and STEM-integrated questionnaire

The purpose of the survey questionnaire was to understand the students' learning and the differences in this learning after the students engaged in the PBL activities. Three experts were invited to review the questionnaire to establish the content-validity of the survey questionnaire, which employed a 5-point Likert scale. After the students had completed the STEM project activities, it was tested using the student self-reporting approach. A total of 40 questionnaires were distributed, and 38 valid responses were returned, yielding a response rate of 95%. Based on the four aspects of STEM that were learned in the project (science, technology, engineering and mathematics), the researchers used a confirmatory factor analysis (CFA) to test the reliability and validity of the item contents and domains (Table 1). The reliability (or R2) of each question item was between 0.35 and 0.76 and thus met the reliability criterion (R2 greater than 0.2). The construct reliability (CR) of each aspect was between 0.81 and 0.90 and surpassed the required standard of 0.6. The validity (λ) values were between 0.53 and 0.69 and were greater than the standard value of 0.5 [29]. Based on these values, the questions associated with the STEM integrated knowledge questionnaire (with the four aspects of science, technology, engineering and mathematics) met the requirements for reliability and validity.

2.4.3 Project activity interview

The outline of the project-activity interview was developed to explore further how factors related to the students' project-related decision making affected the generation of key designs in the students' work. Three teams (a total of 12 students) were chosen for semi-structured interviews after the project activities were completed.

2.5 Data collection and analyses

The principal methods of data collection employed in this study were as follows.

1. PBL and STEM Survey Questionnaires: SPSS for Windows 14.0 was used to conduct statistical analyses on the quantitative data obtained (e.g., analyses of correlation, regression, and variance).
2. On-line Platform Interactions and Activity Interviews: Textual analysis and the principles of textual reference analysis were used to analyse the documentary materials generated by the students, the on-line platform interactions and the interviews. In addition, the frequency of student discussions with the TAs on the plat-

Table 1. Summary of STEM confirmatory factor analyses

	Topic	λ	R^2	CR	AV.
Science				0.88	0.65
	25 I can understand sound phenomenon	0.79	0.62		
	26 I can understand acoustic principles	0.84	0.71		
	27 I can understand and apply electric and magnetic principles	0.82	0.67		
	28 I can understand and apply Fleming's left- and right-hand rules	0.77	0.59		
Technology				0.90	0.57
	29 I can appropriately select materials	0.82	0.67		
	30 I can correctly use tools	0.84	0.71		
	31 I can work with various processing patterns	0.80	0.64		
	32 I can recognize sound development	0.67	0.45		
	33 I can understand the structure of and the principles used for speakers and microphones	0.64	0.41		
	34 I can correctly operate sound equipment	0.88	0.77		
	35 I can implement tests, adjustments and revisions	0.59	0.35		
Engineering				0.87	0.53
	36 I can solve the problems that I may encounter	0.63	0.40		
	37 I can bring my creative thinking into full play	0.72	0.52		
	38 I can design the model of a cup horn	0.77	0.59		
	39 I can design the structure of a cup horn	0.66	0.44		
	40 I can recognize drafts and drawing	0.76	0.58		
	41 I recognize the close relationship between sound engineering and life	0.80	0.64		
Mathematics				0.81	0.69
	42 I learned to do exponential and logarithmic calculations	0.87	0.76		
	43 I learned the definition and calculation of sound pressure (dB value)	0.78	0.61		

Note 1. CR is construct reliability or composite reliability; 2. AV. is the average variance extracted.

form forum was analysed using Pearson Correlation.

3. Results and discussions

3.1 Analyses of learning process of the project

3.1.1 Analyses of content of the learning process of the project

The content discussed on the STEM on-line platform was coded and analysed. The analyses assessed the content with respect to the distribution of the five stages of project-based learning in the STEM network (as shown in Table 2). From the platform analyses, we found that the female students could learn in a stepwise manner through project activities. They could master subject content, collect information, propose hypotheses, conduct hands-on verifications and test and analyse different constructions to find out which ones gave better results. After the presentation and evaluation stages, the students were able to conduct further hands-on modifications to complete and optimize their work. By essentially learning from their experiences with the project, the female students were able to grasp the key points of the PIPER model [12].

3.1.2 Analysis of frequencies in the PBL process

We conducted content and statistical analyses of the STEM website learning forum using the following five stages as the codes: preparation, implementation, presentation, evaluation and revision. These analyses were conducted on discussions that occurred at various times and at different stages in the process. Discussions during the preparation stage (i.e., P1) were the most frequently observed, followed by those in the presentation stage (i.e., P3), and then those at the evaluation stage (i.e., P4). The implementation stage (i.e., P2) and the revision stage (i.e., P5) produced the least discussion (Table 3). The reason for this pattern lies in the fact that the website provided students with more help in the preparation stage; among other things, the students could share and discuss the information collected, explore the principles, question a variety of assumptions, discuss divisions of labour, agree upon items, ask the teacher questions, and confirm the directions being pursued. These were some of the key items discussed in the messages during the preparation stage. With regard to the frequency of interaction between the TAs and the students, interaction was most frequent during the implementation stage, followed by the preparation stage. This information suggests that the TAs may have been of more use to the students when guiding them through the preparation and implementation stages. It also suggests that the TAs seized opportunities (whenever they presented themselves) to guide the students, to raise their levels of interest, to help them fully understand issues or to explain why things happened as they did. The Pearson Correlation of discussion frequencies between female students

Table 2. Coding and analysis of contents from project-based learning stages

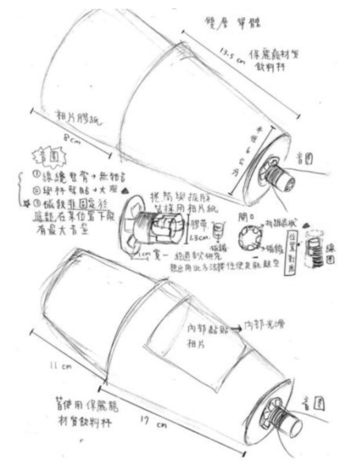
Category	Stage	Coding principles	Example of discussion
P1	Preparation	A. Confirm the scope of the subject B. Confirm prior knowledge C. Present hypotheses D. Collect information E. Prepare materials	• For the subject Cup Horn, we first input an AC signal so that the coil produced a magnetic field. This allowed the interaction between the magnetic fields generated by the coil and the pre-existing magnetic fields to generate vibrations (i.e., employing Fleming's left-hand rule) (A & B). • Assume that if two coils are intertwined, then the electric current will be strengthened (C). • I think we could fix a voice-coil and then compare the plastic cup, the Styrofoam cup and the big paper McDonald's cup to determine the effects of different materials (D & E).
P2	Implementation	F. Hands-on verification G. Tests and analyses	• When the magnet was turned upright, the repulsive effect between the NS pole it generated and the pre-existing NS pole significantly increased (F). • In the test, we accidentally found that the effect of sticking scissors to the magnet and hanging it in the air was better than the effect of putting the magnet on the bottom (G). • The volume of the speaker that was used to post photos was reduced, but it was still 90 decibels. • When we tested an iron bucket packed with tennis balls, the sound became loud and high-pitched. Some students even put a voice coil on a wooden table, which sounded very good; the speaker sound from a trash barrel was very boring (F & G).
P3	Presentation	I. Present the work at each stage	• Present the differences in sound from different coil materials (H).  • The design layout of the sound coil and speaker (H). 
P4	Evaluation	I. Expert evaluation J. Peer evaluation K. Self-evaluation	• The hard plastic cup could not make a sound. If the opening in the bottle was too small, the sound was not easily let out (K). • The sound coil designed by classmates was very special and creative. However, if the result was not so good, why not return to the basic sound-coil type taught by the teacher? (J) • The owner of an appliance store said that the result from a regular winding would be better than that from a random winding (I).
P5	Revision	L. Revision M. Review and improve	• If we turn the sound coil in a perfect circle, will it make the results better? (L) • Should we add towels to our sound box? Maybe that will enhance the sound quality (L & M). • 'How embarrassed we were when we found out the model we made was disqualified' > <.. Wow~~! We had to rebuild it again' (L).

Table 3. Frequencies of discussions during the five stages of PBL

School	P1 Preparation	P2 Implementation	P3 Presentation	P4 Evaluation	P5 Revision	Total
Pingtung Girls' Senior High School	393 33%	163 14%	264 22%	220 18%	157 13%	1030 100%
TA	43 32%	46 34%	12 9%	25 18%	10 7%	136 100%

and the TAs was 0.32 (p = 0.60). This is an unsatisfactory level of significance and suggests that, as the PBL progressed, discussions on the on-line platform were not affected by the number of interventions by the TAs. That is, the students understood that they could participate seriously in the discussions, and they took their own initiative; moreover, the students could share their opinions in constructing their own knowledge and viewpoints [15]. Thus, though TAs indeed provided guidance, they did not significantly affect the students' PBL.

3.2 The STEM contents of the project

3.2.1 Analyses of the STEM on-line platform content

In designing the activities, we used STEM (i.e., science, technology, engineering and mathematics) as the source of our learning content. We coded and analysed the contents of the discussion messages on the platform to explore their distributions. If the content of one message could feasibly cover more than two aspects of STEM, we indicated the overlap (as shown in Table 4). Based on our analyses of the platform discussions, discussions about T (technology) were the most frequent, followed by S (science) and then E (engineering); M (mathematics) was the least-discussed topic. While exploring the activities in-depth, we also designed a four-stage hands-on task guide. The inclusion of numerous repeated experiments encouraged students to seek optimal effects and allowed them to discuss the technology-related aspects of the on-line platform. For example, we had students compare the use of different materials with respect to the following variables: sound, number of turns, comparison of practices, effects of magnet position and quantity, demonstration of production techniques, and use and testing of tools. During the activities, the frequency at which students had discussions with TAs was significantly reduced, and this reduction was related to the subject of design. Because some students had yet to learn logarithms (which are taught in the second semester of the 10th grade), they could not understand or calculate exponents and logarithms. Mathematics was only used in the last stage of testing, and thus there were few discussions about mathematics.

Table 4. Coding and frequencies of contents of discussions from the STEM online platform

Code	Primary contents	Frequency (%)	Summary of discussion examples (based on STEM)
S	Sound Phenomena, Acoustic principles, Electric and, Magnetic Principles, Fleming Rule	268 (26%)	Does the electric current affect the volume of the horn, or is voltage the key to affecting the volume of the speaker? (S) If I make the cup horn oval and bring the speaker into focus, the effects on sound reflections should be good (S & M). Is the number of turns related to the electrical resistance? Is it true that if the turns are tighter then the magnetic field and the magnetic force will be greater? (S&T) Owing to the lack of magnets, we came up with 'magnetization' using a bunch of pins, paper clips, and magnets that were attracted to each other. This made the sound seem louder! (S, T and E) Today, after several failures using different coils, sound was finally generated. The most important reason for the failure should be that the coil magnets we had previously used were locked (T). We have to find a setup in which the magnet could vibrate but not become attached to the surface of the coils. We could put a paper spring under the magnet so that the magnet could vibrate but not stick completely (T & E).
T	Use of tools, Production, Techniques, Material Selection, Equipment Operation, Testing, Adjustments, and Revisions	550 (53%)	
E	Problem Solving, Creative Thinking, Styling Design, Structure Design, Work Design	170 (17%)	
M	Exponential and Logarithmic Calculations, Definition of dB Value	42 (4%)	
Total		1030 (100%)	

3.2.2 Variance analysis of STEM knowledge

The average scores of each STEM aspect in the questionnaire were compared. The scores of the S, T and E aspects were quite similar (between 4.20 and 4.28). This result meant that in the PBL, the students' retention of S, T and E knowledge was highly interconnected. However, the average score of the mathematics aspect was 3.74. This score was the lowest of all of the STEM aspects and represented a response between 'agree' and 'neutral opinion'. Thus, students evaluated their own learning of the M (mathematics) aspect to be less effective than that of the other STEM aspects. We compared this average using paired ANOVA tests (as shown in Table 5) and observed significant differences ($F = 12.21$). In other words, the scores of S (science), T (technology), E (engineering) and M (mathematics) were significantly different from each other. Moreover, post-hoc comparisons found that the scores for S, T and E were significantly higher than the score for M. The reasons for these differences may lie in the fact that, with respect to the overall organization of the course, the mathematics applications were not as strongly weighted as were the others. In addition, there were many factors that the students needed to take into consideration to integrate various professional equipment and calculations while designing the cup-speaker project. Moreover, many scientific instruments were required to test parameter values before calculations and estimations. Because of various constraints, students could not be provided with the equipment necessary to conduct several research-related tests during their PBL activities. Unfortunately, because they were also unable to integrate applications in the design and implementation stages, math concepts were only applied in the final test stage. Furthermore, because many of the participating students had not yet learned exponents or logarithms, it was difficult for the students to apply them to their own work.

3.3 The STEM application of each team's work

3.3.1 STEM application of the features of each team's work

We analysed each team's work according to the team's applied knowledge and field-related skills. The primary fields analysed were S (science), T (technology), E (engineering) and M (mathematics) (as shown in Table 6). We found that the female senior high school students demonstrated technology- and engineering-oriented design and production capabilities while also demonstrating a high degree of creativeness and ingenuity. Mathematics was applied significantly less often than were the other STEM fields, although this may be a reflection of the design of the study. Conventional approaches to speaker design require a considerable number of scientific instruments to measure the necessary parameters or the complex calculations that are required for designing a speaker. However, these instruments were not suitable for the students in these activities. In our study, the object of the student's research was a cup speaker (horn). The project focused on applying simple principles to designing various (creative) horns. Thus, there was a high degree of difficulty in the engineering design. On the other hand, the mathematics content was designed to cover only the material necessary for testing the decibel values in the final stage.

3.3.2 The STEM decision-making factors exhibited in student projects

The results produced by each team were unique and creative. This was not easily discerned from the appearances of the projects but was manifest in the students' designs and descriptions. To understand how students made critical decisions in their designs, we conducted semi-structured interviews with the members of selected teams after they had completed their activities. Before analysing the factors involved in the design decisions made by a team, we established an interview structure based on the characteristics of STEM design (as shown in Table 7). The results from the interviews were synthesized into three key points. These points reflect the primary factors involved in decisions made by the students regarding each STEM aspect.

1. *Unanticipated creativity in hands-on implementation*: We found that (regardless of the particular team) most of the more creative elements that resulted in the STEM design were found accidentally during the hands-on process. The students used these elements to infer possible reasons for what they observed and to complete their designs. For example, two-way speaker

Table 5. Variance analyses of STEM aspects

Aspect	M	SD	F value	Significance	Post comparison
S (Science)	4.28	0.63	12.21	0.00	S > M
T (Technology)	4.20	0.65			T >M
E (Engineering)	4.27	0.68			E > M
M (Mathematics)	3.74	0.94			

Table 6. STEM analyses of the effects and results of students' works

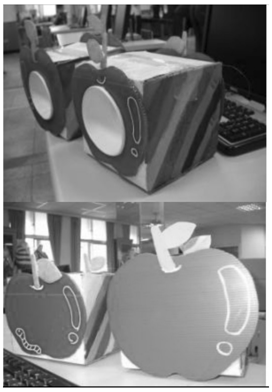
Work	Analysis
	• Sound Coil: The design of the hanging magnet can enhance the sound volume and quality. Two cups were set to a fixed magnet (S&E). • Treble and bass were distinguished by the size of the speaker. The bass speaker was a square Styrofoam structure (T&E). • The net cover was made of stockings, which can help to diffuse the sound (T). • In the internal part of the speaker, we used a towel as an alternative to sound-absorbing cotton (T). • Test: maximum sound pressure of 116.8 dB and output efficiency of 99.5 dB (T&M).
	• Only one speaker was used in the design; the challenge was to produce maximal results with a minimal number of speakers (S & E). • Throughout the experiment, the students carefully drew comparisons of three factors: drum, rhythm and sound. They discovered the different characteristics needed to make the best choice (T). • The final sound coil design had 70 coils connected with four magnets (T&E). • Test: maximum sound pressure of 117.3 dB and output efficiency of 103.1 dB (T&M).
	• The design of an open sound box, with a side of 'a cow' as the opening to the sound box (E). • Students conducted a stress test of the speaker in a semi-confined space to find the optimal direction in which the speaker could resonate with the sound box to increase the sound volume and to reflect the sound (T&E). • A two-stage speaker-lengthening design enhanced the sound reflection (S&E). • A pyramid was designed for the bottom to prevent shock absorption through contact with the surface (T&E). • This design could be based on inaccurate information from the Internet, and its accuracy should thus be tested (E). • Test: maximum sound pressure of 108.3 dB and output efficiency of 103.4 dB (T&M).
	• The horn-style barrel is designed around the idea that increasing the length of the sound-generating body produces reflections. (S&E). • The treble barrel is shorter and the bass barrel is longer in accordance with the principles of acoustic phonetics (S&E). • The team found that the intrinsic musical effects were better and the sound was significantly louder when the magnet was hanging (S&E). • The diameter of the sound coil should be greater than that of the magnet (2 to 3 mm larger) so that the sound coil has enough space to generate sound (S&T). • We found that more magnets did not produce better results. The best sound results from one to one-and-a-half magnets (S&T). • Test: maximum sound pressure of 10.6 dB and output efficiency of 110.4 dB (T&M).

Table 7. Summary of interviews of STEM decision-making factors in students' work

Aspect	Analysis of decision-making factor	Summary of interview examples (Codes (e.g., IP01)): I represents interview, P represents school, and the number is the code for the student
S: Physical phenomenon	The process of experimentation→ accidental discoveries → speculation about the reasons	Teacher: The magnet should not be closely attached to the sound coil because the magnetic forces are at their strongest at the two ends of magnet. How did you find out that the magnet should be placed in the centre of the coils? IP03: *In the process of experimentation, we found that the magnet could be fixed using Scotch tape, but later found that the magnet moved around. We found out accidentally that the magnet moved around when we used our hands to fix it, and also accidentally found that the sound became louder. We all speculated and decided that the reason for this was because the magnetic force is strongest at the two ends of the magnet.*
S: Scientific magnetic force phenomenon	Asked the experts Asked the master workmen	Teacher: The iron sheet was wrapped-up and magnetized. Who found this? What was the reason? Can we use it? IP08: *The master workman found this! Guan-yi suggested that the sheet would fill up the inside of the sheet to enhance its magnetic force. I am not sure if she said so (putting it this way sounds unprofessional, but I really do not understand), but we could not find an iron sheet and the iron wire would not work.*
T: Process of technology	Experiments and comparisons	Teacher: You found that a longer sound coil did not improve the quality of the sound. On the contrary, the results from the shortest coil (1.5 cm) were the best. How did you determine this? IP08: *We had tried over a dozen sound coils, but there was very little difference between them. After making several comparisons among them, we found 1.5 cm was the best.*
E: Engineering design	Experiences of dismantling Experiments and comparisons	Teacher: What was the reasoning behind the idea that the design of the treble could be achieved with two cups fixed to the magnet? How was this idea generated? IP01: *We got the inspiration when we dismantled the speaker and found, after conducting some tests, that the results were better with this alternative; We decided to go with it like the products in the market.*
E: Engineering design	The process of experimentation→ accidental discoveries → speculation about the reasons	Teacher: The design of a two-way speaker is very special. What are the causes and effects associated with it? IP08: *In fact, the design began by accident (but it seemed to be a great learning process). One day I messed up the sound box and installed two speakers. The double speakers turned out to be better. At this time, a strange idea came to me. How about installing something on the back and reflecting the sound?*
E: Engineering design	Network information	Teacher: The design and production of the labyrinth sound box were challenging. What were your reasons for adopting that design? IP08: *We found it on the Internet and felt like this was a great learning opportunity.*
M: Application of mathematics	Asked teachers	Teacher: Was there any difficulty in using exponents or logarithms? IP03: *Because we had not learned them in the classroom, we did not know how to use them. In addition, they were difficult, so we asked our mathematics teacher.*

designs included an all-open reflection sound box, fishing line used as a diaphragm suspension structure, a labyrinth sound box and a horn-style barrel design. The students were often extremely surprised by their discoveries, as accidental breakthroughs tended to create a sense of achievement and to enhance their motivation for continued implementation.

2. *Dismantling Experiences and Comparisons of Experiments*: Dismantling a speaker or a microphone was a very important experience for the students because it was often inspirational. These inspirations were improved upon when coupled with their own creativity and the appropriate theory. The following problems provide examples: suspending the structure,

increasing magnetization, establishing the properties of materials, designing the magnet locations, and establishing the number of turns needed in the construction of a coil. Teams obtained the optimal decisions by repeatedly making comparisons in their experiments.

3. *Making inquiries within the on-line network or asking the experts*: In theory, the students' projects were based on prototype models provided by the researchers. These models were then improved to enhance the quality of the sound. During this improvement process, students used their ingenuity while also making inquiries on the Internet or asking for help from the experts when they encountered difficulties.

As mentioned above, students did indeed ask questions of the teachers in matters of M (mathematics), but they never asked questions of the teachers in matters that related to S, T or E. Instead, decisions regarding these three design aspects were made during the course of hands-on implementation. Thus, hands-on implementation is suitable for experimenting with objects used in daily life. As was observed in research conducted in Taiwan, hands-on experimentation can enhance the motivation for learning and the capacity for implementation. In addition, such hands-on implementation can also enhance the learning experience itself. Through using STEM in the design process of the hands-on implementation, the students were forced to develop their creativity. Essentially, these students were able to gain unique insights and to think in more creative ways.

4. Conclusions and recommendations

4.1 Conclusions

This study aimed to investigate the PBL process, the effectiveness of student projects, and the application of STEM knowledge of 40 female senior high school students by using a STEM knowledge-based on-line platform to assist the students' learning activities. In short, by using a combination of theory and practice, PBL was shown to progress according to the preparation, implementation, presentation, evaluation, and revision stages. We found that female students indeed conducted their project activities based on the PIPER five-stage model. During the PBL process, discussions on the on-line platform were not affected by the Tas' the intervention. The students' engagement in PBL activities deepened the knowledge exploration process and enhanced their impressions of the learning process. The results we observed were conducive to the integration of theory, textbook knowledge, and practice. Through PBL, the female senior high school students were able to effectively integrate knowledge with every aspect of STEM. In terms of the effectiveness of applying STEM knowledge, science, technology, and engineering were used more frequently than maths, probably because maths was applied at the end of the process. Finally, the students' work showed their creativity. Students were able to combine STEM effectively with scientific concepts, choose suitable materials, and produce great designs, and ultimately excellent outcomes. Generally speaking, the students were led to develop unique speakers through integrating the PBL activities with STEM. This was a brand-new learning experience for these Taiwanese female senior high school students. From this process, they experienced the pleasure that comes from participating in engineering design, and their learning progress and overall performances were impressive.

4.2 Recommendations

Based on the findings of the study, the following recommendations were made concerning design activity, interdisciplinary implementation, and future studies for implementing STEM projects. First, in terms of the design of PBL activities, hands-on experiences were the most satisfying element of the student activities. The patterns established in learning by doing (and thinking about that learning) were likely to enhance the students' reflections and motivations. Thus, when designing a hands-on activity-oriented project, the student-centred approach should be implemented, including investigating the students' interests and combining their life experiences with social issues. Next, the contents of STEM activities should be equally distributed among the four different aspects of STEM. The balanced distribution of content should be better attended to, especially during the final testing stage. It should be noted that mathematical learning was relatively weak in our study. In the future, we recommend designing activities that demand knowledge and skills that cover each aspect of STEM, so that the students will have opportunities to develop their different abilities more evenly. Finally, this study was implemented as a special project, and the subjects were female senior high school students only. The design of the study did not entail the use of a control group. Thus, implementing the activities within an experimental framework should be considered in order to enhance the accuracy and the inferential potential of the results of future studies.

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