Int J Technol Des Educ (2011) 21:195–215
DOI 10.1007/s10798-010-9114-8

The impact of problem-based learning strategies on STEM knowledge integration and attitudes: an exploratory study among female Taiwanese senior high school students

Shi-Jer Lou · Ru-Chu Shih · C. Ray Diez · Kuo-Hung Tseng

Published online: 21 February 2010

Abstract This study was designed to explore the effects of problem-based learning (PBL) strategies on the attitudes of female senior high school students toward integrated knowledge learning in science, technology, engineering, and mathematics (STEM). Content analysis and focus group methods were adopted as the research processes. Data and information about the STEM internet platform, an attitude scale and the contents of interviews were also collected for analysis. The subjects were 10th grade students at a girls' senior high school who volunteered to organize teams for a Solar Electric Trolley Contest. A total of 40 students were grouped into 18 teams. The results of the study indicate: (1) that PBL strategies can be helpful in enhancing students' attitudes toward STEM learning and the exploration of future career choices; (2) that the PBL teaching strategy helped to lead students step by step toward completing the contest's mission and to experience the meaning of integrated STEM knowledge; (3) that not only that students can actively apply engineering and science knowledge, but also that students tend to gain more solid science and mathematics knowledge through STEM learning in PBL; and (4) that PBL can enhance

S.-J. Lou (✉)
The Graduate Institute of Vocational and Technical Education, National Pingtung University of Science and Technology, No. 1, Xue Fu Road, Lao Bei Village, Nei-Pu Township, Pingtung County, Taiwan
e-mail: lousj@ms22.hinet.net

R.-C. Shih
Department of Modern Languages, National Pingtung University of Science and Technology, No. 1, Xue Fu Road, Lao Bei Village, Nei-Pu Township, Pingtung County, Taiwan
e-mail: vincent@mail.npust.edu.tw

C. Ray Diez
Department of Engineering Technology, College of Business & Technology, Western Illinois University, Knoblauch 135, 1 University Circle, Macomb, IL, USA
e-mail: cr-diez@wiu.edu

K.-H. Tseng
Department of Business Administration, Meiho Institution of Technology, No. 23, Ping-Guan Road, Meiho Village, Nei-Pu Township, Pingtung County, Taiwan
e-mail: gohome8515@gmail.com

students' abilities and provide them experiences related to knowledge integration and application. Therefore, it is recommended that the curriculum at the girls' senior high school include more content related to specialty subjects to enhance their technological capabilities. In addition, a learning mechanism should be offered to aid advisers or teachers in strengthening students' integrated and systematic knowledge about STEM.

Keywords STEM integrated knowledge · Problem-based learning (PBL) · Girls' senior high school students

Introduction

The 21st century is a century of technology, in which every country is implementing many policy reforms related to scientific education. Although science, technology, engineering, and mathematics (STEM)-related research in Taiwan has just begun, some prior studies have shown positive effects. For instance, studies have emerged on integrating STEM into experiments in teaching using the "Science and Living Technology" curriculum (Chen 2007; Tsai 2007), as have studies on combining STEM and project-based learning and teaching (Chuang 2009; Lou et al. 2009). Furthermore, it has been found in the literature that the combination of theory and practice, the development of problem-solving ability in real situations to enhance abilities related to integrated knowledge, and the transfer of power emphasized by the STEM teaching strategy are in accordance with the spirit of the problem-based learning (PBL) teaching model. With that in mind, this research attempted to design a series of tasks that required the use of STEM knowledge to solve problems using PBL strategies and explored the subsequent effects of those tasks on the attitudes of female senior high school students regarding STEM integrated knowledge learning. The purposes of the study were (1) to explore the impact of PBL on STEM learning among female senior high school students; (2) to explore the effects of PBL strategies on the integration of STEM knowledge among female senior high school students; and (3) to provide suggestions and recommendations for future STEM-related research.

Literature review

The status quo regarding the implementation and teaching strategies of STEM education

In Taiwan, the promotion of the nine-year curriculum has begun the integration of the STEM curriculum and made students the center of learning activity. The nine-year curriculum has been divided into seven major areas. Within the seven areas, "mathematics" and "nature and living technology" are the two areas that are related to STEM. The content of the nature and living technology curriculum includes knowledge and abilities related to materials, energy, life science, the planet, environmental science, wildlife and nature preservation, the use of information technology, science and scientific studies, and respect for life. The mathematics curriculum includes the basic concepts of numbers, patterns, and quantities; calculation ability; reasoning and critical thinking ability; and the ability to discuss mathematics with others (MOE 2003).

Some Taiwanese studies of STEM integrated teaching or learning exist in the literature. Both Tsai (2007) and Chen (2007) have conducted studies on STEM integrated teaching modules and their application in the "nature and living technology" curriculum for Taiwanese junior high school students. The results of these studies indicate that the STEM teaching module can enhance junior high school students' learning and integrated knowledge in science, engineering, technology, and mathematics. The performance of the STEM teaching group was superior to that of the traditional teaching group. In addition, students showed a positive attitude toward STEM learning. Meanwhile, the results of Chen's (2007) study also showed a positive learning attitude and effects on STEM learning. In addition, Lou et al. (2009) used a questionnaire survey and focus group interview to explore students' changes in attitude after participating in a solar trolley contest. The results indicated that hands-on practice can be effective in enhancing students' interest in learning. In addition, learning about engineering can cultivate students' systematic thinking and problem-solving abilities. Meanwhile, learning about science and technology can enhance students' learning satisfaction.

Furthermore, Chuang (2009)conducted a study on integrating STEM activities with project-based teaching among senior high school students through content analysis, questionnaire surveys, and interview methods. Building a cup speaker was the topic, and a STEM website served as an auxiliary learning tool in the study. The results of the study suggested that vocational senior high school students show better creative ability, manufacturing and sound effect skills than do senior high school students. Additionally, the results showed a positive relationship between the frequency of browsing the STEM website and product outcomes. Furthermore, students showed a positive attitude toward the STEM website and the online assistance they received. Finally, the results of the study indicated that STEM activities can enhance teamwork and cooperation in groups.

In summary, the STEM teaching strategy emphasizes that courses should provide opportunities for linking theory and practice to boost students' motivation to learn and their understanding of the applications of STEM to the problem-solving process.

The content, applicability and related research on online problem-based learning (PBL) teaching strategies

PBL is a skill that places a learner in a meaningful learning situation that is focused on the solution to a problem taken from a real situation. The learner takes the initiative to construct knowledge and effectively develop the solution to a problem by providing the necessary resources, guidance, and opportunities for exploration (Williams et al. 2008). The process can not only build a bridge between the theory and the real world, but also boost the learner's conception of integration (Tan 2004). It can also encourage opportunities for subject integration and application (Rankin 1992). Self-modification could bring about greater motivation for and interest in learning (Delisle 1997) because the learner would be able to control the direction of learning and continually develop more professional skills (Steinemann 2003); this concept has been applied to various fields (Williams et al. 2008; Zimmermann and Lebeau 2000), such as medicine, engineering, computer science, and geography (Mykytyn 2007). Chin and Chia (2006) have also pointed out that scientific thought could develop through use of the PBL strategy.

PBL can be applied to the internet environment (Dennen 2008; Gooding 2001; Koschmann et al. 2002; Valcke and Martens 2006) and to cooperative learning among teams (Naidu and Oliver 1996; Overbaugh and Casiello 2008). In the online discussion process (process-oriented), group members can focus on the problem and share knowledge, whereas in the production process (product-oriented), group members can extend their original knowledge and adjust conceptual misunderstandings (Dennen 2008). They will thus obtain new knowledge, learn how to solve problems, use their communication skills, develop team leadership abilities, and most importantly, come to understand the process by which a learner constructs knowledge (Dennen 2000; Jeong and Joung 2004; Jonassen and Remidez 2005; Valle et al. 2003). In other words, the design of the environment for internet-based learning should focus on the discussion of the problem, the sharing of knowledge, and solutions to problems that can enhance learning effects, whereas PBL should focus on the discussion of and solution to problems through learning activities.

In Taiwan, students in senior high schools and vocational schools have served as subjects for some related studies of PBL, which can be combined with IT as a learning strategy. Chu (2005) discusses the process of applying a WebQuest module to a PBL module as carried out by physics teachers and their teaching assistants. They carried out the experiment by delivering lectures in class and via interactive internet-based learning integrated into WebQuest teaching material installed at a K-12 cyber school employing a PBL teaching strategy. In this research, two classes of students from a senior high school in middle Taiwan were chosen as subjects. According to the results of this study, the students thought that they could change their personal learning conditions and increase their level of interest in their studies after the teaching module was implemented. Additionally, PBL helped them to understand things more easily and facilitated their understanding of key points; meanwhile, they were able to obtain skills and knowledge related to computer science. The majority of the students expressed a preference for this e-learning website. Among its features, group discussion was shown to benefit students' learning. The achievements of this study were evident in terms of recognition, interests, and society. In terms of recognition, most students were able to gain a thorough understanding of the concept of the course; in terms of interest, 75% of the students showed a positive attitude toward learning each unit; and in terms of the social aspect, more than 60% of students found it helpful to study together in small groups. Most of the students were willing to help each other by providing encouragement, assistance and praise. Li (2005) chose to study the environmental problems along the coastline and set up a teaching module employing PBL and a WebCT e-learning platform. She collaborated with schools located along the coastline in northern Taiwan, using an actual teaching experiment to prove that this novel teaching methodology can help students to reach learning goals at a higher level. The results indicate that the teaching module can enhance students' knowledge of geography. Through group work and role-playing, students not only became more willing to value and protect the ocean near northern Taiwan, but also learned the skills to communicate with others and improve their friendships. Self-directed learning helps students to develop a higher level of problem-solving ability as applicable to the real world and makes it imperative for students to think independently. That is, PBL with STEM can cause students' active learning and thus improve their attitudes and engagement. Without being limited by textbooks, they cared about their motherland in real life and learned geography.

In short, PBL discussions regarding knowledge-sharing and problem-solving through an internet platform can be applied to the development of the STEM education curriculum model. Requiring the completion of clear, step-by-step PBL tasks and online learning, the model can provide students with the space for in-depth thinking about a problem, exploring and exchanging opinions that can not only boost their creative and innovative thinking, but also help them clarify STEM integrated knowledge and the different aspects of viewpoints that can stimulate their curiosity about knowledge and their interest in learning. Many scholars also agree that PBL is suitable for students who are learning new ways to make inferences and requires guidance the development of in-depth learning (Hmelo et al. 1997; Yeung et al. 1999).

The research design and implementation

The research design

In this research, a “STEM internet platform” was developed to provide group members with opportunities for discussion and sharing of data, as well as to foster an understanding of how group members discuss, pass on, share, and use STEM knowledge—and, finally, to identify problems with STEM knowledge and provide an intellectual model for problem-solving in the context of a contest to build a solar automatic trolley. The last step was to analyze the effects of the activity through the internet platform, STEM knowledge integration, and student learning based on the PBL activity. Figure 1 presents the research design. The subjects of this research were the 10th grade students at a girls’ senior high school in Pingtung County who volunteered to organize teams for participation in the contest. Each team included four to five members, with a total of 40 students on 18 teams.

The problem at the center of this research was the manufacture of a solar automatic trolley that could travel at high speed and would feature an innovative shape. The student teams were provided with an existing solar battery, motor and gear sets; then, they were asked to complete six stages of tasks. The six stages were as follows: (1) the problem confirmation stage, which asked students to confirm and describe through discussion the key questions regarding the solar battery, motor and gear sets; (2) the problem clarification stage, based on the key elements of the problem and the problem-solving points described in the first stage, in which the students were to solve these problems through discussion in order to identify relevant knowledge about science, technology, engineering, or mathematics; (3) the planning stage, which included outlines for planning, including the framework and functions of the solar trolley, and considered the manufacturing process and the difficulties that might arise; (4) the contingency plan stage, which asked students to describe contingency plans and steps that they would take upon encountering difficulties at each stage; (5) the planning reorganization stage, which entailed the completion of the initial model of the solar automatic trolley according to the drafted contingency plans and required a simple introduction to and description of the characteristics of the model; and

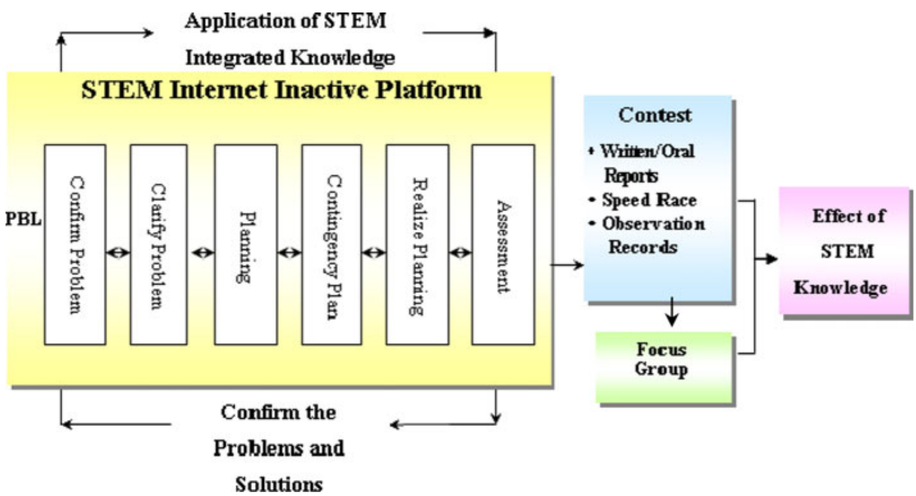


Fig. 1 Research design

finally, (6) the assessment stage, in which the initial model completed in the previous stage was subjected to final testing and modification, along with a description of the process and what the students learned from the testing and modification procedures.

The situation of research

The STEM interactive internet platform designed by the authors was an interactive website (http://stem.nknu.edu.tw/moodle/course/view.php?id=14) for discussion in groups and for the exchange of views between the groups and the research team. Its functions are as follows:

1. Outline of subjects

This area is an important information link between the researchers and the participants exploring the content. It provides the rules, descriptions, reference data, forms, bulletins, and real-time information for the contest.

2. Contextual problem

This area also briefly describes the contextual problem and asks participants to upload data and homework related to the six PBL stages as points of reference for exploring students' progress in constructing knowledge.

3. Activity space

The activity space is designed for group members to discuss and share knowledge and to contact each other; it contains a "discussion area", a "real-time chat room", a "homework loading" area and a space for an "online resources" database.

Research methodology and data collection

Text information was collected to discover how the learners learn. Focusing on the interactive internet platform and the contest process, the researchers collected STEM internet platform data and the reports and homework completed by participants in order to conduct content analyses and explore the learners' progress as they developed their modes of thought using STEM knowledge to confirm problems and determine solutions. A focus group was used to understand how students obtained and integrated STEM knowledge while solving problems. The method and data analysis are shown in Fig. 2.

1. Content analysis

The researchers collected formal texts (homework, reports, information from focus groups and observation records) and informal texts (discussion content, work) to conduct the analysis. The "Observation Records of the STEM Platform" was auxiliary material used to record the frequency with which students accessed and utilized STEM knowledge during the course of the activity and to observe the integration of STEM knowledge by participants. Its reliability and validity were triangulated by multiple sources of data, and it was obtained via mutual analyses conducted by the research team members.

2. Focus group interview

This research adopted a semi-structural method to conduct focus group interviews. The subjects of the interviews were volunteer students from the top five teams. A total of

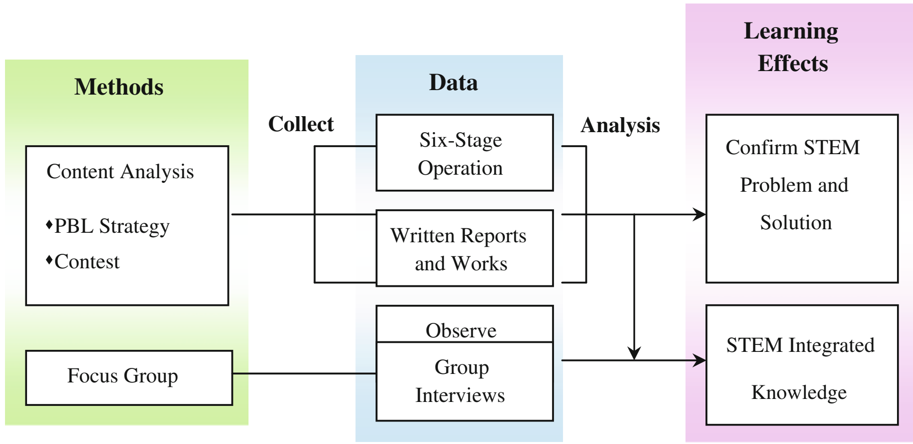


Fig. 2 Research method and data collection

14 students were interviewed. The guidelines for the discussion were to determine how the teams used STEM knowledge and the effects of using the STEM internet platform. The discussion topics are listed in Table 1.

Research procedures

In order to ensure that the students could make use of the internet resources, the research team held an orientation meeting and produced a "STEM Internet Manual". Before the activities began, the team designed six PBL scenarios for the solar electric trolley and developed a STEM internet platform for students to explore, discuss, document, and confirm problems. Such a platform could help students obtain, share, apply, create, and test data relevant to the design and manufacturing of a solar electric trolley. The period of the entire contest was 2 months. Table 2 gives a detailed overview of the processes.

Table 1 The discussion topics for focus groups

Subject	Content
Use of STEM integrated knowledge	1. During the course of the activities, what knowledge of science, technology, engineering and mathematics was used? Please explain in detail 2. During the activities, what (new) STEM knowledge did you obtain? How did you integrate, classify and keep track of that knowledge? Please give examples 3. Through which methods or searching media did you obtain (new) knowledge? How did you share knowledge with others?
Effects of PBL and STEM internet platform	1. Was the PBL (internet platform) pattern helpful to your analysis and handling of the problem? Please give a concrete explanation 2. Will you use PBL when you face problems or to acquire new knowledge? Why or why not? 3. Was the PBL (internet platform) method helpful to your STEM learning? 4. What was the effect of PBL (the internet platform) on your use of knowledge (punctuality, participation, …)?

Table 2 The flow chart of activities

Dates	Contents of activities
2008.1.17	The orientation meeting
2008.1.18	Group registration
2008.1.21–2.22	On-line discussion and PBL tasks begin
2008.2.22	End of data loading and operation
2008.2.23	The contest (oral and written reports 20%, homework 10%, and speed contest 30%)
2008.2.24–3.3	Confirmation of the list of winners (Data analyses 40% and statistical scores)
2008.3.17	Focus group interviews

Data analysis method

Descriptive statistics were calculated to analyze "The Observation Records of the STEM Platform" and the various stages of discussion regarding STEM knowledge and the frequency of encountering problems in order to understand the logical relationships and the context of the data. Table 3 shows the guidelines for encoding.

Results and discussion

This study aimed to cultivate female senior high school students' integrative ability by applying PBL strategies to basic science and mathematical concepts, engineering theory, and technology; it also aimed to enhance students' learning attitudes toward STEM via competitive activities and internet discussion. The results and discussion of the study will be presented in the following sections.

The influence of PBL strategies on students' attitudes toward STEM learning

1. STEM can help students explore their future career choices

After one month of STEM learning in the context of PBL, female senior high school students recognized the importance of promoting their own abilities and acquiring abundant knowledge for their future career choices (Klapwijk and Rommes 2009). In addition, students realized that they could participate in activities to increase their exposure to STEM knowledge, thus enhancing their interest in STEM-related jobs.

Table 3 The guidelines of encoding

Data source	Code	Guideline
Homework	H	Groups a–r (18 groups, 4–5 people per group; codes for members of Group a: a1–a4)
Report	R	Codes for the 6 stages of homework and reports: ①–⑥
Product	P	Ex.
Focus group interview	F	(H-⑥-a) refers to the 6th stage of the homework for Group a (F-i2) refers to interview data for the second member of Focus Group i (P-m) refers to the product of Group m

> This is the era of the knowledge economy; the more we know about it, the better competitiveness we possess. Thus, it will be easier to find a job if we have more knowledge (F-p4)

> The activity has helped us understand more about scientific knowledge-that it is helpful to our work. (F-p2)

In summary, through the application of STEM learning in the PBL context, students' career attitudes have changed, and they have realized that the more knowledge and abilities they possess, the more competitive they will be in the job search process. As Grier and Johnston (2009) point out, possessing STEM ability can influence students' future career choices, encouraging them in the direction of healthcare, national security, environmental, and other science-related careers. Certainly, there are quite a few jobs that require an understanding of natural phenomena, biological characteristics, and professional techniques.

2. Learning STEM knowledge can be very effective and interesting

Students can fit STEM knowledge into their lives through repeated hands-on practice and problem-solving processes, as well as cultivate and promote multiple abilities. "*During the process of completing multiple failed experiments …we also learned how to integrate STEM into life and use it. During the team activities, we improved many of our abilities greatly, such as our problem solving ability, understanding of technology, use of machinery, and calculation. These are the key skills of STEM-science, technology, engineering and mathematics.*" *(R-⑥-j)*. In addition, most students were highly appreciative of the PBL strategies for providing clear steps for learning.

> Step by step processes will allow us to better understand where the problem is. (F-p2)

> As long as we are willing (to learn PBL strategies), the process will be more organized and easier to figure out. (F-i1)

> As a result of having steps, we will not leave knowledge out but will obtain knowledge step by step instead. (F-i2)

However, there were students who held different opinions regarding STEM learning. "*It's true that PBL can (help one to) solve a problem, but it is not so helpful for me… I did not obtain professional knowledge.*" *(F-p3)*. Nevertheless, PBL is not a technique used to obtain a final answer, nor is it a professional skill. Instead, it helps students to think about, address and solve problems. Through this process, students can come to understand a new theory or explanation and thus to show personal growth (Mercier and Frederiksen 2007). Through focus group discussions and dialogues, students can gather related information and knowledge to analyze concepts, brainstorm, further change their patterns of cognition and ultimately experience in-depth and advanced learning. Mykytyn (2007) points out that PBL offers clear direction and tasks. It can lead students to effectively connect their personal knowledge to the process of learning planned and systematic knowledge. Thus, PBL strategies emphasize more the cultivation of abilities related to integration, systematic knowledge, application, and thinking than professional knowledge.

The effects of applying PBL strategies to STEM integrated knowledge learning

According to the "STEM platform observation records" shown in Fig. 3, students involved in competitive activities can assess their possible encountered questions and difficult tasks as well as the use of STEM knowledge. Figure 3 shows the number of questions or difficult

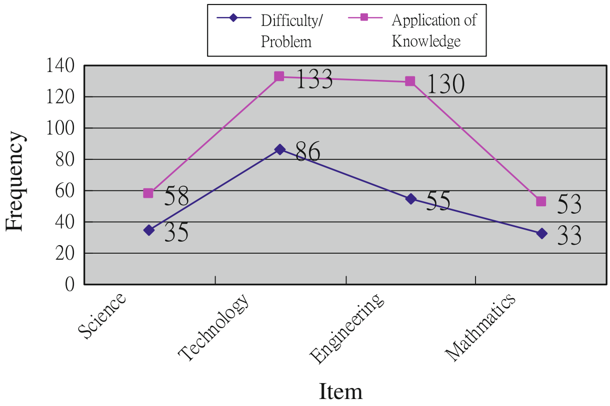


Fig. 3 STEM platform observation records

tasks that the students encountered. The most frequently recorded difficult task, which appeared 86 times, was the "techniques of assembling a solar car." The second most difficult task was the concept of choosing and arranging materials, recorded 55 times. The mathematics concept was recorded 35 times as the third most difficult task. In terms of STEM knowledge application, engineering and techniques were discussed most, with 130 and 133 examples, respectively. The numbers of times these topics were discussed were far higher than were those for science and mathematics, which were recorded 58 times and 53 times, respectively. The researchers further examined the content of these discussions and ascertained that there were many discussions on engineering and technical knowledge—far more than there were discussions of science and mathematics. In addition, students spent more time discussing concrete and technical concepts and less time on abstract thinking.

Figure 4 presents the learning model for STEM for female senior high school students. As a whole, the students tended to possess greater ability to apply basic knowledge of science and mathematics. In addition, students with more basic knowledge of science and mathematics tended to have a better ability to conduct a more meticulous engineering design process. The major factor affecting the results of the contest was technological/ technical skills, with imperfect and immature techniques making the trolley unstable.

Although students spent more time and energy on the discussion of technological skills, the stability of the trolley was not sufficient. In other words, the participants' cognition and science and mathematics concepts were superior to their hands-on ability. Furthermore, the researchers found students' science and mathematics knowledge to be better than their technology and engineering knowledge. However, the discussion frequency rates for these subjects on the internet platform demonstrated an opposite pattern. This was because students lacked hands-on experience. Thus, they discussed technical knowledge most on the STEM platform.

STEM knowledge integration and application

1. Applying the basic concepts of science (S) and mathematics (M) to design the body of a solar trolley

According to REESE (2008), mathematics is the foundation of scientific reasoning. In the process of discussing the manufacture of solar electric trolleys, students were able to use

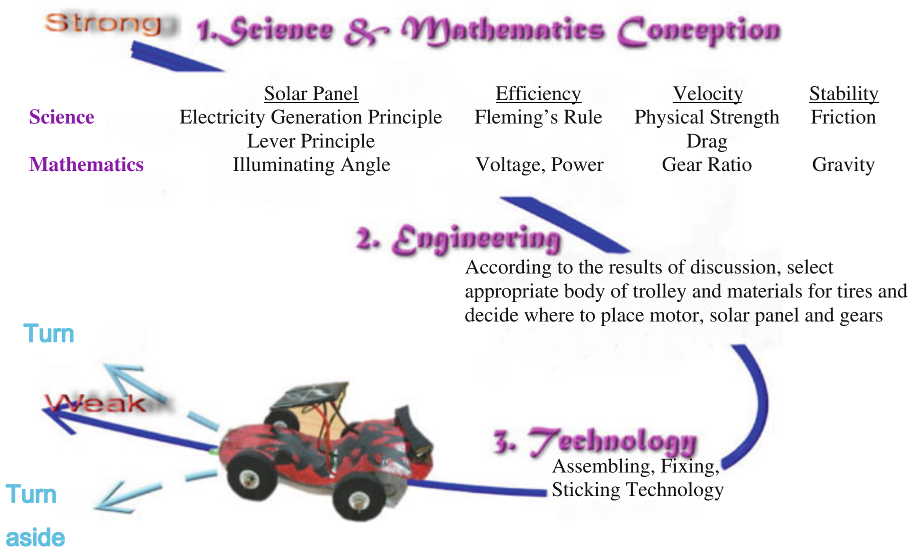


Fig. 4 The learning model of STEM for girls' senior high school students

scientific and mathematical concepts to think about how to increase the solar trolley's speed and stability and to develop the best benefits of the solar trolley and confirm the joint pattern of the solar panel and motor.

In the study, student discussions revealed that students applied and connected mathematics with science knowledge during their PBL process. The students drew conclusions regarding the key factors influencing the speed of the solar trolley: "*After discussion, the students found that the factors affecting the speed of the trolley included gear joint distance, the friction of the wheels, the weight of the trolley body, drag force and the power of the motor.*" *(H-②-h)*. These factors show the relationship between science and mathematics knowledge. For instance, friction, dynamics, resistance, thrust, and torsion are science concepts, and the car's speed can be calculated using mathematics.

> Through the conversion of the gear ratio, we were also able to obtain torsion and changes in the rotation rate. (H-①-q)

> When the gear ratio is 4:1, the speed will be the highest; when it is 5:1, the torsion is best. (R-⑥-i)

> RHO = $F/(A*d*V$^2/2)。 F = force; A = effective sectional area; d = density of air; v = speed (H-②-b)

> voltage = resistance*electric current. When the voltage increases, the electric current increases, too. (H-②-p)

In summary, the process clearly demonstrated the relationship between science and mathematics. That is, science provides mathematics with interesting points to consider, and mathematics provides science with useful analytical tools (AAAS 1990). Mathematics to the application of science also emerged through the process, and science was used to deliver mathematical concepts and information clearly. In addition, abstract mathematics can be easily understood through concrete science interpretations (Tsai and Tuan 2004).

However, in addition to the applications of science and mathematics, mathematical knowledge also emerged as the foundation of the development of technology (MOE 2003). In terms of engineering design and application, we can note that students utilized the mathematical concepts of calculating force and vehicle weight to design the solar trolley: "*With a different amount of pressure, there will be a different friction coefficient that causes a different amount of friction force. The size of the radius of the tires will determine the speed and torsion of the motor as passed from the gear ratio to the heart of the axis of the tire and the speed and strength that pass from the radius of the tire to the ground and move the trolley forward.*" *(R-⑥-b)*. In terms of technology application, students learned how to choose the right tires based on the direct ratio of friction to adhesion:

> The friction coefficient of a tire with soft materials is greater, and the tire will have a greater holding capacity. (H-②-b)

Understanding scientific concepts like the principles of electricity generation and the optimal illuminating angle for the solar panel was important. Through data collection, participants found that they could create the best solar panel by integrating the generation principles of voltage generated by the solar panel with the geographical location in Taiwan.

> One can take advantage of potential difference to generate electricity and solar cells via wireless magnetic waves according the process of semi-conductors. The electricity generation principles is that if one lets sunshine illuminate the solar panel, the panel will absorb solar energy to generate electrons (negative) and electric holes (positive) through p-type semi-conductors and n-type semi-conductors. Then, one simultaneously separates the electron and the electric hole to form a voltage drop and transmits (the electricity) through a conducting wire to load it before it is transformed by the motor in the form of kinetics. (H-②-i)

> Take advantage of the solar panel to absorb light energy and transform it into electric energy that will drive the motor and gear roll and push the solar automatic trolley forward. (H-②-l)

In addition, students' understanding of scientific concepts like "Fleming's left hand rule" and the "lever principle" was important to the mathematical computations and analyses necessary to understand the interaction between the motor and solar panel. For data collection, students understood the roll principle of the motor and gears, and the physical formulas for concepts such as power, resistance, voltage, and electric current. Students were also able to confirm the best joint pattern for the motor and solar panel using mathematical computations and the concept of counterbalancing.

> The roll principle of the motor is based on Fleming's left hand rule. (H-①-q)

> The gears are an important component of the transmission mechanism, as is the application of the lever principle, which can change the strength, direction and speed of the roll. Voltage is equal to resistance multiplied by the electric current, so that the electric current will increase when the voltage increases. (H-②-p)

> I total = $I1$ + $I2$ (H-③-b)

> Power is equal to net force multiplied by displacement. When the displacement is fixed, the power will be in direct proportion to the net force. Additionally, power is equal to squared electric current multiplied by resistance. When the resistance is fixed, the power will be in direct proportion to squared electric current, and the

> electric current comes from a solar battery. Electric current is equal to voltage divided by resistance, and resistance is fixed. Thus, we could prove that voltage is in square ratio to power: the more power, the more voltage. The advantage of a series connection is that each connection's value of voltage is bigger than that of a parallel connection. Therefore, the solar panel should use the series connection method. (H-②-p)

In summary, students were able to strengthen and integrate their basic scientific and mathematic knowledge through the activity. They were also able to apply scientific and mathematical principles to design a highly efficient solar trolley.

2. Apply the concept of engineering (E) to choose appropriate materials and manufacture a solar trolley

Students applied science and mathematics concepts in thinking about how to manufacture a solar trolley with optimum speed and stability. Then, they used the concepts of engineering to find the appropriate materials and develop a feasible manufacturing method. Students pointed out that the most likely problem they might encounter in terms of technology had to do with the choice of materials (body and tires) and which parts to install (tires, motor, gear and solar panel). The solutions recommended by the students were as follows: (1) to use light materials, such as the bodies and caps of plastic bottles or tires from toy 4WD cars as tires; (2) to add rubber bands or coarse rubber to the tires to enhance the coefficient of friction of the tires on the floor; and (3) to use four tires because this makes it easier to find the balance point (most students did this).

- Students chose light materials to achieve the best velocity

Most of the materials used to make the body were light materials like Popsicle sticks, PP board, Styrofoam, foam board, aircraft wood, and cardboard. Most of the tires were made from the tires of toy 4WD cars.

> Use foam board to replace cardboard to reduce the weight of the body. The motor, solar panel and some other parts can help to keep the bottom of the body stable so that the trolley can run smoothly and steadily. (H-⑤-o)

> The bottom of the body was made of aircraft wood (used for making airplane models) because it was light and more able to bear the weight of the motor (H-④-l)

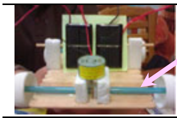
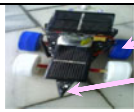
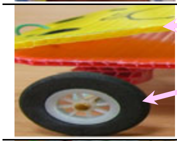
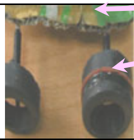
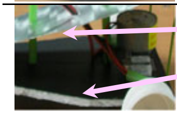
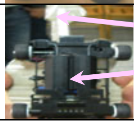
Students chose bottle caps as tires because such tires are easier to make and their friction can help the trolley run steadily.

> A heavy trolley needs wide tires and will have strong holding power, but its friction loss will also be bigger; a light trolley needs narrow tires and will have strong holding power but may not have sufficient power. Considering all factors was necessary to evaluate and make decisions according to the performance characteristics the trolley required. (R-⑥-j)

The description of the work is shown in Table 4.

In addition, students were able to determine the center of gravity to place the motor appropriately, confirm the best angle for the solar panel, determine the number of tires, and ascertain the location of the center of gravity of the body as a basis for placing a motor using a mathematics formula. This reduced the vibration when the motor was in operation; the solar panel was designed to be adjustable and padded as much as possible, and light reflection was used to increase the rate of absorption. The location of the wheels was

Table 4 Description and comparison of materials of body and tires

Work	Description	Work	Description
	Popsicle sticks as bottom of body (P-m)		Bottle caps as tires (P-b) Aircraft wood as bottom of body (P-b)
	PP board bottom and body (P-o) Tires of Aircraft Model (P-o)		Cardboard as bottom of trolley (P-j) Increased friction and holding power via adding rubber band (P-jj)
	Cardboard as body (P-l) Foam board as bottom (P-l)		Cardboard as body (P-c) Bottom and tires of 4WD (P-c)
	Cardboard as bottom (P-e)		

related to the number of wheels used. Students pointed out that "*the solar panel's being perpendicular to the sun is most conducive to generating electricity. However, Taiwan is located on the Tropic of Cancer, so the panel should be installed at an angle of 23.5°; that is the best angle*." *(R-⑥-i)*. Each group presented a different design for the solar panel. However, all designs had some characteristics in common, such as adjustability *(P-p)*, the use of soft wire to support the panel at a greater height *(P-l)*, *(P-p)*, and the use of tinfoil to reflect light *(P-i)*, *(P-h)* and increase the absorption of the solar panel.

> Take advantage of the plasticity of soft wire to install the solar panel on the surface of the body and raise it to adjust the angle at any time to better receive solar light (H-⑤-p)

> Take advantage of the plasticity of the wire to increase the absorption of the solar panel (H-⑤-l)

> Install a reflective object in front of the trolley to increase its speed even when it is facing away from the sun. The first object that we could think of (to use) was a mirror. Because the mirror weighed too much, we decided to use tinfoil instead. (H-⑤-i)

Among the 18 teams, only Teams *d* and *l*2 used three tires, and their performance in terms of speed was not good because having one front wheel could lead to deviation from the desired path unless one extends the axle of the front wheel to increase balance and reduce error. Team *b* extended the axle of the front wheel, but the use of the rubber band increased static friction and decreased speed. The position of the installed materials is shown in Table 5.

> The rubber band could be easily punctured by wire and it could be well fixed. A rubber band is a good material to use, so we decided to use it to fix the wheels and the gear of the motor. (R-⑤-d)

Table 5 Descriptions of the locations of the installed materials

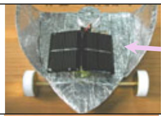
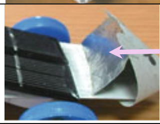
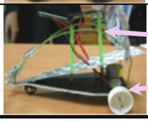
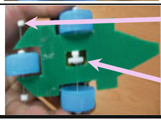
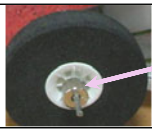
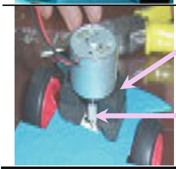
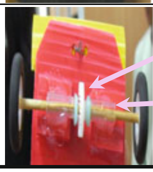
Work	Description	Work	Description
	Find out center of gravity to determine the proper positioning of the motor (P-b)		Tinfoil paper disc will strengthen the absorptive capability of the solar panel.(P-h)
	Tail wing and Streamlined Design (P-p) Mount height of solar panel (P-p)		Reflect light using a tinfoil paper disc (P-i)
	Mount height of solar panel (P-l) Three-wheel design (P-l)		Extend the axis of the front wheel; fixed by rubber band (P-d) Three-wheel design (P-d)

Table 6 Display and description of the solar panel, motor, tires and axle

Work	Description	Work	Description
	Aluminum wire and sponge (P-e)		Axle Fixer (P-p)
	Use of thick double-sided tape to mount the motor at the proper height. (P-e) Space reserved for the connection of the gears. (P-e)		Inflatable nails (P-o) Transparent conduit (P-o)

3. The problems and solutions of technology (T)

The problem that the students most frequently encountered was that the joints of the tires and the axles did not completely fit, which would cause deviation or rolling when the trolley was running; secondly, the occlusions of the gears were not completely matched, which caused the motor to idle, or the abrasion of the gear joints due to rotation caused the expansion of the wheel hole. Most of the students tried to use various methods to solve these problems and repeatedly modified the combination pattern over the course of the experiment. Table 6 presents the display and description of the solar panel, motor, tires and axis.

- The Display of the Solar Panel

Team *j* thought that installing an adjustable solar panel could increase its car's weight. After asking questions, they found that changing the angle had no effect. Thus, they used the simplest horizontal positioning method. *"After discussion, we decided that our solar panel should be horizontally positioned because if we added parts that could adjust the angle, this would increase the weight of the trolley. Also, after internet inquiries, we understood that changing the angle would not make much of a difference."* (*H*-⑥-*j*). Team *e* replaced the steel wire with aluminum wire and replaced the clay with a sponge to fix the solar panel, not only reducing the weight significantly but also protecting the solar panel. "*We used vertical thread to stick both sides of the sponge with foam glue (sandwich biscuits) and fixed on solar trolley before drilling a hole in the bottom of the trolley. We replaced the steel wire with soft aluminum wire and bolstered the main body with two holes and one thread. Twisted aluminum wire could be curved or extended. According to the angle of sun, we adjusted the steel wire to insert it into the sponge. As a result, the solar panel was not only movable, but also fixed and light.*" *(H-④-e).*

The two groups of students above were able to keep the trolley lightweight; although they faced the same problem, their solutions were obviously different. The observation and design indicate that Group *e* applied technology knowledge to the design of the solar panel. The difference in speed between the first and the second place was under .13 s. Obviously, Team *e* displayed better use of technology.

- Motor Fixing Method

The fixing of the motor is a product of engineering knowledge. Team *e* used thick double-sided glue to mount the motor at a height at which it could absorb the vibration generated by its rotation, helping to prevent the motor from deviation due to vibration. The deviation could cause occlusion. Team *l* first observed the rotation direction of the motor before assembling the parts of the trolley in order to prevent the trolley from moving backwards, as happened for other teams.

> We used thick black double-sided tape around the holes that had previously been carved to increase height, which would make the small gears on the motor closely joined with the bigger gears in the rear. (H-⑥-e)

> Our team's trolley did not move backwards because after joining the gears, we observed the direction of rotation of the motor before we decided how to install it in our trolley. This is why our trolley did not move back and saved the time of experiment. (H-⑥-l)

- Tire and Axis Fixing Method

The degree of anastomosis will affect the stability of the trolley when it runs. Students commonly used materials like rubber bands, small bamboo sticks, ballpoint pen refills, straws, Styrofoam glue, and the conduit of sprayer and liquid nails; they adopted a divisive joint method that showed a lack of planning for integrated manufacturing. Additionally, the parallel positioning of the front and rear wheels and the inclusion of small front wheels and big rear wheels made the front part of the trolley light and the rear heavy. In the contest, therefore, these trolleys ran fast, but most deviated and collided with a side boundary, often becoming unable to continue forward.

> We used a material similar to that of a sponge for the tires to enhance the friction on the ground. The axis of the back wheels was not fixed because we used rotating rear wheels and fixed front wheels. We also used tire fixer on the sides of the wheels to fasten them. (H-⑥-p)

> We used the conduit of the sprayer, which was less than 2 cm, as a coating (it made the wheels free to rotate). We fixed the conduit with blue plastic inflatable nails to prevent conduit movement. (H-⑤-o)

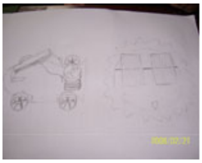
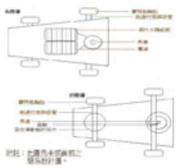
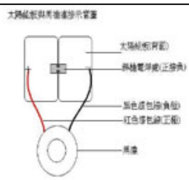
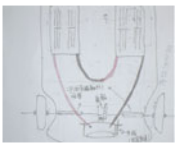
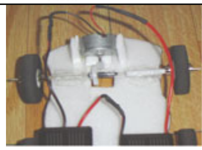
In summary, students were perplexed by the engineering aspects of the use of the circuit, the fitting of the axles to bearings and gears not being able to make the tires rotate in the early stages. Because the students had never acquired the engineering-related knowledge, they could not judge which engineering knowledge and concepts should be used. However, through data collection and the process of experimentation, the students finally manufactured a technologically sound, delicate, aesthetically pleasing and speedy solar trolley; thus, they completed the tasks of PBL.

The further analysis of the vehicles made by three teams of students indicated that Team *e*'s model was excellent in terms of speed, Team *i*'s was excellent in terms of the allocation of circuits and the drafting of the design, and Team *p*'s was excellent in terms of manufacturing, with a fast and stable speed. Their structures and the finished vehicles are shown in Table 7. The engineering designs of these three outstanding teams were as follows:

(1) Team E chose cardboard as the material and designed the solar trolley incorporating the characteristics of the school and the solar trolley to meet the theme. The outcome was aesthetically pleasing. They used tires from a 4WD toy car and a solar panel installed at an angle of 45°, employing their skill at assembly with sponge devices. They displayed an ability to do fine and delicate work. Lastly, the motor was padded with thick double-sided tape that effectively isolated the effect of the vibration on the gears' operation.

(2) Team *i* chose cardboard as the material and designed the trolley with the animal associated with that lunar year—the mouse—as the model, adding a tinfoil-covered paper disc on the solar panel as a reflective mirror to enhance the absorption of solar energy. Regarding the design of the circuit, they considered the factor of resistance and cut the electric wire short to reduce power consumption. Most of the materials were handmade, and no recycled objects were used. Because Team *i* came from a scientific class, they had access to more scientific concepts and manufacturing technology than did the other classes, and their engineering design and planning were more detailed and concrete.

Table 7 Drafts of solar trolleys and finished products assembled by the students

Team	Draft	Frontage	Flank	Assemblage
e				
i				
p				

(3) Team p used foam board as the body of the trolley and an L data folder as the shell of the trolley, designing a miniature version of a racing car. They mounted an adjustable solar panel at a height that would be helpful for the absorption of solar energy. On both sides of the motor, they used aircraft wood to fix the motor and prevent the vibration of the motor from affecting the connections of the gears. The results indicate that some students had excellent assembly skills and exercised engineering concepts and creativity to a high degree. However, the difference between the teams was significant; the degrees of application of scientific and mathematical concepts were average, but the difference between the teams was insignificant. Table 7 shows plans for each solar trolley.

Conclusions and recommendations

Conclusions

1. PBL strategies were helpful in enhancing students' attitudes toward STEM learning and helping them explore their future employment opportunities

Applying PBL strategies to STEM knowledge learning may assist students in exploring future career opportunities and establishing positive attitudes toward STEM learning. In terms of career exploration, students can realize their insufficient knowledge and recognize the importance of possessing multiple kinds of knowledge and abilities. Through participating in activities, students can gain more opportunities to learn about STEM knowledge and enhance their level of interest in STEM-related jobs. In terms of knowledge learning, students can integrate STEM with real-life applications and increase their problem-solving skills, technical cognition, mechanical application, and mathematical calculation abilities. Furthermore, the clear and organized characteristics of PBL enable students to learn STEM knowledge.

2. Female students were able to apply the basics of science and mathematics to concepts of engineering design, but their technological skills were obviously insufficient

The researchers found that the students had a rich body of basic knowledge about science and mathematics and could develop meticulous engineering designs. Students were able to apply the concepts of science and mathematics to the design of a solar trolley. According to the results of the study, students tended to be able to construct deliberate engineering concepts if they possessed an above average level of science and technology knowledge. Based on the activity, students were able to apply science and math concepts to design a proper solar trolley, but the techniques related to the assembly of materials and connection skills were the biggest difficulties for them to overcome. These results reflect the discussions that took place using the STEM platform, in which technology and engineering knowledge were discussed more than science and mathematics. In short, female senior high school students' basic concepts of science and mathematics were superior to their abilities related to the practical fabrication of a vehicle by hand.

3. PBL strategies provide students with an integration and application experience with STEM knowledge

In the context of STEM knowledge learning, students have undergone a series of hands-on processes, including problem-confirming, problem analysis, problem-solving, and assessment, that have allowed them to apply and explore STEM knowledge. Through their activities, students explored possible factors that might affect the forward movement of the solar trolley based their current knowledge of science and mathematics; they used these ideas for reference when they chose solar trolley materials. They also precisely implemented assembly and connection technologies for maximum benefit in the manufacture of a speedy and stable solar trolley. From the beginning to the completion of the solar trolleys, students continuously collected data, discussed their findings with their teammates, conducted experiments, assessed their progress, and modified their designs. These steps broadened students' knowledge and allowed them to put it into practice as well as enabling them to experience the deeper meaning of STEM integrated knowledge.

Recommendations

Based on the findings of the study, we can make several suggestions with reference to STEM learning for future PBL-related studies and planning activities for senior high schools.

1. Integrate PBL learning strategies and promote STEM teaching

According to the findings of the study, students hold largely positive attitudes toward STEM learning in the context of PBL. Not only can it enhance learning effectiveness, but it also provides students with the opportunity to explore their career choices. Thus, teachers should employ the PBL strategies of the STEM-related curriculum and apply them to life issues for students to explore. Through this process, students will be able to combine theory with practice and thus cultivate problem-solving skills and a high level of thinking ability. In addition, students can develop STEM-related career interests and abilities through this exploratory process.

2. Strengthen the teacher's role as facilitator and increase students' abilities with regard to the systematic integration and analysis of STEM knowledge

PBL teaching strategies and competition activities show significant effects on STEM integrated knowledge learning, according to the results of the study. However, the students suggested that learning could be more efficient and effective if they could obtain more guidance from their teachers. Teachers should be invited to become involved in this study; they could play the role of facilitator to provide students with guidance. According to the results, it seems that groups had somewhat different experiences: some groups were able to locate methods and resources applicable to their problems through the STEM online platform, whereas some groups did not find the platform to be of assistance but still participated in the competition. With this in mind, the facilitating role of the teacher could be strengthened to assist students in learning STEM integrated knowledge and in systematically analyzing and generalizing knowledge. Furthermore, teachers are recommended to form a teaching think-tank to strengthen their role and to hold meetings to discuss students' issues and learning to promote a higher level of thinking ability and learning effectiveness for students.

3. Strengthen the "Special Topic Project" curriculum to enhance female senior high school students' technological and technical abilities

In Taiwan, science education at senior high schools for girls tends to emphasize basic knowledge and the performance of experiments; less attention is paid to the application and techniques of science and technology education. PBL teaching strategies can promote the application of basic science and mathematics, but not for the improvement of science and technology. Thus, more applications and techniques from science and technology should be integrated with the "Special topics project" curriculum to explore STEM integrated knowledge learning.

Acknowledgments We would like to extend our special thanks to the National Science Council for their kind financial support of this research (Code of Plans: 96-2516-S-020-001-MY3).

References

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans: Project 2061*. New York: Oxford University Press.

Chen, P. H. (2007). *A study of STEM integrated teaching applied in the field of physics in junior high school*. Unpublished master thesis, National Pingtung University of Science and Technology, Pingtung, Taiwan.

Chin, C., & Chia, L. (2006). Problem-based learning: Using Ill-structured problems in biology. *Project Work Science Education, 90*, 44–67.

Chu, C. C. (2005). *An action research on using WebQuest teaching strategy to implement problem-based learning: Take the lesson of energy and life program in grade 10 as an example*. Unpublished master thesis, National Changhua University of Education, Changhua, Taiwan.

Chuang, S. Y. (2009). *A study of developing project-based STEM learning activity*. Unpublished master thesis, National Kaohsiung Normal University, Kaohsiung, Taiwan.

Delisle, R. (1997). *How to use problem-based learning in the classroom*. Alexandria, VA: Association Supervision and Curriculum Development.

Dennen, V. P. (2000). Task structuring for on-line problem based learning: A case study. *Educational Technology and Society, 3*(3), 329–336.

Dennen, V. P. (2008). Looking for evidence of learning: Assessment and analysis methods for online discourse. *Computers in Human Behavior, 24*, 205–219.

Grier, J. M., & Johnston, C. C. (2009). An inquiry into the development of teacher identities in STEM career changers. *Journal of Science Teacher Education, 20*(1), 57–75.

Gooding, K. (2001). Problem based learning online. http://www.google.com/search?q=cache:q7s4FPGEDBYC:www.flexiblelearning.net.au/nw2001/01_attending/papers/1_8Gooding.pdf+problem-based+learning+%26+web-based+%26+Gooding&hl=zh-TW. Accessed 3 November 2007.

Hmelo, C. E., Gotterer, G. S., & Bramsford, J. D. (1997). A theory-driven approach to assessing cognitive effects of PBL. *Instructional Science, 25*(6), 387–408.

Jeong, A., & Joung, S. (2004). *The effects of constraint-based argumentation on interaction patterns and argumentation in online threaded discussions.* Paper presented at the American Educational Research Association.

Jonassen, D., & Remidez, H., Jr. (2005). Mapping alternative discourse structures onto computer conferences. *International Journal of Knowledge and Learning, 1*(1/2), 113–129.

Klapwijk, R., & Rommes, E. (2009). Career orientation of secondary school students (m/f) in the Netherlands. *International Journal of Technology and Design Education*. doi:10.1007/s10798-009-9095-7.

Koschmann, T., Hall, R., & Miyake, N. (2002). *CSCL II: Carrying forward the conversation*. Mahwah, NJ: Lawrence Erlbaum Associates.

Li, H. Y. (2005). *The application of the problem-based learning strategy for teaching coastal problems in senior high school geography*. Unpublished doctoral dissertation, National Taiwan Normal University, Taipei, Taiwan.

Lou, S. J., Diez, C. R., Hsiao, H. C., Wu, W. H., & Chang, S. H. (2009). *A study on the changes of attitude toward STEM among senior high school girl students in Taiwan*. Paper presented at the 2009 ASEE Annual Conference, Austin, TX.

Mercier, J., & Frederiksen, C. H. (2007). Individual differences in graduate student's help-seeking process in using a computer coach in problem-based learning. *Learning and Instruction, 17*(2), 184–203.

Ministry of Education. (2003). Grade 1-9 curriculum guidelines. http://www.edu.tw/eje/content.aspx?site_content_sn=4420. Accessed 17 November 2009.

Mykytyn, P. P. (2007). Educating our students in computer application concepts: A case for problem-based learning. *Journal of Organizational and End User Computing, 19*(1), 51–61.

Naidu, S., & Oliver, M. (1996). Computer supported collaborative problem based learning: An instructional design architecture for virtual learning in nursing education. *Journal of Distance Education, 11*(2), 1–22.

Overbaugh, R. C., & Casiello, A. R. (2008). Distributed collaborative problem-based graduate-level learning: Students' perspectives on communication tool selection and efficacy. *Computers in Human Behavior, 24*, 497–515.

Rankin, J. A. (1992). Problem-based medical education: Effect on library use. *Bulletin of the Medical Library Association, 80*(1), 36–43.

REESE. (2008). About the national science foundation and the directorate for education and human resources. http://www.nsf.gov/pubs/2007/nsf07595/nsf07595.htm. Accessed 3 April 2008.

Steinemann, A. (2003). Implementing sustainable development through problem-based learning: Pedagogy and practice. *Journal of Professional Issues in Engineering and Education and Practice, 129*(4), 216–224.

Tan, O. S. (2004). Students' experiences in problem-based learning: Three blind mice episode or educational innovation? *Innovations in Education and Teaching International, 41*(2), 169–187.

Tsai, H. W. (2007). *A study of STEM instructional model applied to science and technology in junior high school*. Unpublished doctoral dissertation, National Pingtung University of Science and Technology, Pingtung, Taiwan.

Tsai, S. C., & Tuan, H. L. (2004). The integration of science and mathematics. *Science Education Monthly, 275*, 6–19.

Valcke, M., & Martens, R. L. (2006). The problem arena of researching computer supported collaborative learning: Introduction to the special section. *Computers & Education, 46*, 1–5.

Valle, A., Cabanach, R. G., Nunez, J. C., Gonzalez, P. J., Rodriguez, S., & Pieniro, I. (2003). Cognitive, motivational, and volitional dimension of learning. *Research in Higher Education, 44*, 557–580.

Williams, P. J., Iglesias, J., & Barak, M. (2008). Problem based learning: application to technology education three countries. *International Journal of Technology and Design Education*. doi:10.1007/s10798-007-9028-2.

Yeung, E., Au-Yeung, S., Chiu, T., Mok, N., & Lai, P. (1999). *Application of problem based learning strategies to enhance clinical reasoning and self-directed learning skills in a university physiotherapy programme*. Paper presented at 1st Asia-pacific Conference on Problem-based Learning, Hong Kong.

Zimmermann, B. J., & Lebeau, R. B. (2000). A commentary on self-directed learning. In D. H. Evensen & C. E. Hmelo (Eds.), *Problem-based learning: A research perspective on learning interactions* (pp. 299–314). Mahwah, NJ: Lawrence Erlbaum Associates.