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A Practical Action Research Study of the Impact of Maker-Centered STEM-PjBL on a Rural Middle School in Taiwan

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Abstract
This study explored how a 2-year, maker-centered science, technology, engineering, and mathematics (STEM) project-based learning (M-STEM-PjBL) curriculum aimed at leading students to be makers changed students, science teachers, and a rural middle school in Taiwan, where teachers were stressed due to the low birth rate and low grades in the Comprehensive Assessment Program for Junior High School Students (CAP). This practical action research study utilized data collected from 24 students in a maker class, their peers, 4 teachers, and administrative documents related to school enrollment and student competitions' records. Results showed that teachers had shifted their teaching from being teacher-centered to student-centered. The students who participated in the M-STEM-PjBL curriculum actively assisted peer learning and initiated active teacher–student interactions. Both teacher and student participants improved their practical skills during the process. Students in the maker science class had more positive attitudes toward science and science learning and changed their peers' attitudes in the regular science class. The problematic rate of not meeting the required standard in the science subtest of the CAP was reduced from 36 to 26%. Moreover, student participants' products recommended to the county or national level competitions frequently won awards. Student participants' creativity and the science teachers' teaching efforts were recognized in the media. Parent endorsement of the school was increased, the threat of losing students to other schools was decreased, and the crisis of cutting the number of classes was reduced.

Keywords Attitudes toward science · Creativity · Maker-centered learning · Rural education · STEM-project-based learning (STEM-PjBL)

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Introduction

The decreased birth rate in Taiwan has severely impacted the educational system and has led to a reduction in the number of classes and to surplus teachers (Wu, Tseng & Li, 2009). The impact is particularly severe in smaller, rural middle schools (grades 7 – 9) that were defined as fewer than 12 classes, inconveniences in transportation to school, and relatively scarce educational resources (Chien, 2016). During the middle school years, students and class numbers decrease year by year, causing students' lack of learning competition and a severely imbalanced demand and supply of teachers. Most teachers have a heavy teaching load and need to teach subjects that are not their specialty. The focus of this study is a rural middle school in Eastern Taiwan with 30 students in average in a class (270 students in the school). The student numbers of this school have been decreasing year by year, and it is now considered a small school with only nine classes. A sizeable proportion of the students (36%) failed to reach the basic competence level (C level) in the science subtest of the Comprehensive Assessment Program for Junior High School Students (CAP) in May 2014. This unsatisfactory performance rate was much higher than the national average (25%). The science-related teachers (seven in total, some of these teachers have mathematics expertise but need to teach science) discussed among themselves how they could improve students' attitudes toward science and science learning to reduce the number of students failing to reach the C level in the CAP science subtest. The science-related teachers noticed that, even though these rural school students had poor academic performance, they liked hands-on work and had a pretty good performance in making things. Two of these teachers are the members of the Maker Faire in Eastern Taiwan and actively participated in professional development workshops of the maker movement. Regional university professors encouraged and advised four of these teachers to carry out a practical action research study of establishing and documenting a maker class to explore this problem.

Maker is a widely discussed issue in contemporary education, and it is also seen as an important feature initiating future innovation. The Maker Movement aims at waking up children's inner innovative ideas and their do-it-yourself skills (Dougherty, 2012). Making can be described as project-based learning (PjBL) or hands-on learning, and it exerts a profound influence on innovative teaching in schools (Dougherty, 2013). It promotes active participation in science and engineering practices (Bevan, 2017), and it is often interwoven through science, technology, engineering, and mathematics (STEM) programs (Taylor, 2016). Moreover, PjBL teaching can narrow the achievement gap between high and low socioeconomic students (Halvorsen et al., 2012) and can increase students' scientific knowledge and ensure a higher pass rate in national tests (Geier et al., 2008). Combining PjBL with STEM can enhance students' positive attitude toward science (Tseng, Chang, Lou & Chen, 2013). The STEM-PjBL context for the makers designed by the teachers encourages students to engage in hands-on work and explore learning, improves students' ability to respond to challenges of a fast-changing world, and may help the poor academic students find good jobs in the future.

In this study, the science-related teachers designed the Maker centered STEM-PjBL (M-STEM-PjBL) course and attempted to solve the problems rural students and schools faced, through a 2-year action research study. The research questions in this study were:

1. How does the M-STEM-PjBL course influence rural students' creativity and their attitudes toward science and of science learning?
2. How does the M-STEM-PjBL course influence science teachers when the M-STEM-PjBL course is incorporated into science courses?
3. How does the M-STEM-PjBL course influence students' achievement in the CAP and the pressure on schools for cutting classes?

Literature Review

Maker Movement and Education

The world is fast changing, and science education witnesses a trend of innovation and change to cultivate students who possess adequate abilities to face future challenges. The Maker Movement is diverse, but basically, it involves students designing, developing, and sharing products to solve a realistic common problem or issue. The maker approach and spirit are not knowledge-based learning, but a course centering on hands-on work and innovation. Dougherty (2012, p. 13) argued that the maker education "serve(s) student populations that are not well served by the academic tracks traditionally available to them." It could draw on the future of a new industrial revolution through 3D printing and Arduino microprocessors (Anderson, 2014) and reflect their potential pedagogical impacts on teaching and learning (Halverson & Sheridan, 2014). Maker is rooted in Dewey constructivism that is "learning by constructing knowledge through the act of making something shareable" (Libow, Martinez & Stager, 2013, p. 21). Makers' activities and mind-sets were organized around nine key ideas: make, share, give, learn, tool up, play, participate, support, and change (Hatch, 2014). As long as a person has the enthusiasm to complete a product, everything can be the maker's object of work. Dougherty (2013) believed that maker education could benefit students' potential growth and could provide learning opportunities to individuals and groups.

Maker education in a school is often executed through STEM courses to enhance opportunities to engage in the practices of engineering (Martin, 2015). Therefore, STEM courses centering on the makers can help students improve their proficiency and interest in science, technology, engineering, and mathematics where brainstorming may enhance creativity (Clapp & Jimenez, 2016).

STEM-PjBL

The STEM teaching method integrates courses across disciplines (Czerniak & Johnson, 2014). STEM-integrated courses are diverse and aim to establish a learning environment that is centered on students (Rennie, Venville & Wallace, 2012)—unlike traditional teaching that centers on science courses—and that focuses on concepts related to the real world, personal interests, and students' experiences. When students establish meaningful connections among the new experience and prior knowledge, integrated understanding occurs (Krajcik & Czerniak, 2013). STEM-integrated courses meet the demands of the twenty-first century society and transform traditional science from positivism into constructivism (Krajcik & Mun, 2014).

As making can be described as PjBL, it provides students real, situated learning in the real world for the most effective relevant learning to take place; students can more easily see the value and meaning of the tasks and activities they carry out (National Research Council, 2012; Rivet & Krajcik, 2008). The variety of PjBL's features provides more effective means of adapting to students' various learning styles or multiple intelligences (Thomas, 2000). STEM-PjBL is based on STEM education and is a course model incorporating the project-based learning design (Lou, Tsai & Tseng, 2011). Lou, Chou, Shih and Chung (2017) suggested that STEM-PjBL courses have five phases: preparation, implementation, presentation, evaluation, and correction. This model provides students with clear steps of learning and assists teachers in designing learning opportunities and carrying out teaching. This study adopted these five phases as the basis for both teachers' planning and students' learning.

Creativity

Innovation is an important force to push forward industrial development and is the key to continuous national economic growth. Creativity is an important skill for problem solving and generating new ideas (Chan, 2013). Some scholars pointed out that the Maker Movement and STEM courses could help teachers reimage schools and foster a mindset of creativity and innovation in educational settings, ensure future economic competitiveness, and has been shown to link science learning to creativity and investigation (Bevan, 2017; Peppler & Bender, 2013). However, defining creativity is not easy—and it is hard to build objective evaluation criteria to assess creativity. Epstein, Schmidt and Warfel (2008) believed that creativity could be used in any situation and that it could be implemented, encouraged, and developed. The connotation of creativity is related to four core cognitive abilities: (a) capturing dreams and daydreams as sources of creativity, finds places and times where new ideas can be observed and preserved easily, (b) challenging difficult questions and tasks and trying new actions and methods, (c) broadening things in a new way, and (d) changing physical and social surroundings regularly. The most basic and most widely accepted definition of creativity has two features: the product of the creative process has to be innovative and the product has to be recognized as an appropriate or valuable task (Hennessey & Amabile, 2010).

The method of evaluating students' creativity should be comprehensive and diverse. Hocevar and Bachelor (1989) pointed out that evaluating creativity could include self-reported creative activities or achievements, the evaluation by others, and the assessment of products or works. Yang, Lee, Hong and Lin (2016) also emphasized additional qualitative data analyses from classroom observations and case teacher interviews (e.g. facilitating associative thinking, sharing impressive ideas, reviewing and commenting on group presentations and products) and identified supportive teaching strategies for developing students' creative science thinking. The creativity framework and qualitative measurements of this study are aligned with the connotations or features proposed by Epstein et al. (2008) and Hennessey and Amabile (2010).

Attitudes Toward Science and Science Learning

Attitudes are composed of emotions, cognition, and intentions (Myers, 1993). Attitudes can be seen as the personal faith specific to a particular person (Fishbein & Ajzen,

1975) and may be influenced by various traits. Factors influencing students' attitude toward science learning include their teachers, parents, and peers—among which teachers' teaching methods and the learning environment are the most important (Crano & Prislin, 2006). Students will translate positive classroom experiences into more positive attitudes and effort being put into learning and understanding school science (Juan, Hannan & Namome, 2018).

Furthermore, attitudes toward science means the feelings, beliefs, and values held about an object, which may be the enterprise of science, school science, and the impact of science on society or scientists themselves (Osborne, Simon & Collins, 2003). When students understand the usefulness of science in everyday life and are able to apply or practice the scientific knowledge they have acquired at school, they may enhance their science interest (George, 2006) and even change their attitudes toward science and science learning. Parents and peers are factors in developing positive attitudes toward science. Perera (2014) pointed out that students from poor backgrounds appear to benefit in science achievement from more positive parental attitudes toward science.

Students' attitudes toward science have several features, for example, showing a friendly attitude toward science and scientists; enjoying learning science, engaging in science, and the development of scientific activities; and looking for science-related professions and interests (Klopfer, 1971). Students' attitudes toward science are mainly assessed quantitatively, for example, their opinion about science teachers, anxiety toward science, the value of science, the motivation of science, enjoying science, peers and friends' attitudes toward science, parents' attitudes toward science, and the nature of classroom environment and scientific achievements (Tytler & Osborne, 2012). There are many scholars who evaluate students' attitudes toward science through qualitative means such as interview data. The rich information in interviews seems to be better able to gauge the current condition of students' attitudes toward science (Hu, Zwickl, Wilcox & Lewandowski, 2017; Osborne et al., 2003). As a result, the present study adopted qualitative interviews and response data to document and analyze students' attitudes toward science and science learning.

Methodology

Kemmis and McTaggart (2005) pointed out that a good opportunity to conduct action research is when teachers realize that students have problems in learning and when they start to plan lessons, carry out activities, and observe and reflect on teaching to solve the problems identified. This study sprung from this qualitative research framework. The first author of this study is one of the teachers as well as a trained researcher of action research. The second author is a scholar who provided counsel on the theoretical framework of action research and the M-STEM-PjBL course development.

Research Framework

This study adopted a practical action research approach (Grundy, 1982). The research framework and integrated timetable involved two school years (Fig. 1). First, the teachers made a practical judgment about the problems the school faced and provided ideas about the problems identified; they then attended professional development workshops on the maker approach and action research at a regional university. They counseled the second author about the theory of action research and curriculum development and drafted practical strategies as a workshop product (2014 August). Each year was a unit, and this study lasted 2 years in total. The M-STEM-PjBL course was divided into five phases: preparation, implementation, presentation, evaluation, and correction each school year (Lou et al., 2017) over 11 months (September 2014 ~ July 2015 and September 2015 ~ July 2016). When the M-STEM-PjBL course was over, the group of science teachers held meetings in August and determined the strong and weak points of the problems they encountered; gathered data from the observations and interviews about problems students had in learning; reflected on the influences the M-STEM-PjBL course had on the school, teachers, and students; and drafted an improved action research plan for the next year (2015 August). Upon the completion of the second cycle of the action research, they met and summarized the research (2016 August).

Research Participants

This study lasted 2 years in total representing two action research cycles. There were 15 grades 8 and 9 students participating in the extracurricular M-STEM-PjBL course each year. In the second year, six students from the first year's program continued to participate in the M-STEM-PjBL course (nine students graduated from school) and nine students joined for the first time. The participating students were selected from lower achievers who were recommended by their class teacher and voluntarily joined this program. They demonstrated problem-solving potential, keen on science, and skilled in hands-on work. They attended class meetings together as a club that was scheduled during the lunch break and other flexible hours for the whole school (i.e. elective class activities and self-study times). The M-STEM-PjBL club/course on average met for 100 min, including two lunch periods (~ 40 min) and one class period (45 min), and other opportunities during the winter and summer vacations.

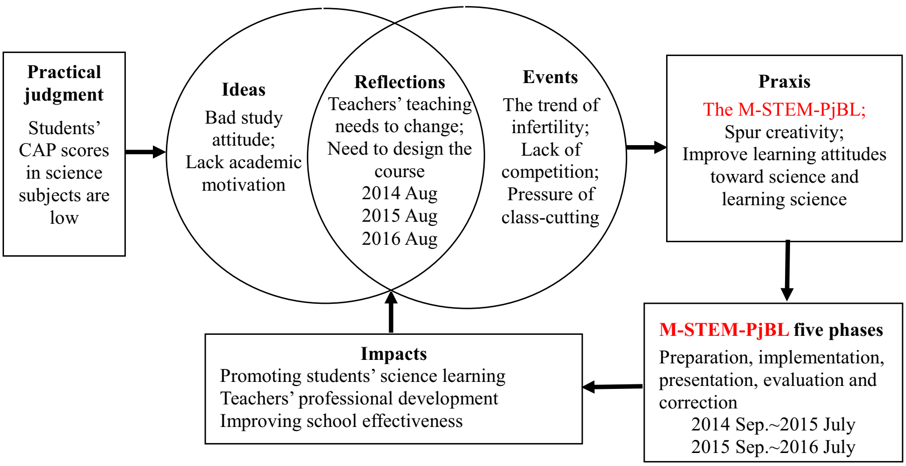

Fig. 1 Research framework of the practical action research (revised from Grundy, 1982)

There were four science-related teachers involved in the instruction for this study, two with expertise in chemistry, one with expertise in physics, and one with a teacher's certificate in electrical engineering, mathematics, and information science teaching (the first author of this article). These teachers dedicated themselves to the interdisciplinary STEM teaching approach and to cultivate students' abilities to raise and solve problems.

Data Collection

Data were collected from multiple sources to document the impact of the M-STEM-PjBL course on the students, teachers, and school. The data about the students' development of creativity included students' study notes, teachers' notes on teaching observations, students' written records on their problem-solving processes, teachers' and students' evaluations of the project products on display in the school, and the judges' feedback for the project products in competitions outside of the school. We used Epstein et al. (2008) and Hennessey and Amabile's (2010) features of creativity as the framework to categorize. The evaluations of students' attitudes toward science and of science learning were based on the following: (a) the study records and homework by the students who participated in the M-STEM-PjBL course each year, (b) the observations and interviews with students who returned to their traditional science classes (including academic performances, peer interactions, and peer evaluations), and (c) the analyses of the CAP science scores for each year. The interview data with the teachers about their feedback and reflections were collected and analyzed in order to evaluate the impact of M-STEM-PjBL. The school data included the feedback from parents of the participants, newspaper and media reports, and the enrollment statistics of new students.

Curriculum Design

Teachers designed a diverse and innovative M-STEM-PjBL curriculum to enhance students' competence in creativity and problem solving, and their attitudes toward science and science learning. Providing students with clear steps of learning, the M-STEM-PjBL curriculum was designed in five phases: preparation, implementation, presentation, evaluation, and correction. In the preparation and implementation phases, teachers taught the necessary knowledge and skills for project production and adjusted study hours according to students' learning progress. In the presentation phase, the teachers arranged a public display of students' products on campus and encouraged students to see or maneuver those products during class breaks. In the evaluation and correction phases, expert, peer, and self-evaluations guided students to modify their project products based on the feedback provided by these evaluations. Finally, each group applied for various off-campus science competitions with their project products.

The first-year curriculum was carried out in coordination with the Science Education Maker Project at the county level. The teaching content included designing GigoToys (https://www.gigotoys.com/en/) challenges and writing S4A programs (http://s4a.cat/), with a basic curriculum of learning how to control sensors by Arduino microprocessors to solve daily-life problems.

The second-year curriculum centering on the makers was coordinated with the Ministry of Education Energy Education Program, highlighting a brainstorming theme of creating green energy. Students were provided with materials needed for creating models. The teachers guided students in brainstorming and finding interactive learning resources as well as provided timely assistance to students in integrating the concepts of STEM. Finally, students completed their project products and reported in groups. Table 1 includes the M-STEM-PjBL courses designed by teachers for the 2 years, the project products that each student group completed, and the STEM concepts and connotations in all project products (i.e. codes S1 ~ S6, T1 ~ T8).

Year 1

A description of time allotment and teaching contents of the five phases from September 2014 to July 2015 (year 1) and the connotations of the four subjects of STEM are as follows.

Preparation Phase (24 weeks)

M-STEM-PjBL was innovative and new to the school, the participating teachers needed to prepare for the course by attending professional development workshops, and students needed time to familiarize themselves with the new approach. Therefore, the preparation phase was relatively long and was divided into two parts of 12 weeks each.

Part I. The main teaching content centered on GigoToys. Students were induced to use various scientific principles to design GigoToys challenges of various stages. The main content embedded in these challenges included small solar panels, wind power, and hydraulic models (Fig. 2).

Table 1 STEM concepts and connotations in all project products across the 2-year study

Science (S)	Technology (T)	Engineering (E)	Mathematics (M)
S1: simple machines	T1: choosing materials	E1: problem solving	M1: angle calculation
S2: density concept	T2: using tools	E2: thinking creatively	M2: density calculation
S3: fluid concept	T3: methods and procedures	E3: designing models	M3: load calculation
S4: conservation of mechanical energy	T4: testing and corrections	E4: designing structures	M4: rotating speed calculation
S5: thermodynamic concept	T5: Arduino microprocessors	E5: electromechanical integration	M5: rate calculation
S6: Newton's laws of motion	T6: S4A program writing	E6: engineering concept map	M6: electric energy calculation
	T7: designing thought map		
	T8: 3D drawing and printing		

Fig. 2 Students design GigoToys challenges of various stages and explain the scientific principles employed in those challenges

Part II. The main teaching content was writing S4A programs and controlling Arduino microprocessors. Working with GigoToys materials and components, students were induced to use Arduino microprocessors to control various kinds of sensors and innovatively create products that could be used in life.

Implementation Phase (16 weeks)

Students were divided into five groups of three people for the implementation stage. Each group decided on a theme based on their expertise, learning interests, or a piece of news from the local, national, or international media. After confirming with teachers the feasibility of a particular theme, each group carried out discussions and hands-on work while the teacher provided assistance in terms of materials and engineering techniques. The names and functions of the project products completed by each group are listed in Table 2.

Presentation Phase (2 weeks)

The school's academic affairs office arranged a public display of students' products on campus. All teachers and students were encouraged to view or maneuver the resulting products during class breaks. Project group members were required to be at their displays and explain their project products (Fig. 3).

Evaluation Phase (1 week)

This phase included expert evaluation, peer evaluation, and self-evaluation. The expert evaluation involved science and mathematics teachers in the rural school recruited as judges to evaluate each group's creativity and product. Each group needed to provide feedback, such as suggestions and ideas to other groups about their product, and a self-evaluation of their group's product.

Correction Phase (5 weeks)

Students were guided to modify their project products based on the feedback received in the evaluation phase. Finally, all groups were recommended to apply for various off-

Table 2 Name and function of each group's project products from September 2014 to July 2015

Group	Project title	Description of the function	Inspiration for theme	STEM code
A	NBA Ocean Park	Assembling 20 stages of GigoToys structures to create a fairy tale world of an ocean park	Student expertise and learning interest	S1 ~ S6 T1 ~ T4 E1 ~ E6 M1 ~ M5
B	Cross-sea bridge	Designing 18 GigoToys stages of challenges, incorporating small solar panels and hydraulic models	Student expertise and learning interest	S1 ~ S6 T1 ~ T4 E1 ~ E6 M1 ~ M5
C	Underground flood warning system	When a great amount of rainfall causes an underground flood, 1. Start warning lights system and block vehicles from entering. 2. Pumping motors works. 3. Emergency manual control.	News coverage	S1 ~ S4 T1 ~ T8 E1 ~ E6 M1 ~ M6
D	Wisdom house	The wisdom house has the following functions: 1. A combination lock. 2. Adjusting room temperature. 3. Switching on lights. 4. A Cloud monitoring system.	Arduino workshop	S1, S5 T1 ~ T8 E1 ~ E6 M1 ~ M6
E	Rear traffic alert system	An infra-red sensor is used to detect rear traffic or people. Detection will start a magnet to suck up the car door. If a person is too close to a trailer, a relay will turn off the car.	News coverage	S1, S4 ~ S6 T1 ~ T8 E1 ~ E6 M1 ~ M6

Please refer to the STEM code found in Table 1

campus science competitions with their project products—GreenMech contest (official website: https://www.worldgreenmech.com/en/eng_index.asp) and the Maker competition held by the county government.

Fig. 3 Students explain the functions of their products. Left: NBA Ocean Park. Right: A house security monitoring system for elderly people

Reflections and Discussions on the First-Year Program in August 2015

After the first year, teachers reflected upon their teaching, preliminarily designed a curriculum plan, and attended professional development workshops of maker and action research. Based on the feedback from teachers and students, the teachers used an inductive method to identify the following curriculum feedback and modifications.

Reflections on the Student Influences.

- It was suggested that the M-STEM-PjBL course should be designed for the entire school year and should bear the same theme to enable thorough learning. Aspects to be avoided were a discrepancy in the object of designing for the first and the second semesters and incoherence in curriculum design
- The classroom space was not large enough to demonstrate the products effectively, and students were easily interfered with while working on their project products
- The M-STEM-PjBL courses were scheduled during lunch breaks and self-study classes. Students complained that they could not take a nap at noon and, consequently, were low in spirit and energy in the afternoon classes. It was suggested that the makers club be established and students use the club activities time for required classes

Reflections on the Science Teachers' Influences.

- The M-STEM-PjBL course represented the school in the county level 2014 Excellence in Teaching Curriculum Selection and won awards, recognizing the efforts of the science teachers. Moreover, all of the students' products obtained excellent grades in competitions, indicating the M-STEM-PjBL course's value and that it was worthy of sustainable efforts
- It was suggested that teachers should be employed to establish and lead the teachers' professional development workshops to benefit other teachers at school and to reduce students' fatigue resulting from commuting for off-campus enrichment courses
- Science teachers were encouraged to apply the designed M-STEM-PjBL course in their science classes, simultaneously display project products, and explain the scientific principles used by the project students in order to strengthen students' attitude toward science

Drafting Curriculum Unique to the School. Based on the reflections and feedback from teachers and students in 2014 school year, the following modifications and adjustments were made:

- The M-STEM-PjBL course in the 2015 school year would be carried out in coordination with the Ministry of Education Energy Education Program and use creating green energy as the theme for innovative brainstorming. Moreover, the M-STEM-PjBL course would join a competition held by the Ministry of Education as a teaching outcome in 2016

- Students who take the STEM-PjBL course would form a club and regularly take class together as a club every week
- Two classrooms would be opened to the STEM-PjBL students to carry out experiments
- The science teachers would be encouraged to submit their STEM-PjBL teaching plan to competitions
- The M-STEM-PjBL year 2 course would start after the fall semester in September 2015. The allotted time for all five phases would be: preparation (16 weeks), implementation (25 weeks), presentation (2 weeks), evaluation (1 week), and correction (4 weeks)

Year 2

The year 2 time allotment and teaching contents of the five phases from September 2015 to July 2016 are as follows.

Preparation Phase (16 weeks)

The preparation phase was divided into two teaching sessions. As the teacher and six original students already had previous curriculum experiences, the original students could cooperatively assist the new students and the teachers' preparation time could be reduced. The first session combined GigoToys and Arduino microprocessors controlling. The second session combined the M-STEM-PjBL course and the Ministry of Education Energy Education Program. Focusing on electricity generation from green energy, the teacher provided various examples from around the world, such as electricity generation from thermal power, nuclear power, hydropower, wind power, and solar power.

Implementation (25 weeks)

Energy education was the main theme of the implementation. Students were divided into five groups of three people for hands-on work. The main task for each group member was different: one was in charge of communication between the teacher and group members, one took charge of hands-on work, and the other one was in charge of programming. New students were assigned to groups based on their expertise. The energy education theme of the project called for more complicated knowledge, tools, and materials. Therefore, 25 weeks were allotted to the hands-on work. The titles and functions of the products completed by each group are briefly described in Table 3.

When students began their projects, they were guided to follow four steps of problem solving: defining the problem, generating alternatives, evaluating and selecting alternatives, and implementing solutions. For example, students inspired to select a theme based on their family organic farm's solar greenhouse cooling system constructed pictorial representations to show their brainstorming ideas and discussed the feasibility of their project products (Fig. 4). They were guided (a) to use a systematical trial-and-error method to select different gears to control the speed of the motors and (b) to

Table 3 Name and function of each group's project products from September 2015 to July 2016

Group	Project title	Description of the function	Inspiration for theme	STEM code
A	Automatic taking clothes out/in system and solar tracking system	Start motor to automatically take clothes out/in according to the numbers measured by a humidity detector. The electricity needed by the motor is provided by the solar tracking solar panels.	Expertise and learning interest	S1 ~ S6 T1 ~ T7 E1 ~ E6 M1 ~ M6
B	House security system for elderly people	The system has the following functions: 1. Lights for taking medicine 2. Toilet night lights 3. Automatic bathroom dehumidifying fan 4. Automatic turning off TV 5. Cell phone monitoring	News coverage	S1 ~ S6 T1 ~ T8 E1 ~ E6 M1 ~ M6
C	Roof ventilator for electricity generation	Making an upright axis generator by putting together an abandoned ceiling fan and a roof ventilation ball. The resulting voltage Vp-p can be as large as 50 V.	News coverage on global warming	S1 ~ S6 T1 ~ T4 E1 ~ E6 M1 ~ M6
D	Solar greenhouse cooling system	Putting black-mesh insulation on the roof of the greenhouse to block out the heat; when the sunshine is not too strong or when it rains, uncover the black-mesh insulation to allow the plants to grow and breathe.	Family farming	S1 ~ S5 T1 ~ T8 E1 ~ E6 M1 ~ M6
E	Rotating solar panels (solar tracking system)	Using Arduino microprocessors to control the rotation angle of solar panels. The increased amount of sunshine allows for saving more electric energy.	News coverage on global warming	S1 ~ S5 T1 ~ T7 E1 ~ E6 M1 ~ M6

Please refer to the STEM code found in Table 1

evaluate the alternative Arduino microprocessors to set the motors forward and reverse and pushing and pulling black-mesh to block out the heat; finally, the students implemented their solutions.

Presentation Phase (2 weeks)

Groups of students displayed their products on campus in a way similar to the presentation that was carried out in year 1. All students were encouraged to use their class breaks to view or maneuver the project products. Group members were required to attend the displays to explain their project product.

Evaluation Phase (1 week)

The evaluation phase in this school year was similar to the previous year. The evaluation principles emphasized creativity, overall appearance, operational fluency, practicality, and the display of environmental protection concept.

Fig. 4 Student brainstorming pictures. Left: A solar greenhouse cooling system. Right: A rotating solar panel

Correction Phase (4 weeks)

The correction phase in this school year was similar to the previous year. The correction principles were based on the recommendations and feedback of teachers and students. The scoring standards used strived to achieve those in place at the national or county competitions. Students submitted their products for the scientific competitions in various fields after making modifications.

Reflections and Discussions on the Second-Year Program in August 2016 (4 weeks)

In August 2016, teachers reflected on and reported on this action research's impact on the school, the teachers, and the students during the preceding 2 years.

Data Analysis

This study collected multiple data sources for triangulation. Three codes were used to code all data. The first code was *role*, which included the teacher(s), student(s), judge(s), and peers. The second code was *data source*, which included feedback, interviews, observations, and reflections. The third code was *school year*. Two authors examined and coded the data. Discrepancies in coding were discussed until agreement was reached. Table 4 provides the coding table for qualitative data, for example:

- T_1-R_1-Y_1 implies teacher 1 made this first note of reflections in year 1 (2014 school year)
- S_{A1}-O_2-Y_1 implies that student 1 representing group A made this second note of observation in year 1
- J_{A2}-F_1-Y_2 implies that judge 2 in group A provided the first feedback on the project product by group A in year 2 (2015 school year)

Research Results and Discussion

Results for the students, teachers, and school are presented as assertions followed by elaboration and evidence for the appropriate data source. The assertion for each area is reported in *italics*, while elaborations are reported in normal font, and coded evidence in small font, while the emphases are underlined.

Table 4 Coding table for qualitative data

Explanation	Code 1: role				Code 2: data source				Code 3: year
Codes	T	S	J	P	F	I	O	R	Y
Meaning	Teacher	Student	Judge	Peers	Feedback	Interviews	Observations	Reflections	School year
Numbering	1 – 4	A1 – A3 ~ E1 – E3	A1 – A3 ~ E1 – E3	1 ~ 20	1 ~ 4	1 ~ 3	1 ~ 6	1 ~ 4	1, 2

The Impact of M-STEM-PjBL on Rural Students

The M-STEM-PjBL teachers used a student-centered approach, provided materials, just-in-time technical guidance required to ensure safety, and encouraged students to discuss their project in groups. The impact of M-STEM-PjBL teaching on rural students' creativity and their attitudes toward science and of learning science is as follows:

The M-STEM-PjBL Course Increased the Opportunities for Students to Self-Direct and Enhance Their Understanding, Skills, Creativity, Attitudes, and Self-confidence

The M-STEM-PjBL students produced a project product and were encouraged to participate in county- or national-level competitions based on school-level evaluations. While in the competitions, students had to clearly introduce and present their products or research results and appropriately answer the judges' questions, which required complete trains of thoughts (Fig. 5). The judges, in general, thought that the students' project products were extraordinarily creative and innovative. For example:

> J_{C2}-F_1-Y_1: These students used the water level alarm sensor to trigger an underground flood warning system. This product is complete and presentable, can solve a difficult task in life, and is very creative. (changing physical and social surroundings regularly, valuable task)
> J_{C3}-F_3-Y_2: A highly creative product. It's such a great idea to put together a ceiling fan wires and a ventilation ball (Fig. 6). (broadening things in a new way, innovative, appropriate and valuable task)

Students reported that their creativity development had improved. Feedback from the teachers and the judges was positive, which encouraged the students to become more positive about doing hands-on projects and thinking creatively. Their learning of science concepts was also strengthened indirectly. For example:

> S_{A2}-R_3-Y_1: My classmates and I created an ocean park with GigoToys. The judges admired our products. Many people visited our group to take pictures with us at the national science competition. (capturing dreams and daydreams as sources of creativity, appropriate and valuable task)
> S_{C2}-I_2-Y_2: I never thought I would be able to join a competition and obtain the first prize in county level … … The judges also thought that it was a great idea to put together ceiling fan wires and a ventilation ball, that we were strong in assembly skills, and that our product was very creative. I felt so fulfilled. (challenging difficult questions and tasks, and trying new actions and methods, innovative)

The M-STEM-PjBL Students Helped Their Peers in Their Science Classes Improve Their Attitudes Toward Science and Learning Science

The M-STEM-PjBL course encouraged students to think proactively, to do hands-on work on a scientific project, and to share the ideas with peers. They showed a friendly attitude toward science teachers and toward engaging in science activities. Moreover,

Fig. 5 Students brought their STEM-PjBL project products to science competitions, answered judges' questions, and maneuvered their products

parents appreciated their performance in the competitions, which enhanced their enjoyment in learning science. Unexpectedly, when the STEM-PjBL students returned to their regular science class, they were able to proactively assist their teachers, increase teacher–student interactions in the classroom, and build a positive attitude and atmosphere among their peers.

> S_{A1}-I_3-Y_1: After I took the maker-centered course, in which our teacher would use some GigoToys to create a car, to make pulley blocks, or to do leverage, I became energetic, and I even actively helped my classmates assemble materials. Naturally I became more serious at science classes. My classmates would look to me for answers to some questions.
>
> P_8-I_2-Y_2: The students whose academic performances were lower than mine, (but after taking the STEM-PjBL courses, they) seemed to have become stronger. Therefore, I changed my attitude toward learning science at class, and became more serious when writing a test paper, for fear that I would lose in competition against the students who took the STEM-PjBL course.
>
> T_4-R_1-Y_1: I discovered that even the student with poor academic performances could perform remarkably well. His classmates, out of fear for lagging behind, would become somewhat more serious in class and more capable of applying science laws to everyday life.

The Impact of M-STEM-PjBL Teaching on Science Teachers

The science teachers in this study changed their traditional teaching methods in a science class and designed the STEM-PjBL course to encourage students to think

Fig. 6 Students disconnected ceiling fan wires and put them together with a ventilation ball to create a roof ventilator for electricity generation

creatively, to solve problems, to look for answers, and to complete a practical product for the STEM-PjBL class.

Teachers' Cooperation, Students' Growth, and Teachers' Confidence Were Enhanced in the STEM-PjBL Teaching

The four participating teachers had inadequate prior knowledge of the GigoToys assembly and the Arduino microprocessors controlled by the S4A program at the preliminary stage of developing and implementing the STEM-PjBL teaching. Therefore, they actively engaged in many Maker-related empowerment workshops held by the department of education and the regional university. During this process, these science teachers helped each other, and the team grew from their cooperation. After a period of time using the M-STEM- PjBL approach, the teachers could see the students' progress, which strengthened their confidence in teaching. Moreover, the teachers were empowered to become makers themselves; they could even write their own textbooks, design experiments, and further incorporate the M-STEM-PjBL project products into their other science courses.

> T_1-R_1-Y_1: I want our rural students to see different teaching scenes. Nowadays' teaching model is interdisciplinary, incorporating technology and the maker movement, and using joint creativity from both the teachers and the students. The teachers have to continuously empower themselves.
>
> T_2-R_2-Y_1: I am a teacher with expertise in Physics, and I am strong in theoretical structuring but weak in hands-on skills, especially in areas that I am not familiar with. … However, when I worked with the science teachers on designing the course, I gained a lot from my observations and my learning. The GigoToys can be used to explain many ideas in Science. I will incorporate the GigoToys into the course and make the experiment classes more interesting and more engaging for the students.
>
> T_3-R_1-Y_2: I am a Chemistry teacher. Controlling the Arduino microprocessors and using the ventilation ball to generate the electricity were new areas of knowledge for me. I could incorporate the ventilation ball into the Electromagnetism unit, and I believe the students from the regular classes would be very impressed by this. Moreover, the GigoToys materials are important tools for successfully carrying out science experiments.

Extending the M-STEM-PjBL Course to the Normal Science Class Transformed Teacher-Centered Teaching to Student-Centered Teaching

As the teachers had been empowered as makers themselves, they valued the students' learning motivations more, assisted the students to develop their abilities into self-regulated learning, developed the students' multiple intelligence, and confirmed multiple evaluations and multiple values. Furthermore, these teachers modified, extended, or adopted the M-STEM-PjBL approach and experiences into their normal science classes and appointed the M-STEM-PjBL students as the teachers' helpers. The students who were not in the M-STEM-PjBL course were inspired to develop their hands-on skills while doing experiments, and the teacher-centered approach was successfully transformed into student-centered teaching.

> T_2-R_2-Y_1: The STEM-PjBL students have become my little helpers. They actively prepared materials, assisted me in experiments and demonstrations, and made experiments easy and successful.
> P_{11}-I_3-Y_1: I think they (the STEM-PjBL students) knew the experiment materials better than our science teachers. They proactively assisted us, probably because they often assembled the GigoToys , had become confident.
> P_4-I_3-Y_2: We preferred to have those little teachers to teach us how to do experiments, because I often failed to understand what our teachers said, and we were more scared of our teachers.
> P_{15}-I_{T4}-Y_2: I feel great to prepare and assemble materials. I don't feel bored at class anymore, and I look forward to having science classes.

The Impact of M-STEM-PjBL on the Rural School

The M-STEM-PjBL students not only increased their confidence by taking part in competitions at levels higher than the county level but also became able to help their peers to learn science and influence their peers' attitudes toward science and science learning. These students became able to assist actively the science teachers in preparing for a class, and their attitude toward science learning changed.

The M-STEM-PjBL Experiences Enhanced the Participants' and Other Students' CAP Scores in Science Subjects

The teachers designed various courses and brought out what students had learned in diverse ways. The M-STEM-PjBL teaching improved students' attitudes toward science, produced a ripple effect in learning where other peers were also influenced, and led to improvements in CAP scores. The students built a positive atmosphere for science learning at school and benefited their peers in learning science as indicated by their enhanced scores in science subjects. The percentage of C-level students in their CAP scores decreased from 2014 to 2016, after implementing a 2-year STEM-PjBL action research program (Table 5).

Table 5 Ratio of C-level students by their CAP science scores from 2014 to 2016 school year

School year	Number of graduating students	Number and ratio of C-level students	National ratio of C-level students (%)
2014 (spring)	101	36 (35.6%)	25.3
2015 (spring)	109	27 (24.7%)	22.8
2016 (spring)	93	24 (25.8%)	22.2

Developing M-STEM-PjBL Courses Helped in Recruiting Students into the School

During the 2 years when the STEM-PjBL teaching was conducted, the students won numerous awards in science competitions, and the local newspaper and media often reported on these positive achievements (Appendix). Therefore, developing featured courses has become an effective weapon against the threat of losing students. The parents in the host school district also endorsed the effects of teaching, and the percentage of new students has been increasing for the last 3 years (Table 6).

Conclusions and Implications

Following the 2-year implementation of the M-STEM-PjBL course, all the students, the teachers, and the school have demonstrated gains in terms of science teaching and learning.

Gains of the Students

The M-STEM-PjBL course provided students an authentic real-world situation for learning and made it easier for them to see the purpose and the values of the tasks and hands-on activities. The teachers and the students strengthened their hands-on skills, creativity, and self-confidence while interacting with each other. Following the completion of this program, the M-STEM-PjBL students were found to have progressed in creativity, positive attitude toward science, and building a supportive and empowering atmosphere among their peers in science learning. This progress was demonstrated by their performances in the science competitions and the CAP science subtest. However, the advantage of action research lies in solving urgent problems faced by schools. Variables cannot be controlled in the action research. Therefore, the researchers could not accurately infer a causal relationship between the M-STEM-PjBL and the students' cognitive process. This is a limitation of this study that we will explore further.

Gains of the Teachers

Under the cooperative support from the school administration and the teachers' community, these science teachers gained more confidence in interdisciplinary

Table 6 Ratio of new student enrollment from 2015 to 2017 school year

School year	Number of new students in that town	Number of new students enrolled	Ratio of enrollment (%)
2015 (fall)	115	73	63.5
2016 (fall)	99	69	69.7
2017 (fall)	114	83	72.8

teaching and also became makers themselves. The maker course successfully transformed their teaching from being teacher-centered to student-centered. The teachers now value students' learning motivations more and assist students to develop their self-regulated learning ability. The M-STEM-PjBL students, when they returned to the science class, actively provided help to their peers in learning, built a favorable environment for science learning, and inspired their peers to engage more in learning science. The students' products enriched the course content. With support from the school administration, the teaching outcomes were submitted to the Ministry of Education's selection of energy education courses and were awarded 100,000 New Taiwanese dollars. This award undoubtedly was the greatest encouragement for the enthusiastic teachers.

Gains of the School

When the appropriate action research plan was implemented, difficulties in teaching could be overcome and a win–win situation was created for the teachers, the students, and the school. The results of this study indicated that the STEM-PjBL course centering on the makers has obviously improved students' CAP science scores and has successfully reduced the pressure to reduce the number of classes for the last 2 years in this rural school. This school has continued to grow with parents' endorsements. The maker course has become one of the school's featured programs and successfully resolved some of the difficulties the small rural school faced. However, this success could be attributed to the relatively ample time and space for the maker education that only rural schools could afford. If this action research were carried out in town or city schools, the students and the parents might resist joining the maker class because of the academic progression pressures.

This finding echoed Dougherty's (2012) claim that the maker education leaves no child behind and enabled these rural school students to experience the joy of learning. Therefore, the emphasis for teacher education should lie on stressing children's multiple intelligences, implementing multiple assessments, and supporting the maker education and the STEM-PjBL via multiple intelligences. In the M-STEM-PjBL course in this study, the teachers and students learned from their practices and practiced what they had learned. Therefore, teachers must cooperate across their communities of expertise and actively participate in their professional development courses. When teachers are willing to change from traditional teaching to student-centered teaching and encourage themselves, their students, and their peers, the fruits of learning will be shared. This situation echoed the Maker Spirit; it resolved the difficulties the rural small school faced, such as the reduced number of students and class reductions that were caused by low population growth.

Based on the implementation results of this study, the researchers will continue to promote the M-STEM-PjBL course, assist other rural small schools that share the same class-cutting pressures to form the Maker Alliances, and carry out the M-STEM-PjBL research across subjects. This study may serve as a reference for researchers and scholars who are dedicated to the improvement of rural schools.

Appendix

Award-winning products in the science competitions in 2014 school year

Group	Name of product	Type of competition	Rank
A	NBA beautiful girls	Maker competition at the county level	3rd place
	NBA Ocean Park	Maker competition at the national level	Excellence award
B	Cross-sea bridge	Maker competition at the county level	Excellence award
		Maker competition at the national level	Excellence award
C	Underground flood warning system	Arduino competition at the county level in year 104	1st place
D	Wisdom house	Arduino competition at the county level in year 104	2nd place
E	Rear traffic alert system	Arduino competition at the county level in year 104	3rd place

Award-winning products in the science competitions in 2015 school year

Group	Name of product	Type of competition	Rank
A	Automatic taking clothes out/in system & solar tracking system	Arduino competition at the county level in year 105	1st place
B	House security system for elderly people	National Arduino competition in year 105	2nd place
C	An analysis of the optimization of the electricity generation by a ventilation ball	55th science fair at the county level	1st place at county; Excellence at national
D	Solar greenhouse cooling system	1st creativity science project competition at the county level	Gold creativity award
E	Solar tracking system (rotating solar panels)	Arduino competition in the Eastern District in year 105	Excellence award


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Fig. 7 Students won awards in science competitions with the STEM-PjBL project products, which was reported by newspapers

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