Practicing integrated STEM in renewable energy projects Solar power

by Tantri Mayasari

Journal of Physics: Conference Series

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Abstract. This paper describes students content knowledge of STEM in the process of project based learning. The selected project in this study is renewable energy (solar power), because Indonesia is located on the equator line which gets abundant sunlight as well as to popularize alternative energy in Indonesia as an effort to prevent global warming. This study was designed to determine the effectiveness of Solar Power Project to promote students content knowledge of STEM. The subjects were 28 pre service physics teachers divided into seven groups. This research used both qualitative and quantitative methods (mixed methods). Pre-test and post-test of STEM knowledge as quantitative data were conducted to determine students' achievement and the effectiveness of learning. Furthermore, the shift of students STEM knowledge was tracked using video recording, task, reports, and interviews. Quantitative data were analyzed using a paired t test, whereas quantitative data were analyzed by triangulation of data. The results of the study showed that science content knowledge experienced the largest increase, followed by engineering, technology and the last is mathematics. Conclusion, solar power project can be helpful in enhancing students achievement of STEM knowledge and generate meaningful learning.

1. Introduction

The first Campaigns to reduce global warming have been done in the elements of society. People from the education field in Indonesia also participate in this campaign such as using clean energy and reducing greenhouse gas emissions (GHG). One of its efforts is to devise effective learning to provide students' experience in the utilization of alternative energy, as a shift in the use of fossil fuels into alternative energy. The alternative energy with the most potential to be developed in Indonesia is solar power, because Indonesia is located on the equator and gets the sun all day from morning to evening with the average solar radiation intensity 4.8 kWh/ m2 in a day. Nowadays solar has been utilized and it is one of the most promising energy sources in the 21st century because it is clean, renewable and has high intensity in Indonesia.

The educational programs must be adapted with international priorities and strategies in the field of energy efficiency in buildings and climate change [1]. Educators need to design innovative learning to

Journal of Physics: Conference Series **1280** (2019) 052033 doi:10.1088/1742-6596/1280/5/052033

get a better understanding of renewable energy sources for sustainable development and to promote awareness to long-term behavioral change. Innovative learning can provide students' experience especially in promoting renewable energy in Indonesia. Learning that is able to provide direct experience can activate the hands-on and minds-on simultaneously, such as project-based learning strategies. Project-based learning has strategies that adhere to the philosophy of "student-centered learning", "learning by doing", and "group learning" [2].

The educational activity of undergraduate science and mathematics students should combine outdoor experiences, hands-on learning, group discussion, collaborative learning, and experimentation, with interpretation and sharing of the results. Students must obtain a conceptual framework for organizing and applying what they have learned. Assessments should be authentic, ongoing, diverse, and be capable of uncovering student misconceptions. These elements share in common the goal of promoting student construction of knowledge [3, 4]. To attain these and other features of student-centered instruction, this study utilizes project-based learning that integrated science, technology, engineering, and mathematics (STEM) knowledge. This study chose a project of solar power used as alternative energy. In the process of developing the project, students must use a variety of disciplines in order to develop a good product. STEM knowledge can develop if it is linked to the environment to realize a study that presents real life experience for students in their daily life activities [5, 6].

This paper discuss the results of learning that integrates STEM on renewable energy projects using solar power. This study answer two questions: 1) how is the effectiveness of project-based learning that integrates STEM? 2) How is the practice of integrating STEM in renewable energy project-based learning?.

2. Methods

2.1. *Research Design*

This study is a mixed methods research that combines quantitative and qualitative data [3]. Quantitative data in this study were the results of STEM tests, while qualitative data were obtained from interviews, portfolios, and tasks. Subsequently, quantitative and qualitative data were analyzed. The results of STEM knowledge tests (pre-test and post-test) were analyzed using paired t-test to determine whether there are differences in students' STEM knowledge before and after learning. Qualitative data were analyzed using triangulation of data and made coding as in Table 1.

Table 1. Qualitative data coding.

Source	Code	Example
Task	T	(I-4-1) refers to interview data for the first member for group 4.
Report	R	(T-3-6) refers to the 3th task from group 6
Product	P	(P-6) refers to the product of group 6
Interview	I	

2.2. *Participants*

The study involved 28 prospective physics teachers divided into seven groups of renewable energy projects with each group of four students in one campus in Madiun, Indonesia. Each group chose its own project in accordance with the problems they found.

2.3. *Instruments and data analysis*

During the study, the researchers recorded the students' activities in collecting ideas, discussing, collecting data, interacting and using STEM to find solutions to problems that have been raised by each group. To determine the effectiveness of the STEM project-based learning, STEM knowledge tests were

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administered before and after learning activities. To find out what STEM was used during the process of project-based learning, the researchers recorded each group using a handy cam. The shift of STEM knowledge that occurred either in individuals or groups during the manufacturing process until the completion of the product was tracked through the video recordings, interviews, portfolios, and tasks. The data that has been collected and the instrument used in this study include:

2.3.1. Tracking STEM utilization in renewable energy projects in solar power. Data related to STEM content analysis was collected through both formal and informal means. Formal data was obtained from STEM knowledge tests, portfolios, reports, tasks, and video recordings during the learning process. Informal data was obtained from discussions and performance. Descriptive analysis was used to analyze both formal and informal data in the study STEM - related content acquired during the learning process.

2.3.2. Students' achievement in STEM knowledge. STEM knowledge tests consist of 20 questions that have been examined by five experts. To determine the validity of the test, it was calculated using Content Validity Ratio (CVR) for each item tests and Index Validity Ratio (IVR) of 0.89 were determined valid. The reliability tests have been tested on 57 students in class trials before the study was conducted. Furthermore, STEM knowledge test results were analyzed using paired t-test.

2.3.3. The response of students to project based learning that integrate STEM. To study the response of the students, questionnaires were distributed to students. The questionnaire consists of 15 items using 5 item Likert scale and it also consists of three domains, namely: effect (Cronbach's α=0.93), attitude (Cronbach's α=0.89), and STEM project-based learning (Cronbach's α=0.87).

3. Result and Discussion

Results of the study were divided into two parts. The first part answers the first research question about the effectiveness of project-based learning that integrates STEM. The second part is "what STEM knowledge that is used to complete the solar renewable energy projects?"

3.1. *The effect of project-based learning that integrate STEM knowledge in students' achievement*. STEM knowledge tests were carried out before the study (pre-test) and after learning (post-test) in order to determine how STEM project-based learning affect the students' learning achievement. Pre-test and post-test assessment results are presented in Table 2.

Table 2. Descriptive statistic students' STEM knowledge before and after learning.

Participant	N	Subject	Pre-test		Post-test	
			Mean	SD	Mean	SD
Students	28	Science	2.586	0.639	3.579	0.279
		Technology	2.664	0.769	3.050	0.521
		Engineering	2.492	0.793	3.493	0.333
		Mathematics	2.407	0.803	3.007	0.534
		STEM (total)	2.537	0.719	3.282	0.389

This study used paired-sample t-test to determine differences in students' knowledge on STEM before and after project-based learning. In general, students' knowledge on STEM changed significantly both before and after the study, as shown in Table 3. Science underwent the biggest change ($t = -11.183$, $p < 0.001$), while technology have the smallest change ($M = -0.386$, $t = -6.854$, $p < 0.001$).

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Table 3. Difference of students' STEM knowledge before and after project-based learning (n = 28, df = 27).

Subject	Pre/Post	Mean	SD	t
Science	Pair 1 Science– post Science	-0.993	0.470	-11.183***
Technology	Pair 2 Technology – post Technology	-0.386	0.298	-6.854***
Engineering	Pair 3 Engineering – post Engineering	-1.000	0.616	-8.592***
Mathematics	Pair 4 Mathematics –post Mathematics	-0.600	0.381	-8.332***
STEM (total)	Pair 5 STEM - post STEM	-0.744	0.364	-10.818***

*$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

STEM content knowledge is examined from interviews and learning observations. The results are: Quantitative data on students' knowledge of science content in both pre-test (M = 2.586, SD = 0.639) and post-test (M = 3.579, SD = 0.279) experienced positive changes and increased significantly (M = -0.993, SD = 0.470, t = - 11.183, p <0.001). Before learning, students demonstrated mastery of science concepts by 64.64%. After the learning process, mastery of concepts students were 89.46%, its increased gain of 0.702 is categorized as "high" increase. Results of the questionnaire on responses of lectures and interviews also support these findings. The students stated "the enhancement of knowledge of science content is very high" (Q-4-1), another response stated "science can be used to solve problems encountered in daily life" (I-1-3). Observation results during the process of project work shows the use of science to complete the project. For example, students used the principles of materials that have properties of conductors and insulators to trap heat inside the solar oven (P5), utilizing the principle of black body radiation by painting black equipment is used as a heat sink (P1,2,4,5,6).

Ideal science learning involves participants actively in the learning process (student-centered), resolve problems related to daily life, enable hands-on and minds-on [3]. Project-based learning is able to accommodate the above characteristics. [4] state that through project-based learning, students become independent learners and thinkers. Students seek a solution of the problems related to everyday life by designing their own inquiry, planning lessons, organizing their own research. [5] research results state that project-based learning activities can improve students understanding significantly. The results of the same study are also stated by [6]. They stated that the project-based learning encourages students to get involved through active participation in mental and physical activities that require in-depth research. When students successfully complete the project by producing a product, then they have understood the topic of the lesson and also the process. In this study, students' knowledge on science experienced the largest increase after joining the STEM project-based learning. High increased knowledge of science cannot be separated from the background of research subjects. The subjects of the study are prospective physics teachers who already have sufficient knowledge of scientific concepts so that when they were stimulated using PjBL to explore science learning, students experienced a significant increase in their science concepts.

Quantitative data on students' knowledge of technology content shows an increase (M = -0.386, SD = 0.298, t = -6.854, p <0.001) in both pre-test (M = 2.664, SD = 0.769) and post-test (M = 3.050, SD = 0.521). Nevertheless, the increase in the technology content is the smallest among others (science, engineering, and mathematics). The most interesting result of this study, before learning technology content tops the list, but after learning, technology content ranks third after science and engineering. The results of interviews with several students indicated "learning that involves technologies, such as utilizing social media to communicate and discuss with your friends and the lecturers are very helpful in completing the projects" (I-7-2, I-1-4, I-6-3), Another statement "we often see solar cells installed on the lights in the street, but we do not understand in detail how the process that occurs in solar cells that can convert sunlight into electricity" (I-1, I-2, I-6).

This findings show that technology has increased at least compared to science, engineering, and mathematics. Although the increase is the smallest, it still increased significantly. The results of interviews with students obtained information that students often see or even use technology in their daily lives. However, students have not studied in depth the work process of technology. Research results by [7] also found that technology increased the least compared to science, engineering, and mathematics. According to [8], students do not have the opportunity to understand the relationship between theory and practice of technology, although they are often used in schools.

Engineering content knowledge increased significantly from both prior learning (M = 2.492, SD = 0.793) and after learning (M = 3.493, SD = 0.333). Before learning, students' mastery on engineering concept was 62.32%. After the learning process, it became 87.32%. N gain score for mastery of engineering concepts is 0.663 and categorized as "medium". At the time of interview, the students stated that "manipulating the tool in order to have a specific function is challenging and extremely exciting" (I-7.3), another statement "engineering is the application of science and it takes creativity to solve everyday problems" (I-2-4). Related learning, students stated that this is their first experience in learning to integrate engineering "integrating engineering into learning is our first experience" (I-3-4), (I-7-4). This is supported by data from the learning questionnaire responses, 96% of students stated that project-based learning that integrates STEM is their first time. Engineering knowledge has increased significantly. Prior to learning, students' knowledge on engineering is in third place after technology and science. After learning, it is in second place after science. The results of interview suggest that students have a positive attitude toward engineering subject, although project-based learning that integrates knowledge of STEM is their first experience. Research results by [7] and [8] stated that project-based learning that integrates STEM can improve achievement in engineering. Quantitative data on mathematics content knowledge both pre-test (M = 2.407, SD = 0.803) and post-test (M = 3.007, SD = 0.534) showed a significant increase (M = -0.600, SD = 0.381, t = -8.332, $p < 0.001$). What made quantitative data interesting is mathematics content ranks last in both before and after learning. The results of interviews state, "the students do not like math because they find it difficult to work on the problems that require logic" (I-3-2, I-6-1). Regarding mathematics content that they apply on this project: "fortunately mathematics that we use to work on our project is not too complicated" (I-5-4, I-4-2) other comments "science, technology and engineering are intimately associated with math, because it is the basis for other disciplines "(I-7-1).

Based on quantitative data, students' knowledge of mathematical concepts has increased significantly. It is also supported by [9] which states that the research results of project-based learning with technology are able to encourage students to achieve significant learning achievement. It provides real learning experiences (authentic learning experiences) needed by students. However, knowledge of mathematical concepts ranks last both before and after the project-based learning. [10] said that there are evidences suggesting that students' learning outcomes are strongly influenced by their attitude towards the subject. Based on interviews, the students do not like math because they find it difficult to solve the problems. [11] stated that most students do not like math because the principles in mathematics are difficult to understand and it takes a long time to understand these principles.

3.2. STEM used in solar renewable energy projects

STEM project-based learning consists of 8 stages: problem identification, exploration, ideate, the analysis of ideas, making the design, project work to produce a prototype, testing and data collection of solar power tool, making improvements, and finally presenting the results of the project. Students use their STEM knowledge at each stage of learning.

In order to focus more on analyzing the STEM knowledge, the researcher chose one of the projects randomly. The chosen group was group 6, which consisted of four students. One member of the group comes from Maospati, a central area of crackers hence that group identified problems in that area. Based on the observations, the majority of cracker sellers dry the wet crackers in front of their house or in the roadside by utilizing direct sunlight. Group 6 identified three issues; 1) drying by utilizing direct sunlight is very troublesome. When it is raining, the sellers have to put the crackers quickly into their house. Moreover, it takes too long time to dry crackers. 2) Drying crackers on roadside is disturbing road users. 3) If the crackers are dried on the roadside, they will be contaminated by dust, dirt, or pollution vehicle,

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then the crackers are unhygienic and not in a good quality. Based on these three issues, group 6 planned a project to make a solar cracker dryer.

The teacher asks students to discuss ideas they have made, each group subsequently writes in an idea tree illustrated in Figure 1a. After the students pour out their ideas, each group makes a preliminary design based on the results of brainstorming and information gathering from various sources they have done in exploration stage. Preliminary design of group 6 is illustrated in Figure 1b.

(a) Ideate tree of group 6 (b) Preliminary design of group 6

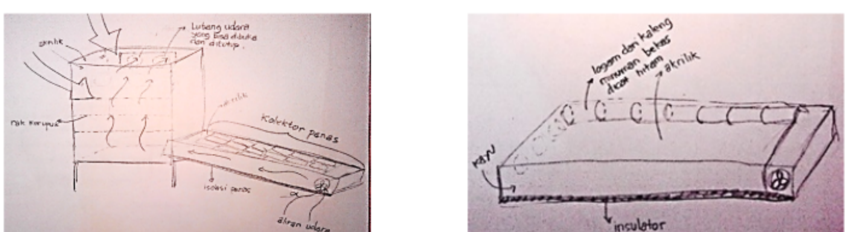
Figure 1. Ideate stage.
STEM integration and its application:

3.2.1. Integration of science (S) and mathematics (M) in making the design of solar dryers. The main principle of the solar dryer is heat and air flow. Group 6 used science and mathematics in an attempt to find ways to make the tool more efficient in drying crackers. This is related to how to increase the temperature in the drying chamber, how to make the collector to be able to collect heat, and how to keep the air circulation in the appliance running properly. Science content knowledge to complete this project were heat transfer (conduction, convection, and radiation), black body radiation, thermodynamics, solar flat-plate collector, active and solar drying, photovoltaic cells, and photovoltaic conversion systems.

Before students start to work on the project and revise the initial design, they review first the position of the sun in the area of study. The area of the implementation is geographically located at 111°E - 112°E and 7°S - 8°S. Each group calculates the declination angle, and the sundial angle to obtain optimal sunlight in the latitude of the location of our place and the test project time. Declination angle is calculated using the formula:

$$\delta = 23.45\, sin \frac{360(284+N)}{365} \quad (1)$$

N is the time we calculate the declination angle in a year, e.g. January 1, N=1, December 31, N=365, while the trial of solar power project was held on May 8, hence N=128. Based on the formula (1), the declination angle of the sun on May 8 is at 16.969°.



(a) Revised design (b) Heat collector

Figure 2. Second design of group 6.

In the analysis of the idea, group 6 reviews the preliminary design they have made (Figure 1b). In the initial design, the students use plastic as a cover for crackers that are dried. Students are planning to make such a greenhouse effect that traps heat (T-3-6, I-6). But with the initial design, an attempt to trap heat is still not well facilitated. In addition, many open cavities results in the heat in the dryer being less than optimal hence the air flow is still less (T-4-6). Thus, it is necessary to revise the initial design. The next design is trying to make both heat and air flow run well in the solar dryer. Next, group 6 thinks of ways on how to keep the temperature inside the tool higher than the temperature of the surrounding environment. According to the group 6, there are two ways, first create a box that is capable of trapping heat (the greenhouse effect), and second, make a heat collector (T-4-6). The second design of group 6 is illustrated in Figure 2.

3.2.2. Applying engineering (E) to select solar dryer's materials. Students use their science and mathematics concept to create a solar dryer that has a high thermal and good air flow. Furthermore, the students use engineering concepts to find the right materials in the developing of solar dryers. In the initial design, the students use wood as the walls of the box, with no additional insulation. However, the wooden walls have not been able to prevent heat loss. Group 6 further add used cardboard and metal sheet on the outside of the wooden wall as an additional thermal insulation. Besides, the metal sheet also serves as a wood protector, hence, it will not be quickly obsolete and as water-resistant material (T-4-6). Related to the greenhouse effect, group 6 in a preliminary design used plastic, but, in retrospect, they stated that the use of transparent plastics is less precise, because the plastic is easily ripped, difficult to clean and easy to expand as it has a linear expansion coefficient of 1.3×10-4/°C. Based on these reasons students take the initiative to use acrylic because it has a clearer translucent quality, has good insulation, flexible, and lightweight (T-4-6). In the solar collectors, group 6 made a rectangular wooden container. Its top uses acrylic material so that it can trap heat and it uses beverage cans that are painted black so that it can absorb the heat. The bottom of the collector is coated by Styrofoam and covered using plywood as a heat insulator to avoid heat loss in the collector. The longer the collectors the more heat is generated to flow into the dryer box of crackers. At the bottom of the collector, there is a hole about 5 cm in diameter, and a small DC fan is added to draw outside air to enter the collector, thus enabling active air flow which can speed up the process of transporting moisture from the crackers' material. The power to turn the fan is obtained from solar cells. For crackers' storage, the students make three racks that use frames with small black nets. The net is to make upward air flow upward can happen easily.

3.2.3. The use of technology (T) in the project. Solar dryers use existing technologies to improve the effectiveness of the tool. Technology used: Polycrystalline solar cells can convert light energy into electrical energy. Polycrystalline solar cells are often found in engineering stores in Indonesia and the price is also cheaper than other types. Solar cell or photovoltaic cell is also commonly called a P-N junction of single crystal silicon. Solar cells utilize photo-electric effects of semiconductor materials that can collect solar radiation and convert it into electrical energy (T-4-6). At the stage of test and refine, group 6 has completed the project and testing the solar cracker dryer to dry crackers. Based on trial results, crackers can be dried for 6 hours in a hot season, whereas when dried directly without solar cracker dryer take as long as 2 days. Groups 6 plan further improvements by adding the amount of heat collectors into the box. Figure 3 present test and refine stage from finishing product.

(a) Finishing solar cracker dryer (b) Try to dry cracker (c) Cry cracker

Figure 3. Test and refine stage of finishing solar cracker dryer.

4. Conclusions

Attempts to prevent global warming should be encouraged by all people for the sake of the earth's survival. One attempt in the field of education is to introduce alternative energy to students. In addition, teachers should teach how to develop alternative energy through project-based learning. The aim of this study is to improve understanding of STEM concepts through alternative energy projects (solar power). Based on the discussions and analyses presented herein, the conclusions have been drawn: The STEM project based learning can promote students' STEM knowledge. In general, students' knowledge of STEM changed significantly. Comparing the effectiveness of STEM knowledge after students implemented STEM project-based learning, the most effective subject is science, the second is engineering, the third is mathematics, and the last is technology. In the STEM project based learning, students resolve problems related to daily life with undergone a series of hands-on and minds-on to apply and explore STEM knowledge. These activity enabling students to experience the deeper meaning of STEM knowledge.

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