JPPIPA 9(5) (2023)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Applying Environmental-STEM Approach on Pollution Issue Material to Enhance Students' Problem-Solving Skills

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Received: March 23, 2023
Revised: May 27, 2023
Accepted: May 29, 2023
Published: May 31, 2023

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DOI: 10.29303/jppipa.v9i5.3846

Abstract: The learning process has not emphasized developing problem-solving skills since students memorize concepts, thus, the skills are not optimally trained. This study aimed to compare students' problem-solving skills between groups of students using the Problem-based Learning (PBL) model with the E-STEM-based student worksheet and the PBL-only model on environmental pollution at one of the Islamic Senior High Schools in Banda Aceh, Indonesia. This study employed a quantitative method with an experimental research approach using the pretest-posttest control group design. The population was all grade 10 students at the school studied, and the sample was 84 students using a total sampling technique. The instrument was ten long answer questions to measure problem-solving skills. Analysis of students' problem-solving skills data was done by t-test at a significant level of 0.05. The results indicated differences in students' problem-solving skills after experiencing the PBL model applied combined with an E-STEM-based student worksheet on environmental pollution.

Keywords: Problem-based Learning; E-STEM Approach; Problem-solving Skills; Environmental Pollution.

Introduction

To be success in academic, one of the important features is problem-solving skills (Gutierrez, 2012), which has stunning benefits for students such as it is students centred, it increases students' achievement and confidence in dealing with problems critically and analytically, promotes collaboration and teamwork, increases metacognitive skills, and helps with long-term knowledge retention (Marshall, 2022). Problem solving is very important for student development because it can foster self-confidence and productivity (Siagan et al., 2019). Practicing problem solving persistently would be able to develop student's awareness of social and academic condition. Besides, students could develop patience and time management.

Problem-solving skills must be trained since it greatly contributes to students' success. Studies in teaching problem solving with various models in Biology learning have been investigated to measure students' ability in dealing with assigned tasks critically (Fitriani et al., 2020; Fradila et al., 2021; Mahanal et al., 2019; Priyadi & Suyanto, 2019; Suwono et al., 2023). Additionally, problem-solving skills are also important for creative problem-solving and information processing (Amran et al., 2019).

A research from Nugraha and Zanthy (2019) explained that students' have low problem-solving skills because the learning process employed conventional learning (using a lecture-style learning model). Most students take notes and pay attention, and only a few actively ask questions (Masitoh & Fitriyani, 2018). This common case of teaching style is also occurred in classroom at some schools in Aceh province.

Initial findings of interviews with biology teachers concerning the teaching and learning at the school

How to Cite:
Artika, W., Amalya, C.P., Safrida, S., Maulida, M., Afandi, A., & Ratna, L. (2023). Applying Environmental-STEM Approach on Pollution Issue Material to Enhance Students' Problem-Solving Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 4036–4042. https://doi.org/10.29303/jppipa.v9i5.3846

studied in Banda Aceh, Indonesia, indicated that the learning has not yet focused on developing problem-solving skills because students tend to memorize the concepts. Most of them still cannot apply the concepts to problems, especially in daily life problems, due to the lack of problem-solving skills practicing. In addition, the learning process in the school has yet to apply the indicators to develop students' problem-solving skills; therefore, the skills cannot be optimized.

Problem-solving indicators in education can vary depending on the specific context and domain. Some examples of problem-solving indicators in education include basic reading skills, problem-solving instruction, problem-solving ability scale, written tests, critical thinking ability, and eHealth literacy. For instance, Sabatini et al., (2014) found that students' skills in basic reading are strengthened by their capability in reading, understanding, and solving complex learning environments problems. Baah Duodu et al. (2019) assessed pre-service teachers' skills of problem-solving of the use of area, set, and linear model fractions using problem solving scale. Alreshidi & Alreshidi (2023) conducted a systematic review on solving problem and critical thinking skills of medical students that has exposed to Problem-based learning.

According to Cahyani & Setyawati (2017), the steps of problem solving of Krulik and Rudnick, Polya and Dewey, are quite similar, yet the Polya's problem solving indicators has widely used and has precise steps. According to Cahyani & Setyawati (2017), Polya's indicators of problem-solving are presented in Table 1, Problem-solving skill can be measured using long answer questions consisting of four indicators as follow:

Table 1. Problem-solving Skill Indicators

Aspect	Indicator
Understanding the Problem	Learners can demonstrate an understanding of the Problem by identifying the known elements.
Devising a plan	Students can create/develop a settlement strategy and represent it
Carrying out the plan	Students can choose and apply problem-solving strategies to get resolved.
Looking back	Learners can conclude

In addition, there are aspects in promoting problem-solving skills including proposing the actual situation of problem, encouraging discussion, sharing opinions, and collaborating to find and solve the problem in numerous ways (Nugraha & Zanthy, 2019). Such aspects mentioned formerly can be promotes by applying Problem-Based learning (PBL) model (Mustofa & Hidayah, 2020; Yıldırım & Sevi, 2016). PBL can help learners develop problem-solving skills because students must be engaged in identifying problems, finding solutions, and evaluating them (Masitoh & Fitriyani, 2018).

The steps of the PBL model are as follows: (1) leading learners to problems, (2) arranging learners to learn, (3) supporting learners to have independent and group investigations, (4) evolving and presenting objects and displays, (5) examining and evaluating the problem-solving process (Arends, 2014). In detail, the steps of the PBL model are presented in Table 2.

Table 2. The Steps of Problem-based Learning (PBL)

Step	Activities
Problem Orientation	Problems are exposed to learners.
Learning Organizations	Learners define and organize learning tasks related to the problems with teachers' assistance.
Individual or group investigations	Learners are encouraged to find the correct information, carry on experiments, and seek for explanations and solutions.
Development and Presentation of the Problem	Learners are assisted to plan and prepare appropriate work, such as reports.
Analyze and evaluate the problem investigation process	Learners make reflection on their investigations and the processes they have done.

Other than PBL, the STEM approach can also improve better independent and logical problem-solving skills in learners (Stohlmann et al., 2012). STEM is an integrated learning model in line with the current era of globalization (Becker & Park, 2012). Studies have shown that PBL in STEM approaches has been successfully applied (Davis et al., 2011; Hunt et al., 2011). For other STEM techniques and disciplines, PBL is also well fitted because it helps improving learner's ability and confidence to solve real-life problems they never faced before (Bransford et al., 2002).

STEM-integrated PBL can be operated by following five stages: firstly, problem identification (the problem is presented in a scenario or directly by proposing to appropriate problem questions and previous knowledge associated with the new topic); next is data collection (including researching what should be learned to find solutions to problems and collecting information and sources); the next step is transferring and designing (by considering the results gathered at the previous stage to solve the problem, the technique design could be formed); and lastly is communication (generating ideas to improve the design, developing designs according to those ideas and retesting) (Sarı et al., 2018).

Environmental STEM (E-STEM) is developed as learning approaches in responding to global issues of environmental changes. The learning process allows individuals to discover environmental issues, involve in problem-solving, perform to increase knowledge and awareness about the environment and the quality of

environment itself, promote manners, motivation, and commitment to the decisions and take reliable action (Apriyani et al., 2019; NAAEE, 2013).

Environmental-STEM emphasizes on the connection between STEM literacy and environment, which include: possessing knowledge in environmental-based issues and STEM-related subjects; comprehending the incorporation of the environment into STEM fields; directing to find the solution for environmental issues or problems using the point of view of STEM education approach; being able to evaluate data and draw conclusions (Kaya & Elster, 2019).

E-STEM can integrate the science, technology, engineering and mathematics disciplines into a paradigm of intelligible teaching and learning and give students the best opportunity to understand the world holistically (Kodariyati & Astuti, 2016). On the other hand, Kaya & Elster (2019) mentioned that the development and the use of technology will influence the use of natural resources, so that the awareness of protecting the environment is encouraged by integrating the environmental issue in STEM education.

The initial data from the school studied showed that more than half of the grade 10 students (69.33%) did not reach the minimum criteria of learning mastery (KKM—*Kriteria Ketuntantasan Minimal*) for biology content. In addition, the PBL learning model using Environmental-STEM-based student worksheets was also not widely used.

E-STEM-based worksheet for students in this study was created by emphasizing on the ability of students to explore the environmental problems, engage in problem-solving, improve the environment condition, and increase knowledge and awareness about the environment. The characteristics of the E-STEM-based student worksheet used in this study are as follows: By assembling kits to prevent/protect environment, students are individually allowed to investigate and solve environmental problems at "the environmental stage"; The process of constructing tools to prevent/protect environment uses science as basic knowledge; Technology is "human-made" tools that ease the assembling kits to prevent/protect environment; Engineering is a modelling or modification in constructing the tools to prevent/protect environment; Mathematics is calculating skills in counting the size of assembling tools.

Method

The research was conducted in class X in the even semester of 2021/2022 at MAN 3 Banda Aceh. The type of study is applied research, and the approach was quantitative. The study used a quasi-experimental method, which conducted to determine the consequences of a treatment given intentionally. The pretest-posttest control group design is used, presented in Table 3**.**

Table 3. The Design of Pretest-Posttest Control Group

Group	Pretest	Treatment	Posttest
A (Experiment)	O1	X1	O2
B (Control)	O1	X2	O2

X1 : Applying PBL model + E-STEM-based student worksheet
X2 : Applying PBL model only
O1 : Pretest scores
O2 : Posttest scores

This population was all 10th grade (grade X) science students at one of the Islamic senior high schools in Banda Aceh. The sample of this study was 84 students (table 4). The parameters in this study were problem-solving skills measured by long answer questions. The test was used to obtain data about students' biology problem-solving skills. The assessment for each item of the problem-solving skills test refers to the indicators and the rubric. The test consisted of ten questions which experts had validated with a reliability of 0.69, indicated as reliable (Ulhaq, 2020).

Table 4. Population and Sample of the Study

Class	Number of Student
X-Science 1	29 (Experiment)
X-Science 2	28 (Experiment)
X-Science 3	27 (Control)
Total	84

The test examined students' problem-solving skills after participating in learning environmental pollution using the E-STEM worksheets based on PBL model. The test results were assessed based on key answer indicators and scoring guidelines. The percentage of problem-solving skills improvement was generated using the following formula proposed by Destalia et al. (2014).

$$P = \frac{n}{N} x100 \quad (1)$$

P = Problem-solving skills percentage
n = Score achieved
N = Maximum score

The percentage was then categorized according to the category in Table 5 (Destalia et al., 2014).

Table 5. Problem-Solving Percentage Assessment

Score Interval (%)	Category
76 - 100	Excellent skill
51 - 75	Good skill
26 - 50	Fair skill
< 25	Poor skill

Once the problem-solving skills score was generated, a one-sample t-test was conducted. It is important to note that the t-test assumes normality and homogeneity, assessed through appropriate tests. The one sample t-test examined the significance of the mean difference between the two groups. This test determined differences in problem-solving skills among students in the experimental and control classes. One sample t-test investigated the difference between the two groups for each variable; if $\rho < 0.05$, H_a is accepted (Santoso, 2015).

Result and Discussion

The research indicated a normal and homogeneous distribution in students' problem-solving skills between the PBL model combined with E-STEM-based worksheets and the PBL model on environmental pollution. Hence, a one sample t-test analysis followed it. Table 6 depicts one sample t-test posttest results.

Table 6. The t-test of Problem-solving Skills

Class	M	SD	t	Sig.*)
Exsperiment	49.79	7.17	48.5	.000*
Control	38.22	6.38		

*) H_a accepted, $\rho < 0.05$

The findings of the one-sample t-test are presented in Table 6, which reports a statistically significant difference in the problem-solving skills in the experimental and control classes ($t(84)= 48.5$, $\rho<0.001$). The results indicate that the implementation of PBL in conjunction with E-STEM-based worksheets led to a significant improvement in problem-solving skills among students in the experimental group when compared to those in the control group. The efficacy of this approach can be attributed to the opportunities it provides for students to identify and address environmental pollution-related problems. Thus, it can be concluded that the use of PBL in combination with E-STEM-based worksheets is a more effective method for enhancing students' problem-solving abilities than PBL alone.

The students in the experimental class, which utilized a combination of PBL and E-STEM-based worksheets, were allowed to identify problems based on factual information regarding environmental pollution. Students were allowed to identify problems following the facts of environmental pollution in the experimental class taught by the PBL combined with the E-STEM-based worksheet. Therefore, the students can be trained to focus on identifying environmental pollution problems. Learning using the E-STEM approach allowed students to observe the phenomena in everyday life and helped them design products that would be produced during environmental pollution learning. Moreover, the E-STEM approach forces students to discuss and express their ideas and thoughts to solve the questions in the worksheet. This is in line with Sarı et al. (2018) who asserted that PBL combined with STEM activities improves teamwork, problem-solving, collaboration, and students' creative skills.

Furthermore, incorporating E-STEM-based worksheets in the learning process proved to motivate the students, who demonstrated enthusiasm for problem-solving activities involving creating various products. This is consistent with the findings of Sarı et al. (2018), who noted that the combination of PBL and STEM education had a positive influence on students' attitudes toward science, engineering, technology, and design, particularly when they were engaged in the process of creating products to address problems.

Although the control class also aimed to enhance students' problem-solving skills, it was found that combining the PBL model with E-STEM-based worksheets was more effective in achieving this goal than the PBL model alone. Table 7 displays the averages for each problem-solving skill indicator among students in both groups.

Table 7. The Average Score (%) of Problem-solving Indicators for Control and Experiment Classes

Problem Solving Indicator	Control Class		Experiment Class	
	Pretest	Posttest	Pretest	Posttest
Understanding the Problem	36.11	72.22	35.13	82.11
Devising a plan	28.08	69.04	29.35	82.20
Carrying out the plan	28.70	68.52	28.88	80.60
Looking back (checking)	33.80	70.37	34.70	83.19

Table 7 shows that in the experimental class, the highest average was on the assessing indicator, followed by understanding the Problem, planning problem-solving, and solving problems. Applying the PBL model combined with an E-STEM-based worksheet provides direct experience to students to evaluate problems based on the results of analyses related to environmental pollution.

At the stage of understanding the Problem by applying the PBL model with the E-STEM-based worksheet, students were allowed to analyze problems regarding the lack of public awareness of environmental cleanliness and littering. Furthermore, at the completion planning stage, students discussed designing the right solution to overcome the Problem. At the problem-solving stage, students looked for solutions to solve the problem. Finally, students assembled a tool to solve the problem by creating a garbage net to filter trash in the gutters to avoid getting clogged (Figure 1). The students also created rubbish bins so that students in the school could dispose of the trash at the designated place.

Students also create short of champagne poster about keeping the environment clean (Figure 1).

Figure 1. Activities in experiment class

In the control class, the highest average score was on understanding the Problem, followed by evaluating, planning to solve problems, and solving problems. In applying the PBL model, students can also conduct problem analysis and do group observations of water pollution using litmus paper. According to El Sayary et al. (2015), the ability to construct knowledge depends on the balance of what is being understood and what must be understood as a respond to the learning activities and environment.

Based on the data presented in table 7, both experiment and control classes have quite similar starting score average of problem solving, which is in fair skill category. Thus, after the application of the learning process of PBL combined E-STEM-based worksheet, the experiment class showed an excellent skill category while the control class achieved good skill category.

Based on the Barrow's PBL taxonomy model, the pure PBL learning can be achieved by proposing unstructured problems through the E-STEM project and learner's self-directedness (El Sayary et al., 2015). So, this model might explain the satisfactory problem-solving result for students in experiment group. Yet, according to Helvaci & Helvaci (2019), E-STEM is useful for increasing environmental awareness. The use of E-STEM has also been carried out by Sümen & Çalisici (2016) and they found that E-STEM education can help the learning process more efficient, easy to remember material, and fun. E-STEM activities have a positive impact on the environment, especially regarding recycling, and the use of various scientific disciplines simultaneously (Helvaci & Helvaci, 2019).

Conclusion

Applying the PBL model combined with the E-STEM-based worksheet on environmental pollution has shown difference problem-solving skills to the class that apply to PBL strategy only. The design of the E-STEM-based worksheet guide students to have problem-solving skills by creating eco-friendly products, namely creating a garbage net to filter garbage in the gutters. Furthermore, students also made banners about littering prohibition as a follow-up to the problem of throwing rubbish into the ditches. The banners were to encourage people not to throw garbage into ditches; this is to foster students' caring character toward the environment. Thus, incorporating the PBL model and E-STEM-based worksheets into high school biology education, specifically in addressing environmental pollution, is a valuable strategy that can support teachers in cultivating students' problem-solving skills.

Author Contributions

This paper is contributed by the work of the authors as follow: conceptualization, methodology, software, formal analysis, resource, and writing original draft preparation, Wiwit Artika & Cut Putri Amalya.; validation, Safrida, Afandi & Maulida.; investigation and data curation, Cut Putri Amalya; writing—review and editing, Wiwit Artika.; visualization, Cut Putri Amalya and Safrida.; supervision, Wiwit Artika & Safrida.; project administration, Maulida.; funding acquisition, Wiwit Artika.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest nor personal circumstances in reporting and presenting this study results. There is no funders and no role assigned in this study report and publication.

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