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Developing Subject Specific Pedagogy of Natural Science Based Problem-based Learning Model to Increase Students' Scientific Literacy and Learning Outcomes

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Abstract:
This study aims to: (1) developing Subject Specific Pedagogy (SSP) of natural sciences suitable for science teaching and (2) knowing the effectiveness of SSP to improve the students' scientific literacy and learning outcomes. This research used the design of ADDIE development (Analysis, Design, Development and production, Implementation, Evaluation). SSP of natural sciences consisting of syllabus, lesson plan, student worksheet, and assessment instrument. The subjects of this research were 86 students from grade VII Pabelan 1 Junior High School in their second semester on 2016-2017 school year, consisting of: (1) 23 students of VII D for preliminary field testing and (2) 31 students of VII B as experimental class and 32 students of VII A as control class for main field testing. The data were qualitative and quantitative. The qualitative data were in the form of suggestions from the validator to the Subject Specific Pedagogy (SSP). The quantitative data were students' test score of scientific literacy and learning outcomes, the response of the students to student worksheet, and the observation form of ongoing learning process. The data were analyzed using descriptive qualitative and quantitative analysis, gain score. The effectiveness of SSP was tested using the design of Pretest-Posttest Control Group Design and analyzed using One Way Manova T^2 Hotteling test. The results of this study show that SSP of natural sciences with problem based learning model: (1) is considered as valid according to experts and practitioners for science learning, (2) and is effective to improve the scientific literacy and learning outcomes of 7th grade students with significance= 0,003< 0,05.

***Keywords**: subject specific pedagogy, problem based learning, scientific literacy, learning outcomes.*

1. Introduction

In the highly competitive 21 century environment, education to prepare the 21st century, education should be focused on constructing knowledge and encouraging new skills (Alismail and McGuire, 2015). Two important skills needed in the 21st century are scientific literacy and learning outcomes. National Research Council or NRC(cited in Bradshaw, 2014) defines scientific literacy as knowledge and understanding of scientific concepts and processes required for making a decision and participating in civic and cultural affairs. While OECD (cited in Fleischman, Hopstock, Pelczar and Shelley; 2010) defines scientific literacy as scientific knowledge and how to use that knowledge to identify questions, explain phenomena scientifically, understand the characteristic features of science as a form of human knowledge and inquiry, aware of how science and technology shape our intellectual and cultural environments; and engage in science-related issues. Bauer (1992) mentions three components of scientific literacy: (1) the substantive concepts within science, (2) scientific activity, and (3) the role of science in society and culture. While OECD (2013) characterizes scientific literacy into four domains: (1) context, (2) knowledge, (3) competencies, and (4) attitudes. Competencies of scientific literacy is very important. Context requires competencies, while knowledge and attitudes are influenced by competencies. OECD (2013) mentions three priority of competencies: (1) identifying scientific issues, (2) explaining phenomena scientifically, and (3) using scientific evidence.NRC (cited in Saul, Kohnen, Newman, et al, 2012) scientific literacy implies that a person can identify scientific issues and be able to evaluate the quality of scientific information. Showalter (cited in Laugksch, 2000) mentions the characteristics of a literate person: (1) understands the nature of scientific knowledge, (2) applies science concepts accurately, (3) develops manipulative skills associated with science and technology, (4) uses process of science in solving problems, (5) develops more richer view of the universe, and (6) understands and appreciates the joints of science and technology.

The importance of scientific literacy (Laugksch, 2000) can be reviewed from macro and micro view. According to macro view, scientific literacy is highly needed due to national economies and science itself. According to micro view, scientific literacy gives direct benefits to individuals. Literate persons are able to negotiate more effectively. Bradshaw (2014) argues that there is a need to expose students to scientific content that is relevant to their daily live. Science must be taught in a contextual manner, so the students are able to transfer the learning gained in the classroom to situations in the real life. The conclusion that can be drawn from previous explanations is that scientific literacy can be defined as the ability of a person to use his knowledge in science (both concept and theory) in solving problems scientifically. Scientific literacy in this research is focused on competencies domain consisting of three indicators: (1) identifying scientific issues, (2) explaining phenomena scientifically, and (3) using scientific evidence.

Learning outcomes have become the main goals for learning process. Learning outcomes of a subject of study have become the focus of international conference for the last few years. Learning outcomes have implication for curriculum design, teaching, learning, and assessment (Keshavarz, 2011).According to Barrow, Gallagher, Stepien, Sher, & Workman (cited in Sungur & Tekkaya, 2006), by using PBL in the learning process means that students are confronted with problems that require them to: (1) define problem clearly, (2) develop hypotheses, (3) access, analyze, and use data from different sources, (4) revise the initial hypotheses as collecting the data, and (5) develop solutions according to evidence. There are some high quality models of learning process that can be implemented to improve scientific literacy and learning outcomes, on of these models is problem based learning (PBL). PBL helps students to resolve questions, curiosities, doubts, and uncertainties complex phenomena in life (Barell, 2007).

PBL is an instructional learner-centered approach that empowers learners in conducting research, integrating theory and practice, and applying knowledge and skills to develop a solution for problems. The important things to success this approach are the selection of problems and the tutor who guides the learning process (Savery, 2006).Barell (2007) argues that PBL challenges students to become deeply involved in a quest for knowledge, a search for answers to their own question, not just answer the questions posed by a teacher or a book.In the initial step of learning process using PBL model, students are confronted with problems. Students are guided to question about the reasons why the problem occurs, how the problem occurs, and how to solve the problems. Thus, in PBL learning process, students should collect informations in order to understand the problem thorouhgly, so they are expected to be able to solve the problems (Norman & Schmidt, 1992). PBL model used by Curry, Lubbers, & Tijoe (cited in Sungur & Tekkaya, 2006) consisted of three phases. In the first phase, students read the case and note the facts, ideas, hypotheses, and issues. In the second phase, students independently identify an issue and gather data from different resources. In the third phase, students met to discuss the new knowledge they had acquired from their independent study.

There are seven steps used in PBL as argued by Bligh (1995). The seven steps are: (1) clarify terms and concepts, (2) define the problems, (3) analyze the problem, (4) list possible explanation, (5) formulate learning objectives, (6) look for additional information, and (7) report, synthesize, and test the information. The syntax of problem based learning model as argued by Arends are consisted of five stages (Arends, 2012). The five stages are: (1) orient students to the problem, (2) organize students for study, (3) do investigation, (4) develop and present their work, and (5) analyze and evaluate problem solving process.

PBL is student-centered learning model. Teacher are problem solving colleagues who nurture an environment that supports open inquiry. While students are engaged problem solvers, identifying the problem and the condition needed for a good solution, pursuing meaning, and becoming self-directed learners (Torp & Sage, 2002). Arends (2012) mentions three learner outcomes for problem based learning. The three learner outcomes are: (1) thinking and learning outcomes, (2) adult role behaviors and social skills, and (3) skills for independent learning.

Wulandari & Solihin (2015) through their research have proved that learning process using PBL model is effective to improve students' scientific literacy. Furthermore, they explain that PBL encourages students to develop their interest in scientific issues during the problem-solving process. It requires students to gather data by their own selves, identify the problem, formulate hypotheses, work effectively in their group, build a network, and think creatively. Boud & Jones et al (cited in Hillman, 2003) argue that there is an important approach used in PBL. This approach requires the students to work on the problems in order to establish deeply understanding of the problems. Knowing the importance of scientific literacy and learning outcomes for the students' future, it is necessary to conduct the learning process using PBL model. Unfortunately, according to observation and interview, teachers are rarely using PBL model in their classes. They focus on graduate competence standard to prepare students for the final exam. The learning processes they usually used only help students to memorize materials and do calculation test.

Hartati (2011) defines subject specific pedagogy (SSP) as a solid and comprehensive educative learning in the form of subject matter packaging which include competency, sub-competency, subject, method, strategy, media, and evaluation. Prayitno & Wangid (2015) and Qodriyah & Wangid (2015) explain that SSP is a comprehensive instructional learning tool; consisted of: (1) syllabus, (2) lesson plan, (3) student worksheet, and (4) assessment instrument; in integrated arrangement to direct the learning process. Sanjaya & Timbang (cited in Hartati, 2016) explain that teaching knowledge differs teachers from a particular field expert. Teacher needs to synthesize two knowledge (subject matter and pedagogy knowledge). While

Grossman (cited in Evans; Hawksley; Holland; & Caillau, 2008) mention four components that should be integrated by a teacher: (1) subject specific matter, (2) knowledge of students' difficulties, (3) knowledge of the curriculum, and (4) knowledge of instructional strategies.

Based on the explanations as mentioned before, it is necessary and important to conduct a research related with the development of subject specific pedagogy (SSP) of natural sciences based problem based learning model to improve students' scientific literacy and learning outcomes on theme environment. Environment issues are being popular recently due to the direct impact from the living things interaction to the environment. It is needed to solve environments problems not only by coherent government-wide policy, but also by civil society (OECD, 2008).

2. The Research Method

2.1. Type of the Research

The type of this research is research and development (R&D). This research used the design of ADDIE development. ADDIE consists of 5 stages. ADDIE stands for Analysis, Design, Development and production, Implementation, and Evaluation.

2.2. Subject of the Research

The subjects of this research were 86 students from grade VII Pabelan Junior High School in their second semester on 2016-2017 school year, consisting of: (1) 23 students for preliminary field testing and (2) 31 students as experimental class and 32 students as control class for main field testing.

2.3. Development Procedure

The first stage was analysis. In this stage, the instructional problem was clarified, the subject matter was identified, and the learner's existing knowledge and skills were identified. From the analysis stage, it was necessary to develop subject specific pedagogy (SSP) of natural sciences with problem based learning model to improve students' scientific literacy and learning outcomes.

The second stage was design. In this stage, the components of SSP were determined. The components of SSP consisted of syllabus, lesson plan, student worksheet, and assessment instrument. The third stage was development and production. In this stage, the initial design which has been developed was validated by four validators. Later on, the suggestions from validators were used to revise the product.

The fourth stage was implementation. In this phase, the product was tested in preliminary field testing and main field testing. In the preliminary field testing, 23 students were involved. Suggestions from the preliminary field testing were used to revise the product. After revising the product, the main field testing was conducted. The main field testing used two classes, experimental class and control class. The evaluation stage was conducted not only in the last stage, but also in every stages.

2.4. Data Analysis Techniques

<u>2.4.1. Analysis of Feasibility</u>

Analysis feasibility of the SSP was descriptive qualitative and quantitative analysis. Descriptive analysis was used to analyze the suggestions from the validator. Quantitative analysis was used to analyze the validation score from the validator and students' responses to student worksheet which were into categorization according to Depdiknas (2010). Marking score conversion of the feasibility product shown in Table 1, while marking score conversion of the students' responses shown in Table 2.

Mark	Interval	Category
A	107,25 < $\overline{X} \leq 132$	Very good
B	82,5 < $\overline{X} \leq 107,25$	Good
C	57,75 < $\overline{X} \leq 82,5$	Enough
D	33 < $\overline{X} \leq 57,75$	Poor

Table 1: Marking Score Conversion of the Feasibility Product

Mark	Interval	Category
A	29,25 < $\overline{X} \leq 36$	Very good
B	22,5 < $\overline{X} \leq 29,25$	Good
C	15,75 < $\overline{X} \leq 22,5$	Enough
D	15,00 < $\overline{X} \leq 15,75$	Poor

Table 2: Marking Score Conversion of the Students' Responses

The content validity of the assessment instruments of scientific literacy and learning outcomes was analyzed using Aiken's formula (1980)$V = \frac{\Sigma s}{[n(c-1)]}$. Notes: *V* is Aiken's validity content, *s* is r-lo, *lo* is the lowest validity score, *c* is the highest validity score, *r* is the score given by the validator, and *n* is the number of validators.

The empirical validity of the assessment instruments of scientific literacy and learning outcomes were determined by using Pearson's technique of correlation product moment. The formula is (Arikunto, 2010):

$$r_{XY} = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\{N\Sigma X^2 - (\Sigma X)^2\}\{N\Sigma Y^2 - (\Sigma Y)^2\}}}$$

Notes: r_{XY} = correlation coefficient between X and Y

The construct reliability of the assessment instruments were analyzed by using Borich's formula. The reliability is considered as good if the R is bigger than or equal to 75% (Borich, 1994). The Borich's formula is:

$$R = 100\%\left[1 - \frac{A - B}{A + B}\right]$$

Notes: *R* is instrument reliability, *A* is the highest score given by the validator, and *B* is the lowest score given by the validator.

2.4.2. Analysis of Ongoing Learning Process

The analysis of ongoing learning process was calculated using formula $P = \frac{\Sigma x}{n}$x100%, with Σx is the total score and *n* is the number of ongoing components observed. After the percentage of the ongoing learning process was obtained, then the reliability was calculated using Borich's formula. The ongoing learning process is considered as good if the R is bigger than or equal to 75%.

2.4.3. Gain Score Analyisis

The gain score was used to analyze the improvement of students' scientific literacy and learning outcomes. The formula is $(g) = \frac{\%post - \%pre}{100 - \%pre}$. Then, the gain score was interpreted according to Hake's categorization (1998), as seen in Table 3.

Interval	Category
g ≥ 0,7	High
0,3 ≤ g < 0,7	Medium
g < 0,3	Low

Table 3: The category of normalized gain score

2.4.4. Paired t-Test

The product effectiveness in improving scientific literacy and learning outcomes in preliminary field testing was analyzed using paired t-test. Paired t test is statistical procedure to determine whether there is a statistically significant difference in the mean of a dependent variable between pretest and posttest.

2.4.5. Manova T^2 Hotteling Test

If the preliminary field testing shows that the SSP of natural sciences is effective to improve scientific literacy and learning outcomes, the main field testing can be conducted. The main field testing involving two classes(experimental and control class). The effectiveness of the SSP in the main field testing was analyzed using Manova T^2 Hotteling test. There are two assumption tests should be fulfilled before conducting the Manova T^2 Hotteling test. The assumption tests are normality and homogeneity. Mahalanobis distance is used to test the normality, while statistical Box's Mis used to test the homogeneity.

If the Manova T^2 Hotteling test is significant, then independent t-test should be conducted to test the difference in the mean of each dependent variable between experimental and control class. Statistical tests in this research were helped by SPSS v 20 program.

3. Results and Discussions

SSP of natural sciences was validated by two experts and two practitioners. The score given by the validators converted to qualitative data with 4 Likert scales to find out the feasibility of the SSP. SSP of natural science was considered as feasible according to experts and practitioners (science teachers) for science learning with A mark and categorized as very good. The mean scores given by the validators are presented in a diagram as shown in Figure 1.

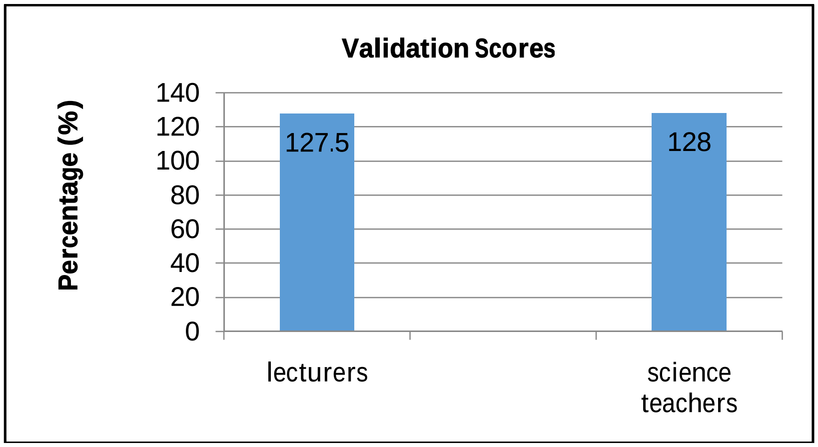

Figure 1: Diagram of Mean Scores Given by the Validators

There were 15 multiple choice items to measure scientific literacy. The content validity of scientific literacy item was determined by calculating the content validity coefficient using Aiken's V formula. The reliability of the instruments were calculated using Borich formula. Based on the content validity analysis, the 15 items test were considered as valid with theoretical reliability 86%.

There were 20 multiple choice items to measure learning outcomes. The content validity of learning outcomes items were determined by calculating the content validity coefficient using Aiken's V formula. The reliability of the instruments were calculated using Borich formula. Based on the content validity analysis, the 20 were considered as valid with theoretical reliability 100%. After the product was considered as valid, the preliminary field testing can be conducted to find out its effectiveness in improving scientific literacy and learning outcomes. The students were given pretest in order to find out their existing knowledge and skills. Then, the learning process using SSP were conducted. After that, posttest was given to the students in order to measure their knowledge and skills after the treatment. Pretest and posttest scores were analyzed using gain score formula. The analysis result showed that there were students' gain, both in scientific literacy and learning outcomes. Students' gain presented in the diagram form as shown in Figure 2.

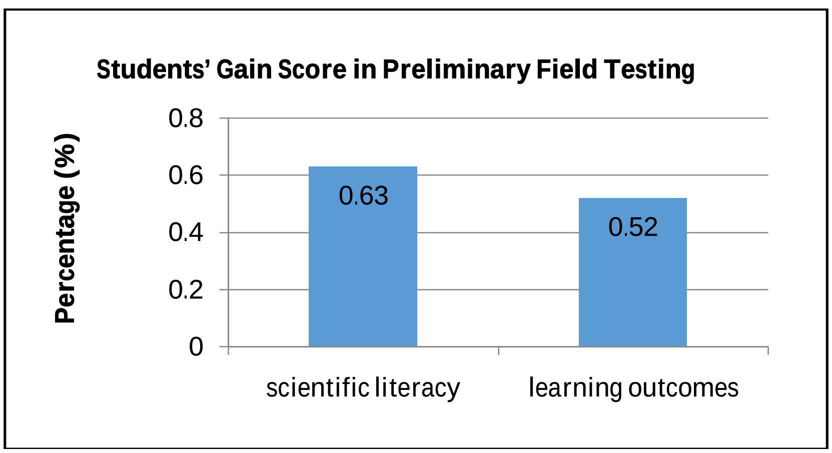

Figure 2: Diagram of Students' Gain Score in Preliminary Field Testing

Statistical paired t-test is used to compare the means of the two samples of related data, the related data refers to pretest and posttest. The result of statistical paired t-test shown in Table 4.

No	Variables	sig.(2-tailed)
1	Scientific Literacy	0,000
2	Learning outcomes	0,000

Table 4: Statistical Paired t-Test Result

According to statistical paired t-test for scientific literacy, the significance was 0,000 or the sig.<0,05, so the H_0 was rejected. Thus, by using α=0,05 could be concluded that learning process using SSP based on problem-based learning model was effective in improving students' scientific literacy.

According to statistical paired t-test for learning outcomes, the significance wass 0,000 or the sig.<0,05, so the H_0 was rejected. Thus, by using α=0,05 could be concluded that learning process using SSP based on problem-based learning model was effective in improving students' learning outcomes.

The mean score of students' response to the student worksheet in preliminary field testing is 32,11 with A mark and categorized as very good. The score of ongoing learning process in preliminary field testing was 96,8%, so it could be concluded that learning process was good.

After the SSP showing its effectiveness in improving scientific literacy and learning outcomes, the main field testing can be conducted. The main field testing was conducted by involving two classes, one class as the experimental class and the other one as the control class. Both the experimental and control class were given pretest to find out their existing knowledge and skills. Later, the learning process in experimental class was conducted by using SSP of natural science, while the learning process in the control class was conducted using conventional learning process. After the learning processes were completed, posttest was given to the students to find out their knowledge and skills after the learning process.

According to the gain score anlysis of the pretest and posttest, there were improvements in scientific literacy and learning outcomes in the both of classes. Yet, there were differences in gain score between experimental and control class. The difference in gain score can be seen in the diagram in Figure 3.From the figure 3 shows that the mean gain of the experimental class is higher than the control class.

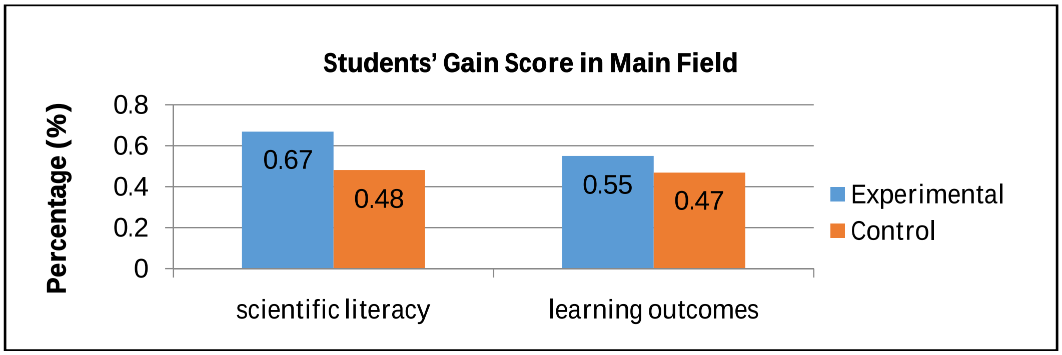

Figure 3: Diagram of Difference in Scientific Literacy and Learning outcomes Gain Score between Experimental and Control Class

The effectiveness of SSP of natural sciences in improving scientific literacy and learning outcomes was tested by MANOVA T^2 Hotelling. Before conducting MANOVA T^2 Hotelling test, there are two prerequisite testing should be fulfilled, normality and homogeneity test.

The multivariate normality test was conducted using Mahalanobis distance. Both experimental and control class showed that the r calculation>r table, so it could be concluded that the data were normally distributed (Fillaben, 1975). The value of r calculation and r table shown in Table 5.

No	Class	n	r calculation	r table
A	Experimental	31	0,986	0,958
B	Control	32	0,990	0,959

Table 5: The Result of Multivariate Normality Test

Statistical Box's M test is used for homogeneity test. The result of Box's M test shown in Table 6. According to homogeneity test using Box's M test, the significance was 0,309which is bigger than α; or 0,138>0,05; so it could be concluded that the population between the two classes were homogeny.

Box's M	3,726
F	1,198
df1	3
df2	693137,195
Sig.	0.309

Table 6: The Result of Box's M Test

The assumption tests are fulfilled, the statistical MANOVA T^2 Hotelling test can be conducted. The result of statistical MANOVA T^2 Hotelling test shown in Table 7.

Effect		Value	Sig.
Class	Hotteling's Trace	0,211	0,003

Table 7: Result of Statistical MANOVA T^2 Hotelling on Science Literacy and Learning Outcomes

MANOVA T^2 Hotelling test was conducted to find out the effectiveness of SSP of natural sciences in improving scientific literacy and learning outcomes. According to the test, the significance was 0,003 or sig.<0,05, so H_0 was rejected. Thus, by using $\alpha = 0{,}05$, it could be concluded that there was mean difference of scientific literacy and learning outcomes between experimental and control class.

To find out the difference in mean of each variable between the two classes, independent t-test was conducted. The result of independent t test shown in Table 8.

No	Variables	Sig. (2-tailed)
1	Scientific literacy	0,001
2	Learning outcomes	0,013

Table 8: Independent t-Test Result

The significance of scientific literacy was 0,001. It could be concluded that the learning process using SSP based on problem based learning model was more effective in improving scientific literacy than the conventional one. While the significance of learning outcomes was 0,013. It could be concluded that the learning process using SSP with problem based learning model was more effective in improving learning outcomes than the conventional one.

The final product of subject specific pedagogy of natural sciences was obtained through some development phases. The development started by analyzing the problems, analyzing the needs, analyzing the subject matter, designing the product, developing the product, implementing the product, and evaluating of the product.SSP of natural sciences in this research has some characteristics: (1) using subject matter of the interaction of living things with their environment, (2) consisting of syllabus, lesson plan, student worksheet, and assessment instruments, (3) using problem based learning model, (4) improving scientific literacy and learning outcomes, (5) using guidance portion appropriate with the time needed, (6) using indicators of competence achievement, (7) determining of time allocation for each activity, (8) using assessment instruments in the form of 15 items of multiple choice to measure scientific literacy and 20 items of multiple choice to measure learning outcomes.

SSP of natural sciences with problem based-learning model was designed to help students to develop their ability to applying their knowledge and skills for their daily life. As mentioned before, the gain score of experimental class is higher than the control class, it can be influenced by the learning model used. Torp & Sage (2002) argue that students' thinking skills can be improved through PBL. Arends (2012) states that PBL helps students to develop their thinking skills. Wulandari and Solihin (2015) through their research find out that PBL is effective to improve students' scientific literacy.

4. Conclusions and Suggestions

Based on the result of the research, it can be concluded that SSP of natural sciences based on problem based learning model: (1) is considered as valid for science learning with A mark, and (2) is effective to improve the scientific literacy and learning outcomes of 7th grade students. The significance score is 0,003 or sig.< 0.05.

Based on the result of the research, it is necessary for teachers to use SSP of sciences based problem based learning model to improve students' scientific literacy and learning outcomes. Teachers can directly use, adopt, or adapt the SSP of sciences by adjusting it with the environmental conditions, facilities and infrastructure available at the school.

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