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The Effectiveness of Student Electronic Worksheet-Based on Project-Based Learning to Improve Student Critical Thinking Skills in Green Chemistry Materials

Fania Fasya Rewanda, Rusly Hidayah*

Chemistry Education Study Program, Universitas Negeri Surabaya, Surabaya, Indonesia
*e-mail: ruslyhidayah@unesa.ac.id

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Abstract: Critical thinking skills are essential abilities that students must have to face the challenges of learning in the 21st century. However, the PISA test results in 2022 showed that the critical thinking skills of Indonesian students were still low compared to the average OECD country. This research aims to produce electronic student worksheets based on project-based learning (PjBL) to improve students' critical thinking skills on green chemistry materials. This type of research is development research with a one-group pretest-posttest design and uses the 4D model from Thiagarajan, Semmel, and Semmel's (1974). This 4D development model consists of four stages: define, design, develop, and disseminate, but is limited to the development stage only. This research was conducted at SMAN 7 Surabaya, with the research subjects being class X-6 students, a total of 28 people. The feasibility of this learning media was reviewed from its effectiveness. The effectiveness was measured through cognitive tests with scores above the learning objective completeness criteria ≥ 75%, which showed a percentage of 100% classical completeness. Effectiveness is also seen from the results of the critical thinking ability test. Critical thinking ability test data was tested with the Shapiro-Wilk normality test and obtained a significance of < 0.05, so further tests were carried out using the Wilcoxon Signed Rank test and obtained a significance of 0.000, which stated that there was a difference between pretest and posttest data. Thus, the learning media developed can be declared effective based on the results of cognitive test data and critical thinking ability test data. Unlike previous studies that focused on creative thinking skills, this study uniquely targets critical thinking skills using PjBL.

Keywords: Critical Thinking; Green Chemistry; Project-Based Learning; Student Electronic Worksheet.

Introduction

The progress of a nation is determined by the quality of its education, because the better the quality of education in a country, the more advanced the country will be. Education will always be related to the curriculum. The curriculum is a learning plan that contains objectives, content, methods, and assessments that are arranged to achieve a learning goal [1]. The curriculum implemented in Indonesia today is the Merdeka Curriculum.

The Merdeka Curriculum is a varied intracurricular curriculum. As the name implies, the Merdeka Curriculum reflects a person's interests and talents in learning [2]. The Merdeka Curriculum was formed in the hope of fixing the problems that arose in previous education. The Merdeka Curriculum also implies that the lesson plans prepared by teachers must be provided in a fun way. Teachers are also expected to guide students to develop their potential.

In the Merdeka Curriculum, there is a Pancasila Learner Profile Strengthening Project or commonly referred to as P5. This is a project aimed at preparing students' competencies to face challenges in the 21st century [3]. There are six dimensions in P5, one of which is critical thinking [4]. According to Sitompul, critical thinking ability is a process for students to analyze, assess facts and the language that underlies others [5].

In fact, when compared to other countries, critical thinking skills in Indonesia cannot be categorized as good. This is evidenced by the results of the Program for International Student Assessment (PISA) test in 2022, which stated that Indonesia was ranked 69th out of 81 participating countries. Although Indonesia experienced an increase in rank compared to 2018 [6], Indonesia's math skills score actually decreased by 13 points [7]. The results of the PISA test can be used as a criterion for measuring the level of critical thinking ability of students because the questions in the test are linked to contextual problems [8]. Thus, critical thinking skills in Indonesia are still in the low category [9]. One of the efforts that can be made to improve students' critical thinking skills is to adjust the learning model used in teaching and learning activities.

To train students' critical thinking skills, of course, the right learning model is needed. The learning model that emphasizes activeness, creativity and innovation, as well as a critical mindset, is the PjBL model [10]. The PjBL learning model is one of the innovative learning models, because in its learning activities, PjBL not only make the teacher the main center for providing material, but also makes the teacher a motivator and facilitator. This PjBL learning activity focuses more on students, so this does not make students passive listeners [11]. In addition, the PjBL model can also support the development of critical thinking skills and responsibility because the PjBL model encourages students to be more active, initiative, independent, able to solve problems, think critically and analytically [12].

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PjBL activities are more prominent in terms of theory and application. The initial stage of the PjBL learning model is gathering information, which can be in the form of ideas or questions raised by students. These ideas and questions can then be developed and adapted to learning activities. PjBL activities can motivate students to design and develop a project, which can be done independently or in groups, to produce a product. Learning activities modelled after PjBL must have topics that are factual, close to the experiences and lives of students, and are interesting [13].

To implement a learning model, of course, the right teaching media is needed to support the smooth running of teaching and learning activities. In learning activities, the media functions as a tool that plays a role in connecting the interaction between teachers and students [14]. The use of creative media can certainly increase students' interest in learning more actively as well as improve their performance in achieving predetermined goals.

The use of interactive media can certainly increase the enthusiasm of students to learn more actively, as well as improve their performance in achieving predetermined goals. One of the learning media that can be developed is the student worksheet. Student worksheets that are used in schools are generally in printed form, so to realise more innovative learning media, learner activity sheets can be packaged in online or electronic form. Student electronic worksheet is an internet-assisted learning media whose preparation is carried out systematically and packaged in electronic format [15]. Student electronic worksheets can display images, videos, text, and sound, which can be designed and organized according to the creativity of the educator.

One of the chemistry materials taught in high school is green chemistry. Green chemistry learning is inherently relevant to the project-based learning approach. This model facilitates students to not only understand theoretical concepts, but also apply them in a real context. Generally, when project-based learning is applied in green chemistry, the emphasis is often on developing students creativity [16]. They are encouraged to design chemical processes that are more environmentally friendly, find alternative raw materials, or develop synthesis methods that are more efficient and safe [17]. This is in line with the principles of green chemistry that encourage innovation and sustainable solutions.

Based on several studies, green chemistry materials taught with project-based learning can not only apply creative thinking skills, but can also improve students critical thinking skills. This is in line with research conducted by Hikmah, Budiasih, and Santoso (2016) that project-based learning can train students critical thinking skills [18].

Based on the results of chemistry teacher interviews that have been conducted at SMAN 7 Surabaya, it is known that green chemistry material so far has been taught only by giving instructions to do the exercises contained in the student worksheet. In addition, green chemistry learning activities in the classroom have never used student electronic worksheet which presents PjBL learning activities, especially on green chemistry material.

Based on the results of the pre-research questionnaire that has been conducted, 81.3% of students stated that green chemistry is one of the difficult materials to learn. According to 56.3% of students, the reason green chemistry is difficult to learn is that there are many green chemistry principles that need to be memorized. However, 96.9% of students revealed that green chemistry material is interesting to apply to phenomena or problems faced daily. In learning activities, 93.8% of students feel happy when learning activities are carried out in groups. Chemistry learning carried out at school so far has only utilised media in the form of a blackboard, PowerPoint, and student worksheet. As many as 65.6% of students stated that they had never heard of a student electronic worksheet, so as many as 75% of students agreed that if a student electronic worksheet development were carried out, it would contain project activities in green chemistry material.

Based on the explanation that has been conveyed, the researcher has an interest in conducting research with the title “Effectiveness of Student Electronic Worksheet Based on Project-Based Learning (PjBL) to Improve Students' Critical Thinking Skills on Green Chemistry Material”.

Research Methods

This type of research is research and development (R&D) using Thiagarajan, Semmel, and Semmel's (1974) 4D development model [19]. There are four stages in this development model, namely the define, design, develop, and disseminate stages. In this study, the 4D model is limited to the development stage only. The Facione’s critical thinking skills trained in this study are interpretation, analysis, inference, and evaluation.

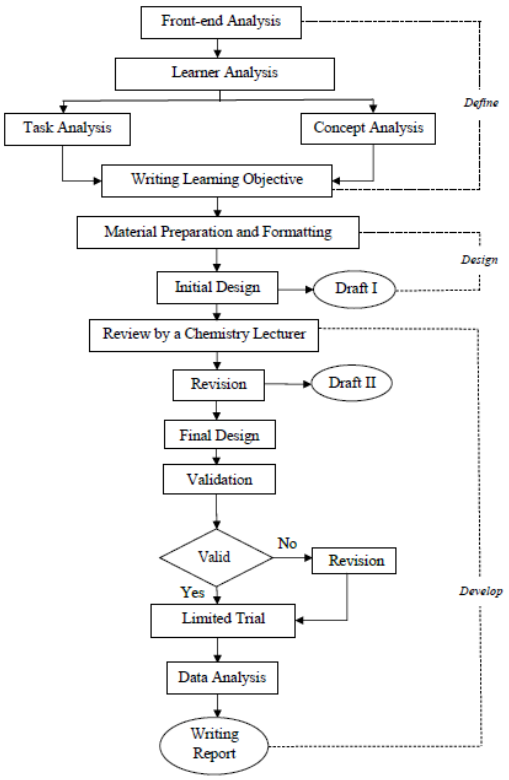

Figure 1. The Research Flow of 4D Model [20]

This research was conducted at SMAN 7 Surabaya, which is located at Jl. Ngaglik No.27-29, Kapasari, Genteng Sub-district, Surabaya, East Java, with a postal code of 60273. The limited trial involved 28 students of class X-6 as research subjects. The research design used in this study was a one-group pretest-posttest design.

Table 1. One Group Pretest Posttest Design [21]

Pretest	Treatment	Posttest
O_1	X	O_2

Validation Methods

Data from the material experts' validation of the learning media were analyzed descriptively and quantitatively. The analysis was carried out on the suitability criteria contained in the validation sheet, including content, language, presentation, and graphic criteria. Validity was assessed based on the assessment scores from 3 validators. Scoring was measured using a Likert scale in Table 2.

Table 2. Likert Scale [22]

Score	Description
4	Very Good
3	Good
2	Poor
1	Very Poor

The data obtained from the validation results are ordinal data. This ordinal data is then analyzed by determining the mode of each indicator with the provisions: If the aspect assessed by the validator has a mode ≥ 3, then the aspect is declared valid. If the aspect assessed by the validator has a mode < 3, then the aspect is declared invalid.

Effectiveness

Effectiveness is defined as the level of success in achieving a goal [23]. The effectiveness of project-based student electronic worksheets on green chemistry materials to improve students' critical thinking skills can be seen from the results of cognitive tests and critical thinking skills tests before and after learning with student electronic worksheets.

Assessment of learning outcomes is done by giving cognitive tests before starting learning activities (pretest) and after learning activities using project-based electronic student worksheets on green chemistry materials (posttest). The results of the students' cognitive domain tests were declared complete if the score ≥ 75 obtained by all students was ≥ 61%.

Table 3. Interpretation of Learning Outcome Completion [22]

Percentage (%)	Description
0-20	Very Poor
21-40	Poor
41-60	Fair
61-80	Good
81-100	Very Good

The critical thinking skills test was conducted with the aim of measuring the improvement of students' critical thinking skills by comparing the test results between the pretest and posttest. To obtain pretest and posttest scores of critical thinking skills, the following formula can be used.

$$\text{Score} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100$$

Furthermore, the percentage of students' pretest and posttest scores was calculated for each indicator of critical thinking skills, then interpreted based on Table 4. Students are declared to think critically if they get a score of ≥ 61.

Table 4. Interpretation of Critical Thinking Skills Score [25]

Percentage (%)	Description
0-20	Not Critical
21-40	Less Critical
41-60	Fairly Critical
61-80	Critical
81-100	Very Critical

To measure the increase in students' critical thinking skills, the Shapiro-Wilk normality test is carried out as a prerequisite to determine whether the data is normally distributed. If the data is normally distributed, then proceed with the parametric test, namely the paired sample t-test [26]. If the data is not normally distributed, then proceed with the non-parametric test, namely the Wilcoxon signed rank test.

Normality Test

This normality test is used to determine whether the data comes from a normally distributed population. In this study, the Shapiro-Wilk normality test was used because the sample data used was small, namely, less than 50 (n < 50). The normality test was carried out using SPSS on the basis of decision making, if the Sig value. > 0.05, then the data is said to be normally distributed, and if the Sig. value < 0.05, then the data is said to be not normally distributed [27].

Paired Sample T-Test

The paired sample t-test aims to determine the average difference between two samples that are paired or related. The paired sample t-test is part of parametric statistical analysis, so the main requirement is that the data must be normally distributed [26].

Wilcoxon Signed Rank Test

The Wilcoxon signed rank test is a non-parametric test used to measure the significance of differences between 2 groups of paired data that are ordinal or interval scaled but not normally distributed [28]. The hypothesis for the Wilcoxon signed rank test is as follows.

H_0: There is no difference between pretest and posttest results.

H_1: There is a difference between pretest and posttest results

The basis for decision-making from the Wilcoxon signed rank test is as follows.

Asymp.Sig (2-tailed) < (0.05), then H_0 is rejected

Asymp.Sig (2-tailed) ≥ (0.05), then H_0 is accepted

Results and Discussion

Limited Trial

Since the electronic student worksheets developed have been declared valid and practical, the next step is to test their effectiveness. The limited trial involved 28 students

from class X-6 of SMAN 7 Surabaya as research subjects. Students were divided into 6 groups, with 5-6 members in each group.. Students who took part in the limited trial were students who had obtained green chemistry material and had never been given project-based electronic student worksheets to improve critical thinking skills on green chemistry material. The limited trial took place for 2 meetings, namely on April 14 and 24, 2025. The following is an overview of the electronic student worksheet.

Figure 2 is the cover of the developed student worksheet. This cover contains several aspects, such as the title of the project, the material taught, grade level, phase, an image relevant to the title, a place to write the identity of the learners, and the identity of the author.

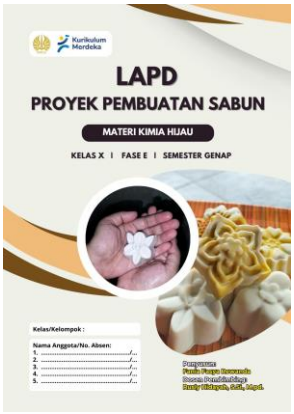

Figure 2. Cover of the Electronic Student Worksheet

Figure 3 presents a phenomenon because project-based learning starts with a problem or question. This student worksheet contains questions that are relevant to the real world or close to the lives of learners, allowing them to connect the knowledge gained during learning with its application in everyday life. In this section, an indicator of critical thinking skills is raised, namely, interpretation.

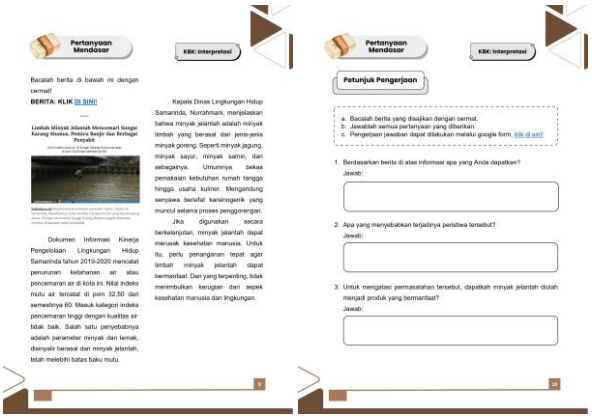

Figure 3. Interpretation Indicators on Electronic Student Worksheets

Figure 4 presents some of the questions regarding the project that the students have undertaken. Students are asked to write down observation data related to the results of their project and then answer some analysis questions. In this section, an indicator of critical thinking skills is raised, namely, analysis.

Figure 5 presents a question that asks students to make conclusions related to the project activities that have been carried out. In this section, an indicator of critical thinking skills is raised, namely inference.

Figure 4. Analysis Indicators on Electronic Student Worksheets

Figure 5. Inference Indicators on Electronic Student Worksheets

Figure 6 presents questions that ask students to evaluate the learning activity and also to give their impressions, messages or criticisms related to the learning that has been done. In this section, an indicator of critical thinking skills is raised, namely evaluation.

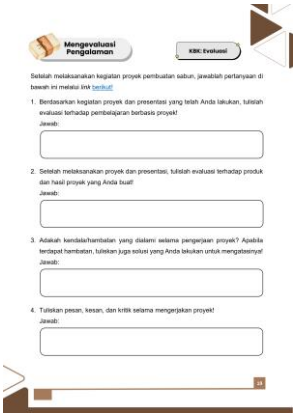

Figure 6. Evaluation Indicators on Electronic Student Worksheets

Effectiveness

Teaching material can be declared effective if it is able to improve student learning outcomes [29]. The effectiveness of project-based electronic student worksheets on green chemistry materials to improve students' critical thinking skills can be seen from the results of the cognitive

test and critical thinking skills test before and after learning with the developed electronic student worksheets.

Cognitive Test

Students' learning outcomes are measured by giving cognitive tests before (pretest) and after (posttest) learning activities using project-based electronic student worksheets on green chemistry materials. Cognitive tests given to students are multiple-choice type, with a total of ten items. The following are the average cognitive test results of 28 students in class X-6 of SMAN 7 Surabaya.

Table 5. Average Results of Pretest and Posttest Cognitive Tests

Pretest	Criteria	Posttest	Criteria
72.14	57% Complete	90	100% Complete

Based on Table 5, the average pretest score of the cognitive domain of students is 72.14, with a percentage of classical completeness of 57%. Then, the results of the average posttest value of the cognitive domain of students are 90, with a percentage of classical completeness of 100%. Thus, the students' learning outcomes test has increased after being treated using project-based electronic student worksheets on green chemistry material.

Critical Thinking Skills Test

The instrument needed to measure students' critical thinking skills is a pretest and posttest sheet of green chemistry material in the form of a description question, totalling 8 items. Indicators of critical thinking skills trained in this test are interpretation, analysis, evaluation, and inference.

Table 6. Comparison of Pretest and Posttest Results of Critical Thinking Skills

Critical Thinking Skills Indicator	Pretest	Posttest
Intepretation	54.17	87.5
Analysis	40.48	85.71
Inference	34.52	88.69
Evaluation	25	79.17

The pretest and posttest data obtained were then subjected to the Shapiro-Wilk normality test to determine whether the data were normally distributed. The normality test was carried out using SPSS, with the basis for decision making being the Sig value. > 0.05, then the data is said to be normally distributed [27].

Based on Table 7, the normality test results for the pretest obtained a significance of 0.019, while for the posttest, a significance of 0.003 was obtained. Because the significance value in the normality test for pretest and posttest < 0.05, the data is not normally distributed, so it is necessary to do a non-parametric test with the Wilcoxon signed rank test.

The Wilcoxon signed rank test is conducted to measure the significance of the difference between 2 groups of paired data that are not normally distributed [28]. The hypotheses for the Wilcoxon signed rank test are as follows.

H_0: There is no difference between pretest and posttest results.

H_1: There is a difference between the pretest and posttest results

The basis for decision making is if Asymp.Sig (2-tailed) < (0.05), then H_0 is rejected and H_1 is accepted.

Table 7. Normality Test Results

	Test of Normality Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	.910	28	.019
Posttest	.872	28	.003

Based on Table 8, the Wilcoxon signed rank test data, the result shows that the Asymp.Sig (2-tailed) value is 0.000. Because the significance value obtained is < 0.05, H_0 is rejected and H_1 is accepted. Thus, there is a difference between the pretest and posttest results.

Table 8. Wilcoxon Signed Rank Test Result

Ranks

		N	Mean Rank	Sum of Ranks
Posttest-Pretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	28[b]	14.50	406.00
	Ties	0[c]		
	Total	28		

Test Statistics[b]

	Posttest – Pretest
Z	-4.650[a]
Asymp. Sig. (2-tailed)	.000

Based on Table 6, it is known that the pretest value of students' interpretation thinking skill obtained a percentage of 54.17% (fairly critical), while the posttest value of students' interpretation thinking skill obtained a percentage of 87.5% (very critical). The students' interpretive thinking skills increased during the posttest. This is because interpretation thinking skills have been taught in the electronic student worksheet in Figure 3, where students are asked to answer questions related to the phenomena presented. So that when students get test questions to answer, they are related to the events that have been presented, students already have the interpretation thinking skill [24] and can answer them well.

Based on Table 6, it is known that the pretest value of students' analytical thinking skill obtained a percentage of 40.48% (less critical), while the posttest value of students' analytical thinking skill obtained a percentage of 85.71% (very critical). The students' analytical thinking skills increased during the posttest. This is because analytical thinking skills have been taught in the electronic student worksheet in Figure 4, where students are asked to write down observation data related to the results of their project and then answer some questions that relate to the data held. So that when students get test questions to answer questions based on the data and facts/statements they have, students already have the analytical thinking skill [24] and can answer them well.

Based on Table 6, it is known that the pretest value of students' evaluation of thinking skill obtained a percentage of 25% (less critical), while the posttest value of students' evaluation of thinking skill obtained a percentage of 79.17% (critical). The students' evaluation of thinking skills increased during the posttest. This is because evaluation thinking skills have been taught in the electronic student worksheet in Figure 6, where students are asked to evaluate the learning activity and also to give their impressions, messages or criticisms related to the learning that has been done. So that when students get test questions to assess the logical strength of the statements presented, students already have the evaluation thinking skill [24] and can answer them well.

Based on Table 6, it is known that the pretest value of students' inference thinking skill obtained a percentage of 34.52% (less critical), while the posttest value of students' inference thinking skill obtained a percentage of 88.69% (very critical). The students' inference thinking skill increased during the posttest. This is because inference thinking skills have been taught in the electronic student worksheet in Figure 5, where students are asked to make conclusions related to the project activities that have been carried out. So that when students get test questions to determine the consequences of a statement presented, students already have the inference thinking skill [24] and can answer them well.

Conclusion

The student electronic worksheet, based on project-based learning to improve student critical thinking skills in green chemistry materials, is suitable for use as learning media in the learning process. Electronic student worksheets are declared effective for use in learning activities, as seen from the results of the cognitive test, which obtained a percentage of completeness of 100% and from the results of the critical thinking ability test, which obtained a significance value of 0.000 in the Wilcoxon signed rank test. In addition, this media can be tested on a wider scale in the future to see the consistency of its effectiveness in various learning contexts. This media can also be used as a reference in the development of interactive project-based learning media, in order to improve students' critical thinking skills.

Author's Contribution

Fania Fasya Rewanda: contribute to learning the concept and design, collecting data, analyzing data, and writing the draft article. Rusly Hidayah: contributed to reviewing the results, providing feedback and suggestions, and approving the draft article.

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