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The Impact of PBL-ESD-Based Electronic Student Worksheets on Developing Scientific Argumentation Skills among Pre-Service Chemistry Teachers

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A B S T R A C T

This study investigates the impact of using Electronic Student Worksheets (E-LKM) based on Problem-Based Learning (PBL) and Education for Sustainable Development (ESD) on enhancing the scientific argumentation skills of prospective chemistry teachers. The research was motivated by the observed low levels of scientific argumentation among chemistry education students, which are attributed to the lack of contextual and student-centered learning approaches that support 21st-century skills. The study employed a quasi-experimental method with a pretest-posttest control group design, involving two classes selected through cluster random sampling. The experimental group used PBL-ESD-based E-LKM, while the control group used conventional methods. Argumentation skills were measured using essay tests, and data were analyzed using N-Gain and independent sample t-tests. The results showed that the experimental class achieved a higher N-Gain score (0.662) compared to the control class (0.544), with both in the moderate category. The t-test indicated a significant difference between the two groups (sig. = 0.000 < 0.05). These findings demonstrate that integrating PBL and ESD in E-LKM is effective in improving students' scientific argumentation skills and fostering critical thinking and sustainability awareness in chemistry education.

1. Introduction

The world of education faces challenges in the 21st century due to the rapid development of science and technology (Setiawan & Lenawati, 2020). Higher education is one of the formal education levels that prepares students to become members of society who are able to apply, develop, and create science and technology for national development and improve human welfare. The learning process in higher education must be able to support the achievement of 21st century competencies (Normawati et al., 2022). However, in reality, many learning processes in higher education still do not support the achievement of 21st century competencies. Research conducted by Alhayat et al. (2022) supports this, because

the research findings show that students studying chemical education in the modern era still lack skills, especially argumentation skills. In chemistry education programs, graduates must not only understand the basic concepts of chemistry, but must also be able to think critically, analytically, and convey scientific arguments based on evidence. Field studies and previous research show that, due to a less varied and lecturer-focused learning approach, the scientific argumentation skills of Chemistry Education students are still low.

In science learning, argumentation has an important role based on the theory of constructivism, which emphasizes that knowledge is built through the process of thinking, debate, and justification based on previous experience and information (Devy et al., 2020; Sabekti et al., 2020). However, field studies and interviews conducted at several chemistry education lecturers in Riau show that students' argumentation skills are not very visible and are still very low. This is in line with the research of Wahdan et al. (2017) who found that the level of scientific argumentation of Chemistry Education study program students at the State University of Malang was still very low. The low level of scientific argumentation skills can be caused because educators have not provided a forum for developing these skills (Pitorini et al., 2020).

On the other hand, the many controversial issues found lately such as social, economic, and environmental issues are part of the sustainable development agenda, which demands an active role for education through the Education for Sustainable Development (ESD) approach. ESD has the main objective to prepare the younger generation to be productive citizens in the future. Students should have the ability to engage in a democratic society and help shape a sustainable society for the future. Sustainable development expects students to have awareness of their environment and to be educated and nurtured to take responsibility for present and future generations (Burmeister et al., 2012). One way to raise learners' awareness of this is Education for Sustainable Development (ESD).

Designing teaching materials can help students actively participate in learning and support 21st century skills (Ameliawati et al., 2021; Fikria & Prodjosantoso, 2021). One of the important steps for a lecturer in the learning process is to fulfill the aspects of teaching materials (Nuryasana & Desiningrum, 2020). The development of student worksheets (LKM) is teaching material that can help learning. The utilization of technology that can be used to support learning is by using electronic-based teaching materials (Noer et al., 2021). MFIs in electronic form (E-LKM) can be one of the innovations in realizing an effective and efficient learning process (Aldresti et al., 2021). Unfortunately, the results of interviews with lecturers and students show that the use of electronic-based teaching materials in chemistry learning is still very limited.

The problem-based learning model is one of the learning models that emphasizes real problem solving, critical thinking, collaborative, and independent learning. Chemistry students are encouraged to conduct scientific research in their lessons. This can be achieved by combining knowledge, perspectives, and skills. PBL enhances intrinsic motivation, effective collaboration skills, effective problem-

solving skills, and flexible knowledge (Hmelo-Silver & Eberbach, 2012). PBL is considered in line with ESD principles because it can foster higher-order thinking skills, the ability to investigate complex problems, and build awareness of social-scientific issues (Hmelo-Silver & Eberbach, 2012; Wulandari & Shofiyah, 2018). In the context of chemistry learning, the integration between PBL and ESD has the potential to provide a more authentic and contextualized learning experience. In addition, controversial contexts that can be studied in an interdisciplinary manner with the main topic of chemistry will help ESD to be integrated.

Based on these problems, this study aims to examine the effect of using electronic student worksheets (E-LKM) based on Problem-Based Learning (PBL) and Education for Sustainable Development (ESD) on improving the scientific argumentation skills of chemistry teacher candidates. The novelty of this research lies in the synergistic integration of PBL learning model, ESD approach, and electronic learning media (E-LKM) in the context of complex basic chemistry materials, which are specifically designed to build higher order thinking skills.

2. Methodology

This study was carried out at Riau University, namely in the study program for chemistry education. The research sample was chosen using the cluster random sampling technique. The experimental group and the control group were the two classes that made up the sample. This study employed a control group design model with a pretest-posttest quasi-experimental methodology. The purpose of this experiment is to compare the argumentation abilities of students who use E-LKM based on PBL-ESD in their learning with those of the control group, which does not use E-LKM based on PBL-ESD. The objective is to evaluate how using the created media affects one's capacity for argumentation and knowledge of sustainability. Table 1 displays the design.

Table 1. Quasi-experimental learning design

Class	Pretest	Treatment	Posttest
Experiment	X_1	Y_1	X_1
Control	X_1	-	X_1

Notes: X1: scientific argumentation skill assessment instrument; Y1: learning using E-LKM based on PBL-ESD.

Scientific argumentation skills measured during the pretest and posttest were then analyzed using N-Gain to see whether there was an increase in scientific argumentation skills of chemistry education students. To determine the N-Gain value, the following formula was used:

$$N - Gain = \frac{posttest\ score - pretest\ score}{\text{maximum score} - pretest\ score}$$

Source by Hake (1998)

With the criteria listed in Table 2.

Table 2. N-Gain Criteria

Range	Criteria
N-Gain > 0,7	High
0,3 ≤ N-Gain ≤ 0,7	Medium
N-Gain < 0,3	Low

The data analysis technique used the analysis prerequisite test with the Shapiro-Wilk test, and the hypothesis test used the independent sample t-test using the SPSS version 24 application. The independent sample t-test was used to see whether or not there was a difference in the improvement of scientific argumentation skills between the experimental group and the control group.

3. Results and Discussion

E-LKM is a teaching resource designed to help students in chemical education build their capacity for scientific argumentation and their knowledge of sustainability. This E-LKM includes learning specifically designed for the previously synthesized syntax. Worksheets can be combined with different learning models and methodologies, according to (Krisnayanti & Sujana, 2022). Figure 1 lists some of the E-LKM displays that use PBL-ESD syntax. PBL-ESD-based E-LKM can help students better comprehend the content based on current sustainability issues. The economic, social, and environmental facets of ESD are framed as issues that need to be recognized and examined at the outset of education. Since there are numerous environmental issues that can be considered in the chemical equilibrium material in solution, the environmental aspect is the one that is most frequently mentioned. When identifying issues, economic and social factors are also covered in the first narrative; these are covered in the form of impacts at the outset. Students are then required to come up with ways to counteract the effects of the three sides of ESD in the following process, which includes developing hypotheses, gathering data, testing hypotheses, and conducting a final analysis. As a result, students have a deeper comprehension of chemical equilibrium material in solution from the E-LKM.

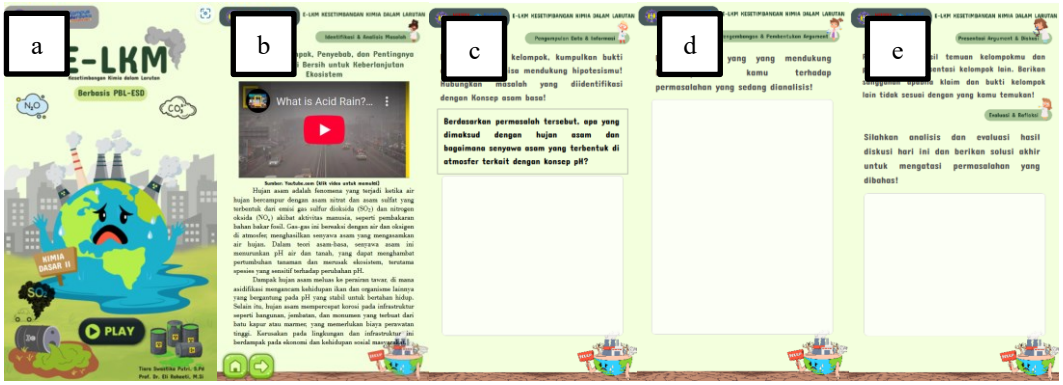

Figure 1. Structure of PBL-ESD based E-LKM (a) cover; (b) problem identification and example issues; (c) data collection syntax; (d) argument development syntax; (e) presentation and evaluation syntax.

Measurement of scientific argumentation skills of chemical education students is done by giving pretest and post-test questions in the form of descriptions. The results of this value are then processed and analyzed to see the difference. The difference in scientific argumentation skills between the two groups can be seen descriptively on the average pretest and post-test shown in Figure 2.

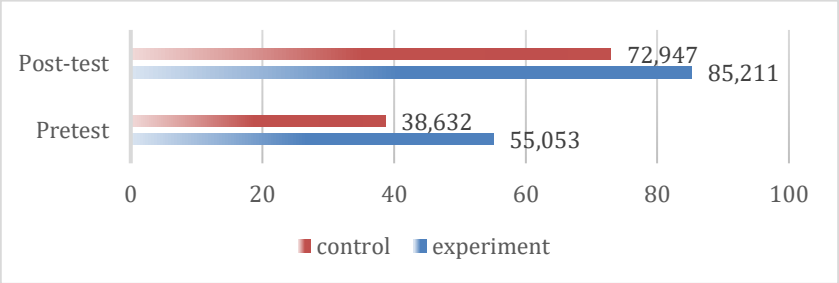

Figure 2. Difference in Average Scientific Argumentation Scores of Two Groups

a. Normalize Gain Test (N-Gain)

The experimental group—the class that used E-LKM chemical equilibrium in PBL-ESD-based solutions to teach—and the control group—which taught as usual—were the subjects of field testing. To observe variations in the two classes' abilities to make scientific arguments, researchers administered pretest and posttest questions. The pre-service chemistry teachers' scientific reasoning skills demonstrate the disparities between the experimental group's pupils who learn utilizing E-LKM chemical equilibrium in PBL-ESD-based solutions and the regular classroom techniques. This is evidenced by the average Normalized-gain (N-Gain) value of the experimental group which is greater than the control group in Table 3 which shows that the increase in both control and experimental classes is in the moderate category, namely in the range of 0.3 - 0.7.

Table 3. Total Acquisition Score of Experimental and Control Groups

Group	Number of students	Mean score		
		Pre-test	*Post-test*	N-gain
Control	38	38,632	72,947	0,544
Experiment	38	55,053	85,211	0,662

b. Test of Hypothesis

Before conducting hypothesis testing using the independent sample t test, the data must be ensured to meet the requirements of normality and homogeneity. A data is said to be normal and homogeneous if it has a significance value above 0.05. In this study, normality testing used the Shapiro-Wilk test, this is because the amount of data from each group was not more than 50. The results of the normality test can be seen in table 4 and the homogeneity test in table 5.

Table 4. Normality Test Results

Group	Shapiro-Wilk		
	Statictic	df	Sig.
Control	0,969	38	0,364
Experiment	0,953	38	0,112

In table 4, it can be seen that according to the Shapiro-Wilk test, the experimental group data has a significance value of 0.364, so it can be stated that it is greater than 0.05 (0.364> 0.05), while the control group data has a significance value of 0.112, so it can be stated that it is greater than 0.05 (0.112> 0.05). Based on this table, it can be stated that the experimental group and control group values have normally distributed data.

Table 5. Homogenity Test Results

Group	f	Sig.
Argumentation Skills	3,886	0,052

In table 5, it can be seen that the significance value of the data significance value of 0.052 is greater than 0.05 (0.052 > 0.05). So it can be concluded from these data that both data from the pretest and posttest have homogeneous data. After the data is confirmed to be normal and homogeneous, hypothesis testing is then continued using the independent sample t test. Independent sample t-test statistical analysis (often abbreviated as t-test) is used to test whether there is a statistically significant difference between two groups.

Table 6. Independent Sample t test Results

Group	t	df	Sig. (2-tailed)
Argumentation Skills	5,968	74	0,000

Figure 2 shows that the mean score of the experimental group is higher than that of the control class. The scientific argumentation skills of the two groups differ in this respect. The results of the independent sample t test, presented in Table 5, can be used to statistically determine the difference. The results show a significance of 0.000, which indicates that the value is smaller than the significance level (0.005). These results indicate that the scientific argumentation skills of chemical education students are very different when they do learning with PBL-ESD-based E-LKM or without E-LKM.

The learning process using E-LKM, which is based on PBL-ESD, presents students with challenges that are contemporary global issues and links them to the lessons they have learned. This is what causes the difference in scientific reasoning skills. Students are then invited to identify and offer hypotheses pertaining to the difficulties that have been presented. Students can hone their scientific argumentation abilities in this way. The first steps towards improving pupils' scientific argumentation abilities are these two phases. The use of appropriate teaching materials is one of the things that can make learning successful. This suggests that the scientific reasoning abilities of chemistry education students from

a wide range of backgrounds are impacted by the use of E-LKM chemical equilibrium in solutions based on PBL-ESD. The use of electronic teaching materials based on problem investigations can also greatly improve scientific argumentation skills, particularly in the argumentation skills of the claim and evidence aspects, according to research studies by Hendratmoko et al. (2025) and Nurinda et al. (2018). According to research by Kundariati et al. (2023), PBL has been demonstrated to enhance a number of scientific argumentation skills, such as claims, evidence, reasoning, and refutation. ESD included into PBL further enhances the development of argumentation skills by offering real-world contexts and sustainability concerns that call for critical thinking and evidence-based reasoning, according to research by Mohd-Yusof et al. (2015).

4. Conclusion

The study's findings suggest that, in comparison to traditional instruction, the use of electronic student worksheets (E-LKM) based on Problem-Based Learning (PBL) and Education for Sustainable Development (ESD) greatly enhances the scientific argumentation abilities of aspiring chemistry teachers. This is demonstrated by the experimental group's greater increase in N-Gain scores and the t-test results, which reveal significant group differences. Through pertinent social, economic, and environmental issues, the integration of PBL and ESD offers an authentic learning environment that fosters critical thinking, the development of arguments supported by evidence. As a result, using electronic teaching resources that are contextually based on PBL-ESD can be a useful tactic to help students in chemistry classes develop 21st century abilities.

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