Augmented Reality-Problem Solving Lab: Does It Foster Elementary Students' Understanding of Submicroscopic Phenomena in Physics?

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***Abstract*—Electrical concepts are difficult for students to understand because they involve abstract concepts that cannot be seen with the naked eye, making it necessary to use technology to visualize submicroscopic levels of electrical concepts. One method that can be used to improve students' understanding at the submicroscopic level is the PSLab-AR method. This study aims to examine the impact of applying the PSLab-AR method on students' conceptual understanding at the submicroscopic level. The research method used is a quasi-experimental design with a Nonequivalent Control-Group Design. The sample consisted of 42 students (22 female and 20 male) divided into two classes. The instrument used was an essay test. Data analysis was conducted using a rubric to assess levels of understanding, N-gain, and effect size. The results showed that 41% of students using the PSLab-AR method improved their understanding to the highest level for verbal submicroscopic questions. In comparison, 54% of students increased their understanding to the level of scientific drawing for visual questions. Based on N-gain, the improvement in student's conceptual understanding of verbal questions was in the medium category with an N-gain of 0.69, while for visual questions, the improvement was in the high category with an N-gain of 0.73. The effect size analysis showed values of 1.14 for verbal questions and 1.10 for visual questions, indicating that the impact of using the PSLab-AR method falls within the large effect category compared to the control class that did not use PSLab-AR.**

***Keywords*—PSLab AR, level of understanding, electricity**

I. Introduction

Natural Science (Science) learning at the elementary school level aims to give students an initial understanding of the natural phenomena around them. In the concept of science learning, there are three primary levels of concern, namely macro, micro, and symbolic [1, 2]. At the macro level, students are invited to understand phenomena that can be observed directly, such as the movement of objects, changes in weather, and plant growth. Meanwhile, at the micro level, students begin to be introduced to objects that are invisible to the naked eye, such as cells, air particles, or atoms [3]. At the symbolic level, students learn abstract representations of various natural phenomena, including the use of chemical symbols, mathematical equations, and graphic models to help visualize more complex scientific concepts. An approach that combines these three levels aims to enrich students' understanding of nature in a comprehensive and in-depth manner [3] while encouraging the development of critical and analytical thinking skills from an early age.

A problem that often occurs in elementary schools is that many students have difficulty understanding Natural Science (IPA) concepts. This is caused by various factors, such as less interesting learning approaches or limited use of interactive learning media. Many students have difficulty understanding abstract or complex concepts, such as the concept of electricity, energy changes, material properties, and natural cycles, because these concepts cannot always be observed directly [4]. Students' lack of involvement in experiments or practical activities also makes it difficult for them to connect theory with reality in the field. As a result, many students do not understand the concept of science as a whole, which has an impact on their low interest and motivation in learning this subject. This issue is highly urgent to address promptly because students' difficulties in understanding scientific concepts will impact Indonesia's PISA scores [5] in the science domain. The 2022 PISA data shows that Indonesia's science score dropped from 396 to 383, ranking 67th out of 81 countries.

One solution that can be implemented is the application of the PSLab-AR method. This method is a development of the problem-solving practicum by integrating augmented reality (AR) technology into its stages [6]. The importance of incorporating AR into practical activities is based on several reasons. First, AR enhances multi-modality in concept representation [7]. With AR technology, students can directly interact with phenomena displayed during the practicum, such as visualizing the movement of electrons in an electrical circuit through interactive visualization. Second, AR provides a unique experience for students by combining elements of the real and virtual worlds [8, 9], creating a more engaging learning environment. Third, AR helps students better understand abstract concepts through the dynamic visualizations provided by the technology [10–12].

The novelty of this research lies in the PSLab-AR method itself. This method has never been developed in Indonesia, providing a new and innovative alternative to practical models that can be implemented in schools. This method is based on several studies indicating that combining two types of laboratory practices, real and virtual, is the most effective

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strategy [13, 14]. One way to integrate these two forms of practice is by utilizing AR technology. Several studies have shown that AR technology not only enhances students' conceptual understanding [11] but can also be applied in laboratory practices [15]. However, no research has yet combined AR technology with the PS laboratory method using a markerless approach. In fact, the PS method offers advantages in improving the quality of laboratory implementation and training students' problem-solving skills [16, 17]

The purpose of this research is to examine the impact of the PSLab-AR method on elementary students' levels of conceptual understanding. To focus the research, we have formulated two research questions:

1) What is the overview of elementary students' level of understanding of Ohm's law?
2) How effective is PSLab AR in increasing students' level of understanding of concepts?

II. Literature Review

A. Previous Research on Electricity Concepts

In the subject of science, the topic of electricity is considered abstract because it involves the concept of electrons, which cannot be seen with the naked eye, making it difficult for elementary students to comprehend. As a result, various studies have been conducted at the elementary school level to improve the quality of electricity teaching. For example, integrating higher-order thinking questions in the teaching of electricity [18], using physical artifact media [19], and applying various teaching models such as the collaborative inquiry approach [20], STEM inquiry-based learning [21], the 5E Inquiry Model [22], and problem-solving with a Personal Response System (PRS) [23]. In addition to using these models, other studies have implemented various technologies, such as Makey Makey circuit boards [24], Arduino [25], and augmented reality technology [26]. These models and media have successfully improved various skills, such as learning outcomes, conceptual understanding, computational thinking abilities, critical thinking skills, and students' attitudes toward science. However, no research has specifically focused on the microscopic level of understanding.

B. The PSLab-AR method

One method that can enhance students' understanding, particularly at the microscopic level, is the PSLab-AR method. This innovative approach integrates augmented reality technology into the problem-solving practicum method, as shown in Fig. 1 [27]. The method consists of 6 stages and 12 sub-stages [6], as outlined in the Table 1.

Based on the table above, the PSLab-AR method is divided into two sessions; the first is the pre-lab session; in this session, student activities are carried out outside the laboratory. In this session, there are two main stages; the first is the preparation stage, where at this stage students are asked to understand the objectives of the practicum, read the material and answer questions; the aim of this stage is for students to understand the basic concepts that will be used in the practicum activities, the second stage is the problems, where students are asked to understand the problems presented in the student worksheet by discussing them with their respective groups and making predictions regarding the solution to the problems presented.

Table 1. PSLab-AR method stages

Session	Stages	Sub Stages
Pre-Lab	1. Preparation	1.1 Understanding the purpose of the laboratory
		1.2 Reading the material
		1.3 Answering conceptual questions
	2. Problem	1.1 Studying the context of the real-world problem
		1.2 formulating the problem
		1.3 Making predictions
Lab activities	3. Exploration	3.1 Determining tools and materials
		3.2 Understanding the function of the tools
		3.3 Composing the experimental procedure
	4 Measurement	Data collection (AR integration)
	5 Data analysis	Data analysis
	6 Conclusion	Conclusion

After the pre-lab session, the next session is a lab activity carried out in the laboratory with answers to conceptual questions and an understanding of the problems that will be solved through practicum. The laboratory activity session is divided into four stages; the first is to explore the tools; students are asked to understand the function of the tools used, and then they carry out the measurement stage. At this stage, students use the AR application so that when making measurements, they can see the speed and direction of movement of electrons that change when a voltage is connected. Enlarged. After completing the measurement, students return to discuss with their groups to complete the stage, namely the data analysis stage. At this stage, students process the data with the data they obtained and also the theory they understand, and the last stage in the lab activity is the conclusion stage. Students discuss to make conclusions and compare. The results of their findings are based on the predictions they wrote in the pre-lab stage.

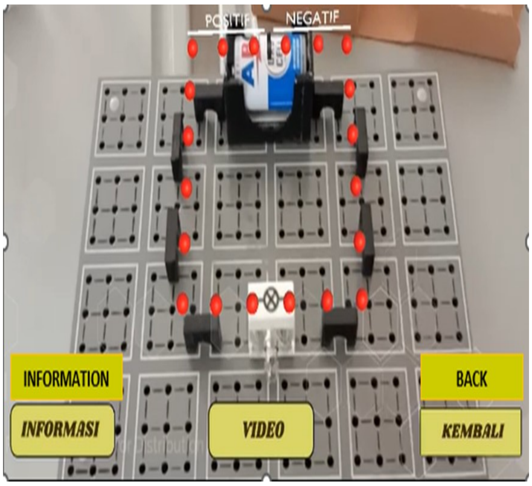

Fig. 1. Animation model of electron movement.

III. Materials and Methods

The research method used in this article is a quasi-experiment with a Nonequivalent (Pretest and Posttest) control group Design [28]. This method involves two groups, namely an experimental group that receives special treatment and a control group that does not receive treatment as shown in Table 2. In both groups, pre-experimental and post-experimental measurements were applied. The presence of a pre-test in the method helps to determine the degree of similarity of groups before the experiment and corrects the post-test results accordingly.

Table 2. Nonequivalent (pretest and posttest) control-group design

Group	N	Pre-test	Treatment	Post-test
Experimental	22	0_1	X	0_2
Control	20	0_1		0_2

$$X = PSLab{-}AR$$

A. Research Sample

In this study, the sample was determined using purposive sampling due to limited availability and ease of access for the researcher [29]. The sample consisted of 42 elementary school students from one school in Garut Regency, with 22 female students and 20 male students, divided into two classes: the control class, which used the cookbook practicum model (20 students, 47.6%), and the experimental class, which applied the PSLab-AR method (22 students, 53.4%). The students were aged between 11 and 12 years old.

B. Instruments and Data Analysis

The research instrument used in this study was a test administered during both the pretest and posttest. The test consisted of two essay questions designed to measure the student's level of understanding at the microscopic level, with one question presented in verbal form and one question presented in visual form.

The instrument developed was then analyzed for validity and reliability using SPSS software [30]. Validity measures the extent to which a test instrument measures what it is intended to measure. Reliability relates to the consistency of the research instrument, meaning that if it is used with a different sample, the results will remain consistent. The conceptual understanding test instrument was piloted on 17 sixth-grade elementary school students in one of the elementary schools in Garut Regency. The validity analysis of the conceptual understanding test questions revealed that the verbal submicroscopic questions had a validity score of 0.946, and the visual submicroscopic questions scored 0.922. These values indicate that both questions are valid because they exceed the r-table value of 0.482. Meanwhile, the reliability of the conceptual understanding test showed a reliability coefficient of 0.847. This result indicates that the reliability coefficient of the conceptual understanding test demonstrates a very high level of stability. Thus, the instrument is deemed suitable for use as a research tool.

C. Data Analysis

This study categorized understanding levels into two types of questions: verbal and visual. For data analysis, the assessment of student's understanding levels for verbal questions used a rubric adapted from the one developed by Abraham [31], as explained in Table 3.

Table 3. Verbal question understanding level rubric

Skor	category	Answer Criteria
4	Understanding Completely (MU)	All correct answers show understanding of all the concepts asked.
3	Understanding Partially (MS	Partially correct answers indicate an understanding of some of the concepts asked, and there are no wrong answers.
2	Partially Understanding with Misconceptions (MS/MK)	Partially correct answers show understanding of some of the concepts asked, but there are also some incorrect answers
1	Misunderstanding (MK)	• Irrelevant or unclear answers • Answers include illogic or misinformation
0	Not Understanding (TM)	• Do not fill in the answers • Answered, "I do not know/understand" • Answer Repeat the question

Abraham's level of understanding [31] is also adopted for visual understanding levels, as explained in Table 4.

Table 4. Visual question understanding level rubric

Skor	category	Answer Criteria
4	Scientific Drawing (GI)	The picture drawn comprehensively reflects all scientific components.
3	Partially Correct Drawing (MS)	The images depicted only reflect some of the scientific components, and there are no unscientific or erroneous images.
2	Partially Understanding with Non-Scientific Drawings (MS/GTI)	The images depicted only reflect some of the scientific components, and some images are unscientific or incorrect.
1	Non-Scientific Drawings (GTI)	The image depicted reflects all components that are unscientific or erroneous.
0	Not Drawing (TM)	• Does not create images • Answer Repeat the question

We involved three raters to evaluate the verbal and visual submicroscopic questions developed by the researchers. Subsequently, we applied Cohen's Kappa (k) [32] to calculate inter-rater reliability to ensure that the decisions made were free from bias. The analysis results showed that two k values fell into the moderate category: one for the pretest of visual submicroscopic questions in the class using PSLab AR and the other for the pretest of verbal microscopic questions in the control class. Meanwhile, six other k values were categorised as substantial agreement [33], as detailed in Table 5.

Table 5. Inter-rater reliability

Question	Verbal Submikroskopis		Visual Submikroskopis	
	k	Category	*k*	Category
Pre-test PS Lab AR	0.616	Substantial Agreement	0.559	Moderate Agreement
Post test PS Lab AR	0.719	Substantial Agreement	0.797	Substantial Agreement
Pre-test CookBook	0.515	Moderate Agreement	0.669	Substantial Agreement
Post-test CookBook	0.748	Substantial Agreement	0.667	Substantial Agreement

To measure how effective the PSLab-AR method is, the first step is to convert the level of understanding into a scale of 100, and then the data obtained is analyzed using N-gain [34] to see how much the student's understanding has increased at the submicroscopic level with categories such as shown in Table 6. Apart from that, data analysis was also carried out using the effect size formula [35, 36] with the criteria as explained in Table 7. This effect size is used to measure how big the difference is in the influence of PSLab-AR on students' level of understanding of concepts at a microscopic level when compared to the control class.

Table 6. N gain

Nilai N-Gain	Kategori
$G \leq 0.3$	Low
$0.3 < G \leq 0.7$	Medium
$G > 0.7$	High

Table 7. Effect size Category

Effect Size	Kategori
0.1	Very Small
0.2	Small
0.5	Medium
0.8	Large
1.2	Very Large
2	Huge

IV. Result and Discussion

A. Result

1) Levels of students' conceptual understanding

Understanding Levels of Verbal Concepts The categorization of understanding levels for verbal concepts, specifically submicroscopic verbal concepts, is divided into five levels: understanding completely (MU), understanding partially (MS), partially understanding with misconceptions (MS/MK), misunderstanding (MK), and not understanding (TM). The frequency and percentage data for each understanding level in both the control class and the experimental class are presented in Table 8. The description of the understanding levels for verbal concepts can be observed in the points below.

- **Understanding Completely (MU):** At the MU level for submicroscopic electrical verbal concepts, the PSLAB-AR group experienced an increase of 41% in the number of students. This value is derived from the difference in the percentage of students during the pretest, where there were no students (0%) who understood completely, rising to 9 students (41%) who understood completely during the posttest. This increase is higher than that of the control group, which had no students at the complete understanding level (0%). Overall, these findings indicate that the PSLAB-AR practical method can enhance verbal understanding to a state of complete comprehension. This practical method could undoubtedly be considered one of the best alternatives for science education in elementary schools.
- **Understanding Partially (MS)**: At the MS level for submicroscopic electrical verbal concepts, the PSLAB-AR group experienced an increase of 32% in the number of students. This value is obtained from the difference in the percentage of students during the pretest, where there were two students (9%) who partially understood the concepts, rising to 9 students (41%) who partially understood during the post-test. Meanwhile, the control group experienced an increase of 50%, where the percentage changed from no students (0%) partially understanding the electrical concepts in the pretest to 10 students (50%) in the posttest. Although the data indicate that the PSLAB-AR group's improvement is smaller than that of the control group, it is essential to note that the dominant increase in the PSLAB-AR group occurred in the MU category.
- **Partially Understanding with Misconceptions (MS/MK)**: At the MS/MK level for submicroscopic verbal concepts, the PSLAB-AR group saw a decrease of 9% in the number of students. This value is derived from the difference in the percentage of students during the pretest, where there were six students (27%) with partial understanding and misconceptions, reducing to four students (18%) with the same understanding during the post-test. Conversely, the control group experienced an increase of 10% in the MS/MK category, with the number of students increasing from seven students (35%) during the pretest to nine students (45%) during the posttest. Overall, the significant reduction in the MS/MK category indicates the success of the PSLAB-AR practical method in providing better understanding at the level of complete comprehension.
- **Misunderstanding (MK)**: At the MK level for submicroscopic verbal concepts, the PSLAB-AR group experienced a decrease of 64% in the number of students. This value is derived from the difference in the percentage of students during the pretest, where there were fourteen students (64%) who still misunderstood the concepts, dropping to zero students (0%) in the posttest. In contrast, the control group saw a decrease of 60%, with the number of students who misunderstood changing from thirteen students (65%) in the pretest to one student (5%) in the posttest. Overall, while there is a reduction in understanding at this level, it cannot be considered a better or equal measure compared to the other group when the reduction still leads to MS or MS/MK levels in the control class.
- **Not Understanding (TM)**: At the TM level for submicroscopic electrical verbal concepts, both groups showed the same initial and final conditions, as there were no students who did not understand the concepts.
- **Understanding Levels of Visual Concepts**: The categorization of understanding levels for visual concepts, specifically submicroscopic visual concepts, is divided into five levels: scientific drawing (GI), partially correct drawing (MS), partially understanding with non-scientific drawings (MS/GTI), non-scientific drawings (GTI), and not drawing (TM). The frequency and percentage data for each understanding level in both practical groups are presented in Table 7. The description of the understanding levels for visual concepts can be observed in the points below.
- **Scientific Drawing (GI)**: At the GI level for submicroscopic electrical visual concepts, the PSLAB-AR group experienced an increase of 54% in the number of students. This value is derived from the difference in the percentage of students during the pretest, where no students (0%) understood completely, rising to twelve students (54%) during the posttest. This increase is higher than that of the control group, where no students were at the scientific drawing level (0%) either before or after the Cookbook practical model was

applied. This data shows that the PSLAB-AR group succeeded in providing better visualisation compared to the other practical group by involving AR in the practical activities.

- **Partially Correct Drawing (MS)**: At the MS level for submicroscopic electrical visual concepts, the PSLAB-AR group experienced an increase of 23% in the number of students. This value is obtained from the difference in the percentage of students during the pretest, where no students (0%) had partially correct drawings, rising to five students (23%) during the posttest. Meanwhile, the control group experienced a 50% increase, where the percentage changed from one student (5%) with a partially correct drawing in the pretest to eleven students (50%) in the posttest. Although the PSLAB-AR group's increase is smaller than that of the control group, it is due to the dominant improvement in the PSLAB-AR group occurring in the GI category.
- **Partially Understanding with Non-Scientific Drawings (MS/GTI)**: At the MS/GTI level for submicroscopic visual concepts, the PSLAB-AR group experienced a decrease of 27% in the number of students. This value is obtained from the difference in the percentage of students during the pretest, where there were eleven students (50%) with partial understanding and non-scientific drawings, decreasing to five students (23%) with the same understanding during the posttest. Conversely, the control group experienced an increase of 10% at the MS/GTI level, with the number of students increasing from seven students (35%) during the pretest to nine students (45%) during the posttest. Overall, this data indicates that the reduction in the MS/GTI visual understanding level in the PSLAB-AR class occurred due to the increased understanding of students at the GI level.
- **Non-Scientific Drawings (GTI)**: At the GTI level for submicroscopic electrical visual concepts, the PSLAB-AR group experienced a decrease of 45% in the number of students. This value is derived from the difference in the percentage of students during the pretest, where ten students (45%) still had non-scientific drawings, dropping to zero students (0%) during the posttest. Meanwhile, the control group saw a 60% decrease, with the number of students changing from twelve students (60%) during the pretest to zero students (0%) during the posttest. Overall, this decrease in understanding at this level cannot be considered better or equal compared to the other group when this decrease still leads to MS or MS/GTI levels, as seen in the control class.
- **Not Drawing (TM)**: At the TM level for understanding the visual aspect of submicroscopic concepts, the PSLAB-AR group experienced a decrease of 6%. This value is obtained from the difference in the percentage of students during the pretest, where one student (6%) was at the not drawing level, dropping to zero students (0%) during the posttest. In contrast, the control class showed the same initial and final conditions, as there were no students at the not drawing level.

Table 8. Frequency and percentage of student's level of understanding

Question form	Level of Understanding	PSLab-AR		Konvensional	
		Pretest N (%)	Posttest N (%)	Pretest N (%)	Posttest N (%)
Verbal	MU	0 (0)	9 (41)	0 (0)	0 (0)
	MS	2 (9)	9 (41)	0 (0)	10 (50)
	MS/MK	6 (27)	4 (18)	7 (35)	9 (45)
	MK	14 (64)	0 (0)	13 (65)	1 (5)
	TM	0 (0)	0 (0)	0 (0)	0 (0)
Visual	GI	0 (0)	12 (54)	0 (0)	0 (0)
	MS	0 (0)	5 (23)	1 (5)	11 (55)
	MS/GTI	11 (50)	5 (23)	7 (35)	9 (45)
	GTI	10 (45)	0 (0)	12 (60)	0 (0)
	TM	1 (5)	0 (0)	0 (0)	0(0)

2) The effect of PSLAB-AR on students' level of understanding

An N-gain analysis was conducted to determine the significance of the difference between the average pretest and posttest scores. Based on Table 9, when considering the N-gain values for verbal questions, the increase in student's conceptual understanding using the PSLab-AR method falls into the medium category, with an N-gain value of 0.69. This means that, on average, students were able to improve their performance by 59% in answering verbal submicroscopic conceptual understanding questions. For visual questions, the increase in student's conceptual understanding is categorized as high, with an N-gain value of 0.73. This indicates that, on average, students were able to enhance their performance by 73% in answering visual submicroscopic conceptual understanding questions. This improvement in conceptual understanding is higher compared to that of students in the control class, which falls into the medium category with lower N-gain values of 0.44 for verbal submicroscopic questions and 0.46 for visual submicroscopic questions.

Table 9. N Gain

Question form	PSLab-AR			cookbook		
	Average Pretest	Average Posttest	N gain	Average Pretest	Average Posttest	N gain
Verbal Submikroskopis	36.4	80.7	0.69	33.75	61.25	0.44
Visual Submikroskopis	36.4	82.9	0.73	36.25	63.75	0.48
Total	36.4	81.8	0.71	29.0	62.5	0.46

Table 10. Effect size test results

Question form	class	Mean	Standard deviation	sample	Effect size
Verbal	Experiment	80.7	18.8	22	1.14
	Kontrol	61.2	15.1	20	
Visual	Experiment	82.9	20.8	22	1.10
	Kontrol	63.7	12.7	20	

To assess the impact of using PSLab-AR on students' understanding levels at the microscopic level, the researcher employed effect size analysis. The effect size results indicated a value of 1.14 for verbal questions, suggesting that the impact of using PSLab-AR is classified as significant when compared to the control class that did not use PSLab-AR. For visual questions, the data processing yielded an effect size value of 1.10. Similar to verbal questions, this value also indicates that the impact of using PSLab-AR is significant compared to the control class. Complete effect size data can be found in Table 10.

B. Discussion

In the context of improving submicroscopic understanding, the N-gain of 0.69 and the increase in the percentage frequency of understanding verbal submicroscopic aspects to a whole understanding level (MU) of 41% is significantly higher than that of the control class. This is attributed to the presence of the "measurement" stage in the PSLab-AR method, which is crucial in supporting the optimization of submicroscopic understanding. During this stage, students observe AR submicroscopic modelling regarding the abstract concept of electric current during practical activities. The visualization of electron movement when the circuit is connected to a single battery source appears different from when it is connected to a source with two battery potentials. Therefore, using AR technology that presents reality and virtual objects together in practical activities can contribute to students' learning experiences, especially for those facing specific learning difficulties [37, 38]. In other words, when learning difficulties related to visualization are bridged by AR technology, students' understanding of submicroscopic visualization improves, which positively impacts their conceptual knowledge [39, 40].

Lastly, discussing why the improvement in understanding visual submicroscopic aspects and the percentage frequency change toward scientific drawing (GI) is higher compared to the control group is essential. This is closely related to the context of integrating AR technology in the "measurement" stage. After students repeatedly collect data for the observed variables, they collectively observe the modelling for each experiment they conduct. This AR environment can visualize abstract submicroscopic concepts, leading to better cognitive processes in students' understanding of these concepts than when they are not visualized. Another impact of integrating AR is not only seen in the improvement of conceptual understanding and experiences [41]. However, observational results indicate a change in student behavior during learning. When conducting practical activities that integrate AR technology [42, 43], students show greater interest in observing the visualizations presented. This was evident during the implementation of the PSLab-AR method. These results significantly impacted the significant improvement in understanding visual submicroscopic aspects compared to other practical models.

This study's findings align with previous research demonstrating that AR is an effective medium for enhancing student achievement. Various studies have shown that the use of AR can improve both learning achievement and outcomes across educational levels, including elementary school [44, 45], junior high school [46, 47], senior high school [48, 49], Vocational School [50, 51] and university [52, 53]. The novelty of this study, compared to previous research, lies in its specific focus on analyzing improvements in submicroscopic understanding. Additionally, the AR technology employed in this study uses a markerless approach. It is integrated with a problem-solving laboratory method, distinguishing it from prior studies that have not explored these particular combinations. This unique integration highlights the innovative contribution of our research to the development of effective teaching strategies using AR technology.

V. Conclusion

The results show that, for students using the PSLab-AR method, 41% achieved a complete understanding level, and 41% reached a partial understanding level for the verbal submicroscopic question type, meaning a total of 82% of students were at a high level of understanding. This is significantly higher compared to the control class, where only 50% of students were at a partial understanding level, with none achieving complete understanding. For the visual question type, 54% of students reached the level of scientific drawing, and 23% demonstrated partially correct drawings, resulting in a total of 77% of students at a high level of understanding. This is better than the control class, where only 55% of students achieved partially correct drawings, and none reached the level of scientific drawing.

In terms of improvement in understanding levels, 41% of students using the PSLab-AR method advanced to the highest level of understanding for verbal submicroscopic questions. In comparison, 54% improved to the scientific drawing level for visual questions. The N-gain score for verbal questions showed that the improvement in students' conceptual understanding using the PSLab-AR method was in the medium category, with an N-gain value of 0.69. For visual questions, the improvement was categorized as high, with an N-gain value of 0.73. The effect size analysis showed a value of 1.14 for verbal questions and 1.10 for visual questions, indicating that the impact of the PSLab-AR method is classified as significant compared to the control class, which did not use PSLab-AR.

Future research could compare the PSLab-AR method with the standard PSLab method to analyze the extent to which AR technology enhances students' conceptual understanding levels.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors contributed to the writing and revision of the article. The tasks of individual authors. e.g., A Ismail and LD Kemalia contributed to data collection by conducting research; L Sari contributed to instrument development; Isrok'atun contributed to data analysis and interpretation; DD Bahkti contributed to AR product development; all authors have approved the final version.

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