Low-Cost Light Sensor-Based Physics Experiments: Enhancing Students' Experimental Skills

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ABSTRACT

Purpose of the study: The purpose of this study is to examine the effectiveness of a simple light sensor-based experiment in improving students' experimental skills in physics learning, particularly in the topic of optics, among eleventh-grade vocational high school students.

Methodology: This study used a quantitative experimental method with a one-group design. The tools included a simple light sensor based on an LDR, breadboard, resistors, LED, buzzer, and multimeter. Data were collected through observation sheets, product assessment, and student response questionnaires. Data analysis was conducted using IBM SPSS Statistics software.

Main Findings: Students' experimental skills reached a high level with a mean score of 81.61, significantly exceeding the Minimum Completeness Criteria score of 75 ($p < 0.05$). All students successfully completed the simple light sensor experiment. Skill indicators showed an overall average of 86.67. Student responses to the media and learning process were very positive, with mean percentages of 87.07% and 86.90%, while product evaluation by teachers and observers reached 100%.

Novelty/Originality of this study: This study provides new empirical evidence on the effectiveness of low-cost, simple light sensor (light dependent resistor)-based experiments in real vocational classrooms, focusing on direct measurement of students' science process skills. It advances existing knowledge by demonstrating that affordable, hands-on experimental media can significantly enhance practical skills and learning engagement in physics education contexts with limited laboratory resources.

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1. INTRODUCTION

Education plays an important role in creating high-quality human beings. Education is also viewed as a means to produce individuals who are intelligent, creative, skilled, responsible, productive, and possess good moral character [1]-[3]. However, the reality in the field has not yet shown satisfactory results. One of the main problems in learning within formal education (schools) today is the low level of students' learning absorption [4]-[6]. This can be seen from students' learning outcomes, which remain very concerning [7], [8]. This condition is certainly the result of conventional learning practices that do not adequately address the students' own learning dimensions, namely how learning actually takes place (learning how to learn) [9], [10]. In a more substantial sense, the learning process to this day is still dominated by teachers and does not provide sufficient opportunities for students to develop independently through discovery and their own thinking processes.

Essentially, learning is a process characterized by changes within an individual. These changes as a result of learning can be indicated in various forms, such as changes in knowledge, understanding, attitudes and behavior, competencies, skills, and abilities, as well as other aspects within the learner [11]-[13]. One of the school subjects that can serve as an object of creative activity is natural science [14], [15]. For example, in physics, one of the objectives is for students to master various concepts and principles in order to develop knowledge, skills, and self-confidence that can be applied in daily life [16], [17]. Physics instruction is also intended to develop positive attitudes toward physics, namely fostering interest in learning physics further by appreciating the beauty of the order of natural phenomena and the ability of physics to explain various natural events and their applications in technology.

In physics learning, teachers are expected to provide learning services that accommodate students' diverse abilities, potentials, interests, talents, and needs. This approach enables optimal interaction between teachers and students as well as among students themselves in learning physics concepts [18], [19]. To implement effective learning, teachers should create an active and democratic learning environment by using a variety of teaching methods and presenting problems that stimulate students to think [20], [21]. Teachers also need to motivate students, consider individual differences, design appropriate lesson plans, and provide constructive feedback to support students' learning [22], [23]. In addition, learning should be integrated and connected to real-life contexts to enhance students' understanding and engagement.

Moreover, when discussing natural phenomena related to optics, learning can be achieved by understanding the relationships among the quantities involved in optical concepts. In optics, there is a device known as a light sensor [24], [25]. An optical or light sensor is a sensor that detects changes in light from a light source, reflected light, or refracted light that strikes objects or spaces [26]-[28]. Light-sensitive elements are reliable tools for detecting light energy [29], [30]. These devices exceed the sensitivity of the human eye across all color spectra and also operate in the ultraviolet and infrared regions. When light energy is processed appropriately, it can be utilized optimally for measurement techniques, control systems, and compensation techniques.

Although various studies have developed physics teaching aids and practical modules based on sensors or hands-on activities that have been proven to visualize physical phenomena and train students' science process skills [31], [32]. Their focus has generally been on product validity and descriptive analysis of students' general skills. Studies such as those conducted by Maemunah, Siswoyo, and Wibowo [33] only demonstrate that sensor-based practical tools can be used as learning media, without measuring in detail the extent to which the direct use of sensors influences students' skills in the context of learning optics. Furthermore, although the meta-analysis by Jiang et al. [34], shows the effectiveness of information and communication technology-assisted experiments in physics learning in general, most of these studies discuss learning combined with digital or virtual technologies without examining the effectiveness of simple sensors (for example, light dependent resistors) in real face-to-face classrooms at senior high schools and vocational schools. Even the study by Wang et al.[35], indicates the potential of combining real and virtual experiments; however, there is still limited empirical evidence that directly measures the effects on students' physical hands-on skills, particularly in optics learning using simple light sensors. Therefore, this study is important to fill this gap by examining the actual effectiveness of implementing simple light sensor tools on students' science process skills in Grade Eleven of a vocational high school, thus providing stronger empirical evidence compared to previous studies.

The novelty of this study lies in its empirical focus on directly testing the effectiveness of implementing a simple light sensor based on a light dependent resistor as a real practical tool to improve students' skills in optics learning within the context of vocational high schools. Unlike previous studies that generally focused on the development of sensor-based media or modules and the evaluation of product validity, this study emphasizes the real measurement of students' skills after engaging in practical activities using simple light sensors, particularly in aspects of science process skills such as observing, measuring, interpreting data, and drawing conclusions. In addition, this study was conducted in a school environment with limited laboratory facilities, thereby providing a practical contribution in the form of a low-cost, easy-to-assemble, and contextual practical tool implementation model that is relevant for vocational schools. Thus, this study not only enriches the theoretical discussion on experiment-based learning but also offers an applicable solution that can potentially be replicated in physics learning in schools with limited resources.

A light dependent resistor is a type of resistor whose resistance value is influenced by the amount of light it receives. The magnitude of resistance in a light dependent resistor depends on the intensity of the light received by the component. Examples of its applications include garden lights and automatic lighting systems, as well as indoor lighting devices. The school selected for this study is one of the schools that rarely conducts practical activities as a supporting process in physics learning. Conducting practical activities in physics learning can improve students' skills in learning and enable them to recognize practical tools and their components in detail. Therefore, this study is in line with the researchers' expectations in conducting data collection at the selected school. This study aims to determine students' skills after the implementation of a simple light sensor in Grade Eleven of the Nursing Program at Laniang Makassar Vocational High School, and to examine the effectiveness of implementing the simple light sensor on students' skills in the same class.

2. RESEARCH METHOD

This study employed a pre-experimental research design, which is a type of experimental research in which the dependent variable is not solely influenced by the independent variable, due to the absence of random sampling. In this design, a single group is exposed to the experimental treatment, and the dependent variable is subsequently observed and measured to evaluate the effect of the experiment [36]-[38]. The research design used was the One-Shot Case Study Design. The implementation of the light sensor served as the independent variable, while students' skills functioned as the dependent variable.

The population of this study consisted of all students in Grade Eleven of the Nursing Program at Laniang Makassar Vocational High School. Based on observational data provided by Imam Permana, Bachelor of Education, Master of Education, who is the physics teacher, the total number of students in Grade Eleven of the Nursing Program at Laniang Makassar Vocational High School was 101 students. From this population, a sample was selected to represent the population in order to facilitate the collection of concrete and relevant data. Using purposive sampling, one class was selected, namely Grade Eleven of the Nursing Program, consisting of 40 students. This class was chosen because it had relatively similar academic abilities and heterogeneous characteristics.

The data collection techniques in this study involved conducting field research to obtain concrete data using research instruments, as well as reviewing relevant references and literature through both direct and indirect citations. The implementation stage included the preparation of tools and components, the design of the system, and the development of work procedures. The tools and components used in this study included a circuit board, a light dependent resistor, connecting wires, a buzzer or room lamp, and a battery. The design configuration is illustrated in Figure 1.

Figure 1. Design Scheme of the Simple Light Sensor Implementation

The working procedures to be carried out in constructing this device are as follows:

Table 1. Work Procedure

No.	Indicator science process skills	Work Procedure
1	Observing	Checking the specifications and feasibility of the tools and components needed during the practicum.
2	Classifying	Separating/distinguishing between the tools and components that will be used during the practicum and arranging the circuit according to the diagram.
3	Measuring	Checking the components that may not be properly connected and strengthening the connections using a soldering iron.
4	Communicating	Testing the feasibility of the sensor by using light and observing the indicators (buzzer or room lamp), then recording the observation results in the table.
5	Inferring	Drawing conclusions from the simple light sensor experiment.
6	Predicting	Predicting the application of the simple light sensor experiment in daily life.

The research instruments are tools used to collect data. The instruments employed in this study had previously been validated by two experts, namely Rafiqah, S.Si., M.Pd., and Imam Permana, S.Pd., M.Pd. The instruments used to collect the data included an observation sheet, which was used to gather data on students' skills during practical activities. The data were obtained through direct observation by the researcher of students' experimental activities that reflected science process skills, such as observing, measuring, classifying, communicating, drawing conclusions, and predicting. In addition, product assessment was used to evaluate students' work in the form of a simple light sensor product. The assessment focused on the final product without observing the manufacturing process. The aspects assessed included product shape, quality, size, usability, and neatness. Finally, a student response questionnaire was used to determine students' responses to the implementation of the simple light sensor media and the learning process. The questionnaire was distributed to all research samples and completed based on students' experiences and perceptions. The measurement scale used was the Likert scale.

The data in this study were analyzed using IBM SPSS Statistics software by applying descriptive and inferential statistics. The analysis was conducted by calculating the mean and standard deviation. The mean was used to determine the overall level of students' skills, while the standard deviation was used to examine the data distribution. Students' skill results were then categorized based on the standards of the Ministry of Education and Culture (2016), namely: 86–100 (Very Good), 71–85 (Good), 56–70 (Fair), and less than 55 (Poor). Inferential statistics were used to test the effectiveness of the implementation of the simple light sensor on students' skills. The test used was the one-sample t-test by comparing the mean score of students' skills with the Minimum Mastery Criteria score (75). Data on students' responses to the learning media and learning process were analyzed using percentages. The percentage was calculated based on the number of students who gave positive responses compared to the total number of students. The media and learning process were considered effective if at least 80 percent of students gave positive or very positive responses, or if the average score was in the positive or enjoyable category.

3. RESULTS AND DISCUSSION

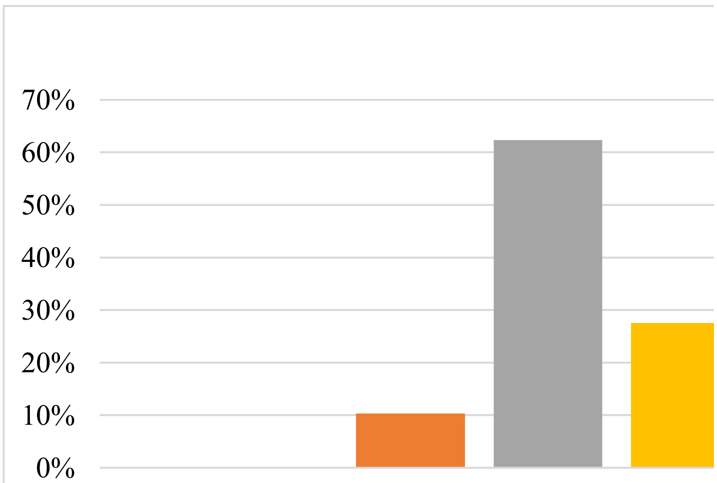
3.1. Results of Students' Experimental Skills Scores

The main objective of analyzing students' experimental skills scores is to determine the effect of the learning media on students' skills. The results of the analysis of students' experimental skills are presented in Table 1 as follows:

Table 1. Descriptive Statistics of Students' Skills

Score Range	Frequency	Percentage (%)	Category	Max	Min	Mean	SD	Variance
< 55	0	0	Poor	94.44	66.67	81.61	7.870	61.93
56–70	3	10.34%	Fair					
71–85	18	62.34%	Good					
86–100	8	27.59%	Very Good					
Total	29	100%						

The results of the analysis of students' experimental skills are illustrated in Figure 2 as follows:



Gambar 2. Results of Analysis of Students' Experimental Skills

Based on the graph above, it can be seen that the level of students' skills in constructing the simple light sensor was 100 percent successful. These data were obtained from the observers' observations during students' experimental activities in the classroom. The average score was in the "very appropriate" category, with a mean value of 81.61 and a standard deviation of 7.87. The maximum score was 94.44 and the minimum score was 66.67, resulting in a score range of 27.77.

Based on the results of the normality test using the chi-square test, a significance value of 0.58 was obtained. From the data analysis and the chi-square table, a chi-square value of 0.173 was obtained with Sig > α (0.05). Therefore, it can be concluded that the students' skills data were normally distributed at the significance level of α = 0.05 or 5 percent. The following are the results of the inferential analysis using the One-Sample t-test.

Table 2. Results of the One-Sample T-Test on Students' Skills

N	Mean	Std. Deviation	Test Value	t	Mean	Sig. (2-tailed)
29	81.61	7.87	75	4.522	28	0.000

The results of the one-sample t-test indicate that the average score of students' skills was 81.61, which is higher than the Minimum Mastery Criterion value of 75. The significance value of 0.000 ($p < 0.05$) indicates that there is a significant difference between the average students' skills score and the Minimum Mastery Criterion value. Therefore, it can be concluded that the implementation of the simple light sensor is effective in improving students' skills in physics learning at Sekolah Menengah Kejuruan Laniang Makassar. Based on the results of hypothesis testing using the t-test, the calculated t value was 4.522, while the critical t value was 2.045. Since the calculated t value is greater than the critical t value, the null hypothesis is rejected and the alternative hypothesis is accepted. Thus, it can be concluded that the students' skills in Class Eleven Nursing Program at Sekolah Menengah Kejuruan Laniang Makassar in the physics subject on the topic of optics have reached the Minimum Mastery Criterion standard of 75.

3.2. Results of Students' Skills for Each Indicator

The main objective of analyzing the observation of students' skills for each indicator is to determine the effect of the learning media on students' skills in each indicator. The results of the analysis of students' skills for each indicator are illustrated in Figure 3 as follows.

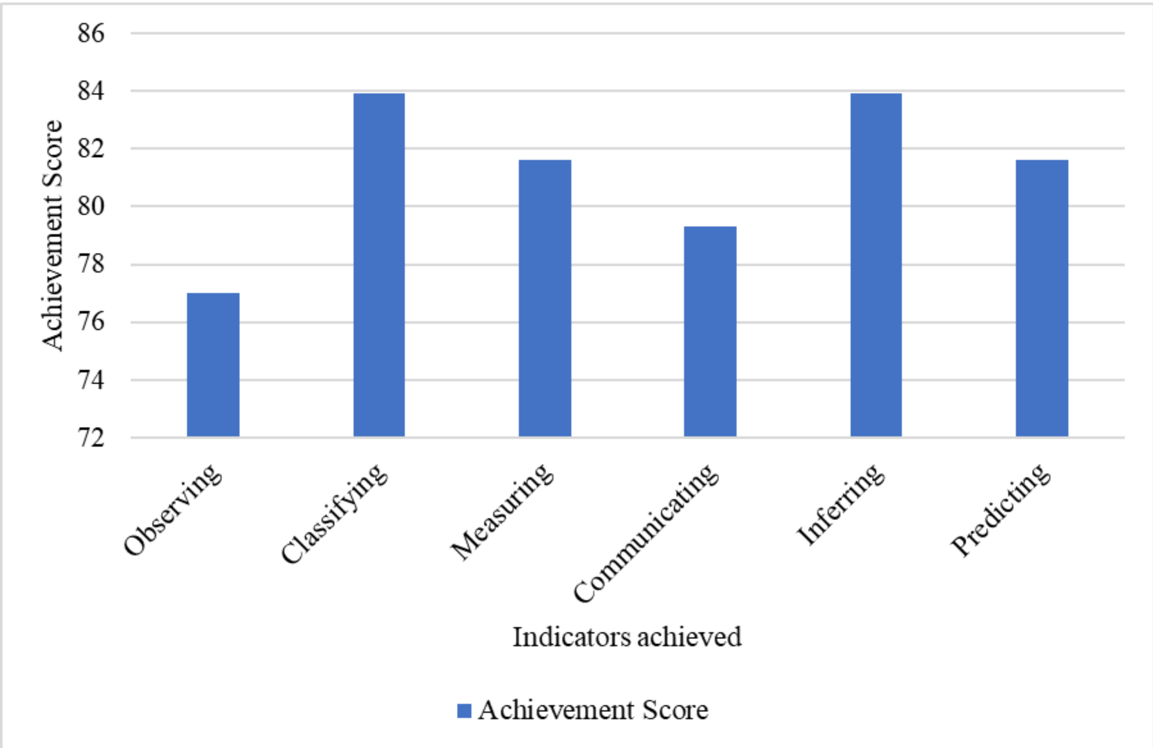


Figure 3. Overall Students' Skills Scores for Each Analyzed Indicator

Based on the graph above, it can be seen that the level of students' skills for each indicator in constructing the simple light sensor was at an average score of 86.67, which falls into the "appropriate" category.

These data were obtained from the observers' observations, namely Nuravia and Junaedi, during students' experimental activities in the classroom.

3.3. Students' Responses to the Learning Media

The main objective of analyzing students' responses to the learning media is to determine students' responses toward the media. The results of the analysis of students' responses to the learning media are illustrated in Figure 4 as follows:

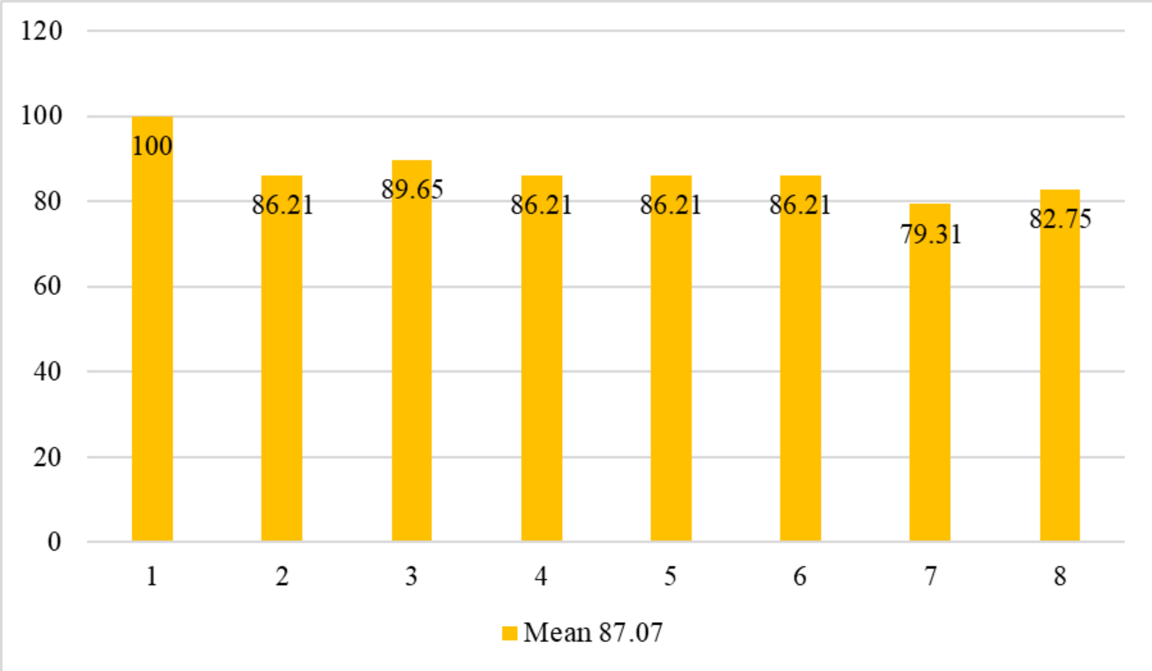


Figure 4. Analysis of Students' Responses to the Learning Media

Based on Figure 4, it can be seen that all indicators of students' responses to the simple light sensor learning media fall into the positive to very positive categories, with an overall average score of 87.07%, which exceeds the established effectiveness standard of 80%. This indicates that, in general, students provided very positive responses toward the learning media used.

For the first indicator, namely the ease of designing and constructing the simple light sensor, the highest score of 100% was obtained. This finding indicates that students perceived the learning media as very easy to design and build, thereby supporting the independent implementation of practical activities. This indicator is important because ease of design is a key prerequisite for the wide application of learning media in schools with limited laboratory facilities.

The second and fourth indicators, namely ease of assembly and the suitability of the sensor quality with the expected data, each obtained a score of 86.21%. These results indicate that students did not experience significant difficulties in assembling the device and were able to obtain experimental data that aligned with the learning objectives. This suggests that the learning media is not only technically easy to use, but also functionally reliable as a practical learning tool.

The third indicator, related to the safety of using the sensor, achieved a score of 89.65%, which confirms that students felt safe and comfortable when using the media. The safety aspect is crucial in practical-based learning, as low perceived risk can increase students' confidence to experiment and actively participate in laboratory activities.

The fifth and sixth indicators, namely the relatively standard size of the sensor and the ability of the media to increase students' learning motivation, each obtained a score of 86.21%. These findings indicate that the physical design of the media is appropriate for student characteristics and is capable of fostering intrinsic motivation through direct hands-on learning activities.

For the seventh indicator, which concerns the ease of identifying the usefulness of the sensor in everyday life, a score of 79.31% was obtained. Although this score is slightly lower than other indicators, it still falls within the positive category. This suggests that most students were able to relate the concept of the light sensor to real-life contexts, although there remains room for strengthening contextual learning aspects.

The eighth indicator, related to the structure and neatness of the device, achieved a score of 82.75%, indicating that students' products were generally neat and well-structured, although further improvement could be achieved through more systematic laboratory work standards.

Overall, these results indicate that the simple light sensor learning media is not only technically effective, but also pedagogically effective, as it enhances students' motivation, engagement, and meaningful learning experiences. Therefore, this media is suitable to be used as an alternative physics practical learning tool that is affordable, safe, and applicable, especially in schools with limited laboratory resources.

3.4. Students' Responses to the Learning Process

The main objective of analyzing students' responses to the learning process is to determine students' responses toward the learning process. The results of the analysis of students' responses to the learning process are illustrated in Figure 5 as follows.

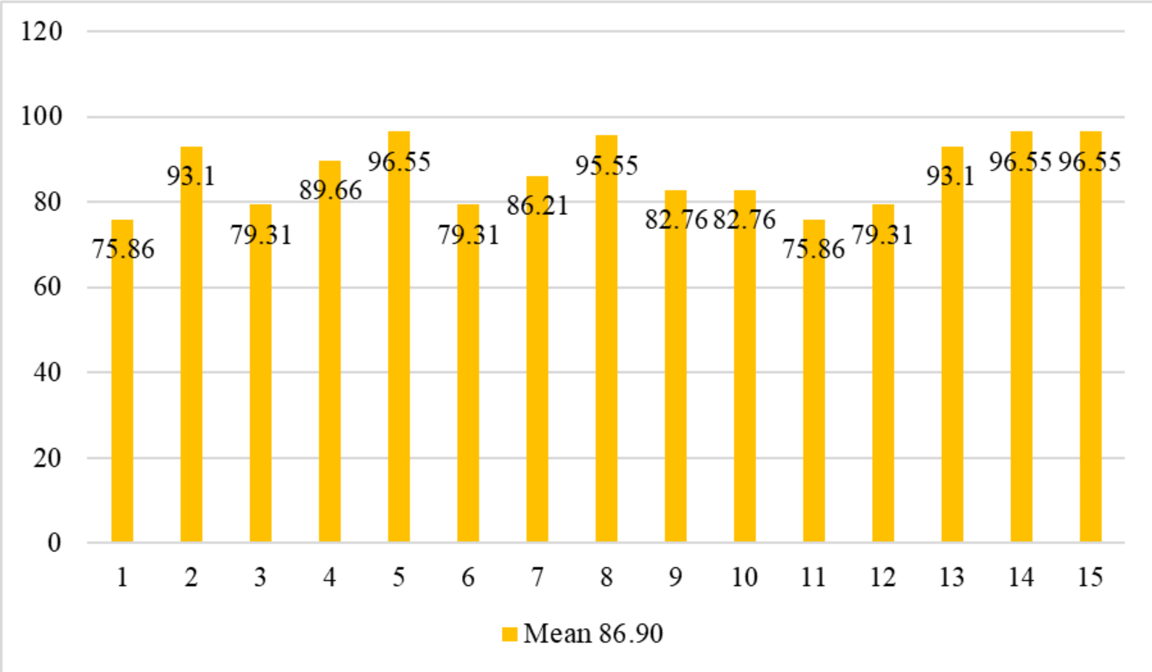


Figure 5. Analysis of Students' Responses to the Learning Process

Based on Figure 5, students' responses to the learning process fall into the positive to very positive categories, with an average score of 86.90%, which exceeds the established learning effectiveness standard of 80%. This indicates that, in general, students felt comfortable, motivated, and actively engaged in physics learning on optical topics through the implementation of the simple light sensor learning media. High scores on indicators such as the usefulness of learning optics (96.55%), the teacher encouraging students not to feel lazy about coming to school (93.10%), and learning making students diligent and happy to attend school (93.10%) indicate that the learning process was able to build positive attitudes toward physics.

Furthermore, indicators related to conceptual understanding and learning interaction also showed positive results. The statement that optical lessons are easy to understand obtained a score of 79.31%, while learning that encourages students to ask questions and engage in discussions ranged from 82.76% to 89.66%. These findings indicate that the use of simple light sensor media promotes more interactive, dialogic, and student-centered learning, thereby facilitating both cognitive and social engagement in the learning process.

In addition, indicators related to the role of the teacher and classroom atmosphere achieved very high scores, such as the use of positive language by the teacher (96.55%), the teacher's friendly appearance that creates a comfortable learning environment (96.55%), and systematic and easily understood teaching methods (93.10%). These results confirm that learning success is not solely determined by the learning media, but also by the quality of pedagogical interactions provided by the teacher, which together contribute to creating enjoyable, meaningful, and effective physics learning experiences for students.

3.5. Product Assessment

The main objective of the product assessment of the simple light sensor learning media is to determine the quality of the product that has been developed by the researcher. The results of the product assessment analysis of the simple light sensor learning media are illustrated in Figure 6 as follows.

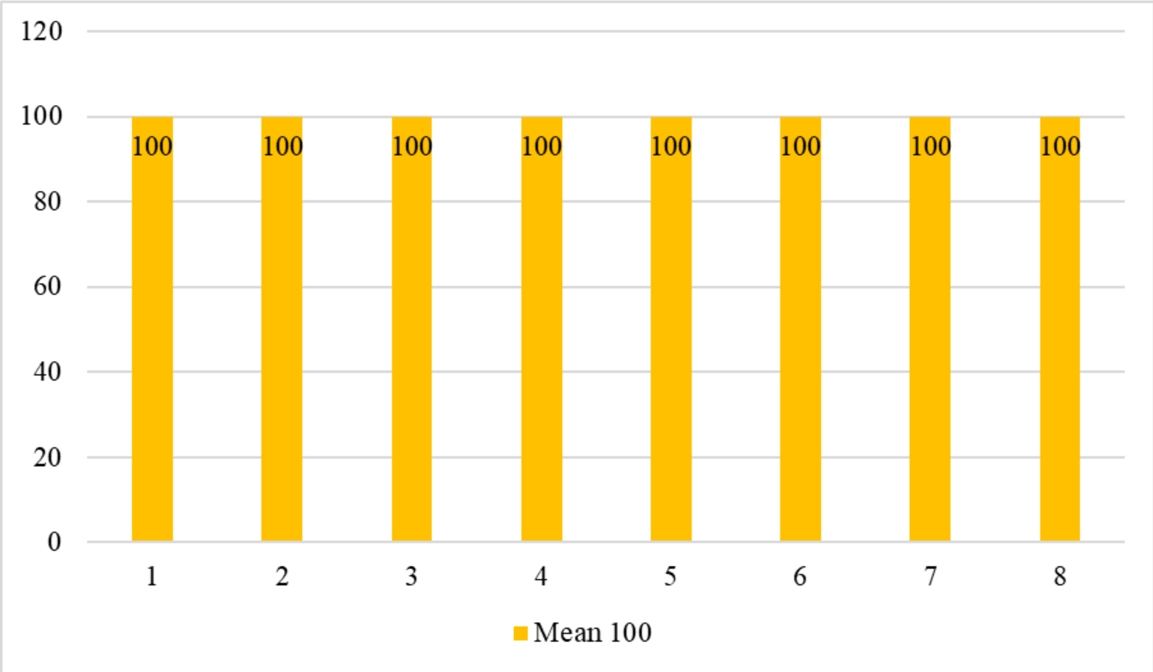


Figure 6. Analysis of Product Assessment Results

Based on Figure 6, it can be seen that the assessments provided by the teacher and observers regarding the simple light sensor learning media were categorized as effective because the response results exceeded the established standard, with a response score of 100%, while the effectiveness standard was set at 80%. The average assessment fell within the positive and very positive categories. The results of the product assessment analysis indicate that 100% of the teacher and observers gave positive and very positive responses, stating that the product was appropriate and very appropriate according to the predetermined indicators, including product form, product quality, product size, product usefulness, and product neatness.

The findings of this study indicate that the implementation of simple light sensor learning media significantly improves students' skills in physics learning, particularly in science process skills and positive responses toward more active learning of optics. These findings are consistent with studies in physics education that emphasize the importance of direct experimental experiences in the learning process. A study published on ScienceDirect reported that real experimental activities help students understand concepts more deeply and enhance investigative skills and positive attitudes toward physics learning due to students' active involvement in collecting and interpreting experimental data [35]. This is relevant to the students' responses in this study, which showed high skill scores and positive perceptions of the simple light sensor as a tool that helps them understand optical phenomena.

Furthermore, previous research has shown that experimental approaches in physics not only improve conceptual understanding but also develop broader cognitive competencies. Another study on ScienceDirect found that learning that combines real and virtual experiments can optimally facilitate students' conceptual understanding, especially when experiments are designed within an inquiry-based learning framework that emphasizes exploration and reflection on physics phenomena [39]. In this context, the use of simple light sensor media in this study also contributes to the development of scientific thinking skills, as students directly perform observation, measurement, and data analysis during practical activities, which are core characteristics of inquiry-based learning.

The findings of this study can also be viewed within the framework of the development of physics experiments, which is currently a major focus of modern physics education research according to Springer literature. Physics learning approaches that emphasize active practical activities have been identified as essential elements in increasing student engagement and understanding complex concepts such as optical phenomena in real-life contexts [40]. Therefore, the findings of this study not only support previous empirical evidence highlighting the value of experiment-based learning, but also provide additional evidence that low-cost and simple practical media such as light sensors can serve as effective solutions to overcome limited laboratory facilities in schools while still supporting students' science process skills and learning motivation.

The novelty of this study lies in the direct empirical evidence regarding the effectiveness of simple light sensor media based on Light Dependent Resistors as a physics practical learning tool in improving students' skills in the context of vocational schools. Unlike previous studies that generally focused on media development, product validation, or digital and virtual technology-based learning, this study emphasizes the real implementation of simple devices assembled directly by students and measures science process skills through experimental observation, inferential statistical testing, and analysis of students' responses. Thus, this study enriches physics education research through a low-cost experimental learning approach that is not only pedagogically effective but also contextual, practical, and relevant for schools with limited laboratory resources.

The short-term implications of this study include providing an alternative physics practical learning medium that is affordable, easy to assemble, safe, and effective in improving students' skills and learning motivation in optical topics. In the long term, this study contributes to strengthening contextual experiment-based physics learning models that can be widely adopted in secondary schools, particularly vocational schools, as part of the development of Science, Technology, Engineering, and Mathematics learning and twenty-first-century skills. However, this study has limitations, including a relatively small sample size and the use of a one-group design without a control group, which limits the generalizability of the findings. In addition, this study only measured students' skills in the short term and did not explore long-term effects on conceptual understanding or cognitive learning outcomes. Therefore, future studies are recommended to use stronger experimental designs, involve control groups, and examine the effects of light sensor media on various aspects of student learning outcomes.

4. CONCLUSION

Based on the results of the data analysis, it can be concluded that the implementation of simple light sensor learning media is proven to be effective in improving students' skills in physics learning on optical topics at Sekolah Menengah Kejuruan Laniang Makassar. This is indicated by the average students' skill score of 81.61, which is significantly higher than the minimum mastery criterion value of 75 ($p < 0.05$), and is supported by students' responses to the learning media and learning process, which fall into the positive to very positive categories. The simple light sensor learning media not only helps students understand optical concepts through direct practical experiences, but also enhances students' motivation, engagement, and active learning interactions. Future studies are recommended to employ stronger experimental designs by involving control groups, larger sample sizes, and to examine the long-term effects of using simple light sensors on other aspects such as conceptual understanding, cognitive learning outcomes, and higher-order thinking skills.

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