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Improving high school students' research skills through light diffraction experiments using the problem-based learning model

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Abstract
This research aims to improve students' research skills through light diffraction experiments using the problem-based learning model. This research is included in the type of classroom action research. The research took place in two cycles. The respondents were 33 class XII Science students from SMAN 1 Tanjung. Students' research skills are reviewed in three aspects: skills in using tools, compiling reports, and presenting results. The rating scale used is a 4-point Likert rating scale. Research skills were analyzed using the Wilcoxon Signed Rank Test, stacking analysis, and racking. The results of the analysis show that there is a significant difference between students' research skills in cycles 1 and 2. After learning in cycle 2, it was identified that students to gain research skills in the low category. Of the three aspects of research skills studied, the skill of presenting results experienced the highest increase compared to the other two aspects. So, applying PBL learning through two-cycle PTK research has improved the research skills of class XII Science students at SMAN 1 Tanjung.

Keywords: Research skills, Racking and Stacking, Problem-Based Learning

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I. Introduction

Research skills are an inseparable component of education at the senior high school, significantly impacting students' intellectual development. The research process allows students to deepen their understanding [1], [2], develop critical analytical skills [3], [4], and build a strong foundation of scientific literacy [5], [6]. In this context, light diffraction emerges as a very relevant and interesting subject matter for developing students' research skills. The phenomenon of light diffraction involves a deep understanding of the nature of light, its interactions with matter, and the underlying physical principles [7]. Therefore, understanding and mastering these concepts is useful in scientific research and in developing critical thinking and problem-solving skills, which are important competencies for students' future development.

Problems related to high school students' research skills are quite a big challenge in education [8]. One glaring problem is that students often need more skills to design and carry out scientific experiments, as well as their ability to analyze data and prepare systematic research reports. Several factors may be the cause of this problem. First, many students need more practical experience conducting research, so they may feel less confident or less skilled in dealing with more complex research assignments at the secondary school level. Second, limited resources, whether limited laboratory facilities [9], minimal equipment, or inadequate teaching

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materials [10], can also hinder students' ability to develop their research skills. Lastly, learning methods that are less effective in developing research skills can also cause these problems. For example, a learning approach that is too theoretical without adequate practical experience or a lack of clear guidance in carrying out research can make it difficult for students to develop their research competencies.

Research skills are essential to senior high school students. Its urgency lies in its positive impact on students' intellectual development and abilities [11]. By mastering research skills, students understand scientific concepts more deeply and gain invaluable critical analysis skills [12]. They learn to formulate questions, design experiments, collect and analyze data, and prepare systematic research reports. These are not just academic skills but also relevant skills in everyday life and understanding an ever-evolving world.

Research skills play an essential role for students who wish to continue their studies at university, where these skills are a must. The ability to conduct research well provides a competitive advantage for those wanting to pursue a scientific career or enter a field emphasizing analysis, problem-solving, and strong writing skills. Various learning models have been applied to improve students' research skills [13], [14], such as project-based approaches that promote holistic experiences in all stages of research [15], [16]. On the other hand, scientific experiments focus on the practical skills of designing and carrying out experiments. At the same time, problem-based learning encourages students to solve real problems by identifying relevant research questions. These all stimulate students' critical thinking and creativity in developing their research skills.

Problem-based learning (PBL) is a promising learning approach for improving high school students' research skills. PBL provides students with a unique opportunity to hone their research skills practically and meaningfully. In PBL, students are given real tasks or problems related to the subject matter they are studying [17], [18]. PBL encourages students to seek solutions actively and involves them in critical thinking [19], [20]. They must identify relevant research questions, carefully collect data, analyze the results, and prepare systematic research reports. This approach promotes important research skills such as problem-solving, scientific communication, and data analysis.

However, further research is needed to understand more deeply the extent to which PBL is efficacious in improving high school students' research abilities in light diffraction. Careful scientific evaluation can help measure the impact of PBL on student achievement regarding research abilities. Thus, this research has the potential to provide valuable insight into how PBL can be used effectively in developing secondary school students' research skills, particularly in the areas of physics and light diffraction phenomena.

By understanding the background of these problems, this research aims to test the potential of PBL in improving high school students' research skills through light diffraction experiments. The results of this study will likely contribute to developing effective learning methods to enhance high school students' research skills in the physical sciences and provide further insight into the use of PBL in this context.

II. Methods

Classroom Action Research (CAR) follows the framework proposed by Kemmis and McTaggart [21], aiming to improve students' research skills. This research was carried out in two cycles, each involving planning, implementation, observation, and reflection [22], [23]. Applying the problem-based learning model is integrated with the planning and implementation stages of learning. Figure 1 depicts the stages of learning implementation used in this research.

This research involved as many as 33 students of class XII IPA 1 who were students of SMA Negeri 1 Tanjung. Three of the 33 students were excluded from the data analysis process because they had extreme values that could affect the results.

This research uses a non-test instrument as an observation sheet to observe students' skills in each cycle. The observation sheet consists of three aspects: skills in using tools, compiling reports, and presenting results. The assessment scale used is a 4-point Likert rating scale [24], [25], with a score of 1 (not good) given if the student successfully completes 25% of the assessment aspects, a score of 2 (fair) if the student successfully completes 50% of the assessment aspects, a score of 3 (good) if the student successfully completes 75% of the assessment aspects, and a score of 4 (very good) if the student successfully completes 100% of the assessment aspects. The reliability analysis results show that the instrument's overall reliability, shown by Cronbach's alpha value, is 0.75, and the product-moment correlation significance value is <0.05. These two values indicate that the instrument used has good validity and reliability.

Kemmis and McTaggar's four standard stages of Classroom Action Research were used. The planning stage is used to prepare learning materials, plan the implementation of learning material on physical optics and experimental equipment for light diffraction at a single slit, compose and prepare instruments, journals, interviews, and photo documentation, as well as collaborating with fellow teachers as observers and class XII students. The Action Phase is the core activity of this research.

The core activities in learning are carried out in the following stages: (1) students are divided into eight groups, each consisting of 4 students. (2) With teacher guidance, each group carries out a single-slit light diffraction experiment and analyzes the results of the experiment. (3) each group presents the results of their experiment in front of the class. On the other hand, other groups provide responses, opinions, and rebuttals; (4) the teacher strengthens the results of experiments and student discussions after all groups have made presentations; (5) students convey the difficulties experienced in carrying out single-slit diffraction experiments to understand the material of light diffraction as a whole (6) teachers and students ask and answer questions to correct errors in understanding, provide reinforcement and conclude. In main learning activities, colleagues who act as observers help observe students' skills using previously developed instruments.

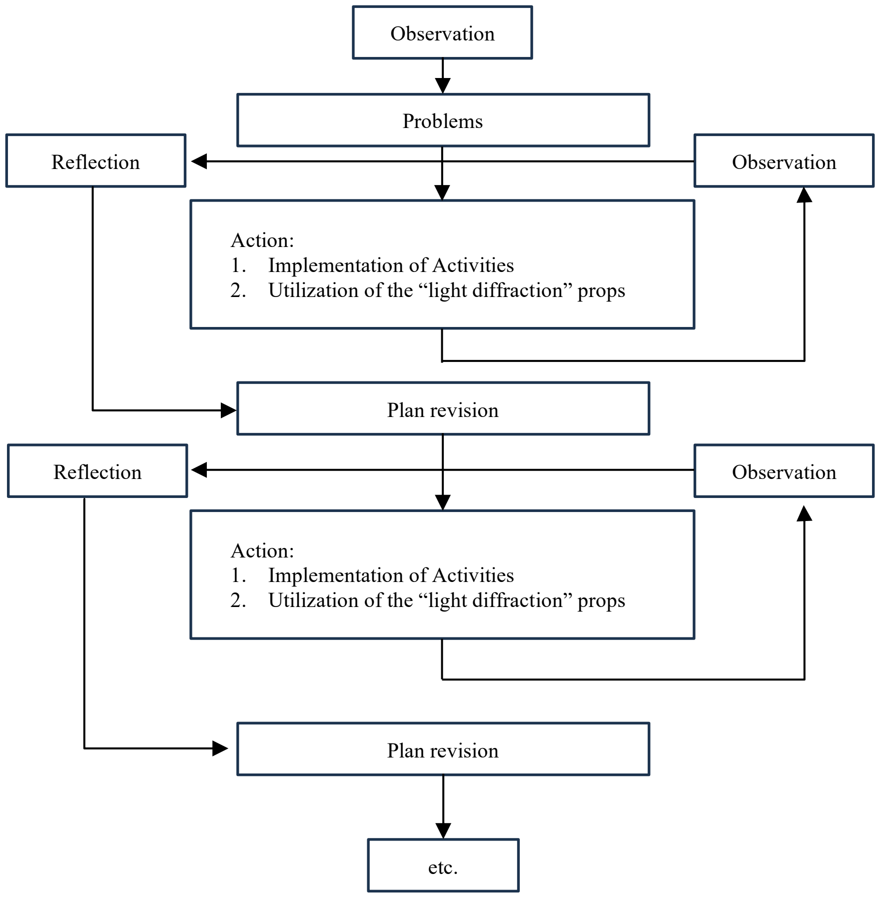

Figure 1. Stages of learning implementation

Skill data in the two cycles were analyzed using the Wilcoxon Signed Rank Test [26], stacking analysis, and racking [27], [28]. The Wilcoxon Signed Rank Test was used to see whether there was a significant difference between students' skills in cycles one and two. There was a significant difference if the significance value was smaller than the critical value of 5% (sig. < 0.05).

Stacking and Racking analysis was first introduced by Benjamin Wright to analyze changes that occur at the student and item level [28], [29]. Stacking and Racking analysis are measurement techniques that refer to Rasch modeling [30], [31]. Stacking analysis analyzes students who experience skill changes during learning in cycles one and two. Racking analysis is used to analyze what types of skills change [29], [32], [33]. Grouping students' skill levels refers to the Logit Value of Person (LVP) [34], and grouping the difficulty level of skill aspects refers to the Logit Value of Item (LVI) [35], as shown in Table 1 and Table 2.

Table 1. Criteria for changes in student skill levels

No	Range of LVP	Criteria/Categories
1	LVP ≥ M + SD	Very high
2	M ≤ LVP < M + SD	High
3	M – SD ≤ LVP < M	Moderate
4	LVP < M – SD	Low
5	LVP ≥ M + SD	Very high

Table 2. Criteria for changes in skill level aspects (items)

Range of LVI	Degree of difficulty	Categories
LVI ≥ M + SD	Very difficult	Very low
M ≤ LVI < M + SD	Difficult	Low
M – SD ≤ LVI < M	Moderate	Moderate
LVI < M – SD	Easy	High
LVI ≥ M + SD	Very difficult	Very low

III. Results and discussion

Differences in Students' Research Skills

The results of different tests of students' research skills in cycles one and two are shown in Table 3.

Table 3. Wilcoxon Signed Rank Test result

	Cycle 2 - Cycle 1
Z	-3.777[b]
Asymp. Sig. (2-tailed)	0.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

The Wilcoxon Signed Rank Test analysis results listed in Table 3 provide important information in describing changes in student skills from cycle 1 to cycle 2. The Z value obtained in this test was -3.777. The resulting significance or p-value is 0.001, clearly smaller than the previously determined significance level (0.05) [36], [37]. A p-value of less than 0.05 is a strong indication that there is a significant difference in student skills between cycle one and cycle two. This means that the results of this test statistically validate that the improvements in student skills in physical optics material are real and not just a coincidence.

These results show that the PBL model applied in cycle two improved students' skills significantly compared to cycle 1. This is a positive achievement in the learning process, which illustrates the effectiveness of the PBL method in improving students' research skills. Thus, the results of this analysis provide strong support for the success of the learning model that has been used in teaching students about light diffraction material.

Stacking

The results of the analysis of improving students' research skills are shown in Table 4. Data analysis in Table 4 shows a striking change in student skill scores from cycle 1 to cycle 2. In cycle 1, the average student skill score was 2.35 logits. However, a remarkable change occurred when cycle 2 began, with the average score jumping to 6.22 logits. A change of this magnitude reflects a significant increase in students' ability to conduct physics experiments on light diffraction material. Apart from that, if you look at the scores range in the two cycles, there are quite striking differences. In cycle 1, students' skill scores ranged from -11.98 to 11.64 logits, indicating wide variation in their skill levels. However, in cycle 2, the score range changed from 1.91 to 11.64 logits. This change shows that in cycle 2, there were no students whose skill scores were negative, and most had higher scores than in cycle 1. This is clear evidence of an overall increase in student skills.

Table 4. Analysis of changes in student skill levels using the Stacking technique

No. Resp.	Cycle 1		Cycle 2	
	Logit	Level	Logit	Level
P01	-0.46	Low	5.19	High
P02	5.19	High	5.19	High
P03	5.19	High	5.19	High
P04	9.27	Very High	9.27	Very High
P05	9.27	Very High	9.27	Very High
P06	1.91	Moderate	9.27	Very High
P07	-0.46	Low	5.19	High
P08	11.64	Very High	11.64	Very High
P09	-0.46	Low	5.19	High
P10	11.64	Very High	11.64	Very High
P11	5.19	High	5.19	High
P12	-0.46	Low	1.91	Moderate
P13	5.19	High	5.19	High
P14	9.27	Very High	9.27	Very High
P15	-0.46	Low	5.19	High
P16	-11.98	Low	5.19	High
P17	5.19	High	5.19	High
P18	5.19	High	5.19	High
P19	-5.44	Low	5.19	High
P20	5.19	High	5.19	High
P21	-0.46	Low	5.19	High
P22	1.91	Moderate	9.27	Very High
P23	-5.44	Low	5.19	High
P24	-0.46	Low	5.19	High
P25	-0.46	Low	1.91	Moderate
P26	-0.46	Low	5.19	High
P27	5.19	High	5.19	High
P28	-0.46	Low	5.19	High
P29	-0.46	Low	5.19	High
P30	1.91	Moderate	9.27	Very High
Average	2.35		6.22	
Minimal	-11.98		1.91	
Maximal	11.64		11.64	

In cycle 1, there were quite striking variations in students' skills in conducting physics experiments on light diffraction material. Only 17% of students have skills in the "very high" category, while 27% have "high" skill levels. On the other hand, 10% were in the "medium" category, and the majority, namely 47%, were in the "low" category. However, significant changes occurred when cycle 2 began. There has been a tremendous improvement in students' skill levels. The "Very High" category increased to 37%, while the "High" category jumped to 67%. Even the "Low" category experienced the most striking change, namely becoming zero percent, indicating that there were no students with a "Low" skill level in cycle two. This is clear evidence that the improved learning approach implemented in Cycle 2 increased students' abilities significantly, changing their skills from various levels to high and very high levels. This change reflects the success of the PBL learning method that has been implemented and is an encouraging achievement in the learning process.

Problem-based learning (PBL) is a learning model that places students as researchers because it contains five learning stages that support the formation of the researcher's character [38]–[41]. PBL allows students to develop hands-on skills using research tools. During two learning cycles, students are asked to conduct experiments to answer the research questions that have been prepared. This process involves the use of relevant research tools. For example, in experiments, students must use equipment such as prisms, diffraction gratings, or other experimental devices. In this case, PBL allows students to experience and master practical skills using relevant research tools.

In the aspect of skills in preparing research reports, PBL also makes a significant contribution. Students involved in PBL must compile the results of their research in a systematic report. They must combine the information they collect, analyze the data carefully, and detail their findings. This involves learning scientific writing skills, organizing information, and summarizing research results. Therefore, PBL helps students develop important skills in preparing good research reports.

PBL also supports the development of skills in presenting research results. In many cases, research results discovered through PBL must be presented orally or in writing to the group or class. Students learn to speak in public, convey information clearly, and respond to questions or feedback from other students. This hones scientific communication skills that are essential in communicating research results.

Racking

Changes in skill aspect (item) levels are summarized in Table 5.

Table 5. Changes in skill levels based on Racking techniques

Item	Description	Measure (Logit)			Item difficulty shift
		Cycle 1	Cycle 2	Change	
Item 1	Skills Using tools	3.10	-0.74	-3.84	Very low to high
Item 2	Skills in preparing reports	-1.33	-2.56	-1.23	High to very high
Item 3	Skills to Present Results	2.87	-1.33	-4.20	Very low to high
	Average	1.55	-1.54	-3.09	Low to high

Based on the data in Table 5, there has been a significant change in students' skills in carrying out physics experiments on Light Diffraction material. Initially, the average logit value of students' skill levels was 1.55, which indicated that the majority of students had low skill levels. However, after going through several learning cycles, this logit value decreased to -1.54, which shows that there has been a significant increase in students' skills to become high. If we look deeper, there have been significant changes in several aspects of skills. For example, the skill “Use of tools” in cycle 1 has a logit value of 3.10, which indicates a very low level. However, in cycle 2, the logit value increased drastically to -0.74, showing a remarkable increase in this skill to a high level.

On the other hand, the “Preparing Reports” skill underwent the opposite change. Initially, this skill has a logit value of -1.33, which indicates a high level. However, in cycle 2 the logit value fell to -2.56, which indicates that students experienced an increase in their ability to prepare reports from a high level to a very high level. A similar situation also occurs with the skill “Presenting the results” of an experiment. Initially, the logit value of this skill is 2.87, which indicates a high level. However, in cycle 2 there was a significant decrease to -1.33 logit, which shows that students experienced increased skills from the low to high category.

Overall, these changes reflect the effectiveness of the PBL learning model applied in improving students' skills in conducting physics experiments on light diffraction material. This proves that a good and sustainable learning approach can significantly impact students' abilities.

IV. Conclusions

Based on the results of the analysis and discussion that has been carried out, there is a significant difference between students' research skills in cycles one and two. The analysis results change the students' research skills average from 2.35 logits in cycle 1 to 6.22 logits in cycle 2. As many as 17% of students with research skills in cycle 1 increased to 27% in cycle 2. The percentage of students in the high category in cycle 1 was 27, rising to 67% in cycle 2. Meanwhile, students with research skills were in the medium and low categories. In cycle 1, there was a very significant decline. The percentage of students with research skills of 10% in the medium category becomes 7%, and 47% in the low category becomes 0%. The skill aspect of using tools and presenting results in cycle 1 experienced significant changes in cycle 2. So, applying light diffraction experiments using the Problem-Based Learning model has improved the research skills of SMAN 1 Tanjung students.

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