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Research Artikel

IMPROVING SCIENCE LITERACY THROUGH VIRTUAL EXPERIMENTS IN INQUIRY-BASED LEARNING: A QUASI-EXPERIMENTAL ANALYSIS ON THE CONCEPT OF OPTICAL INSTRUMENTS

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Abstract

PISA 2022 showed that Indonesian students' scores declined from 396 in 2018 to 383. This was evident in the 2022 National Assessment, where the science literacy ability at the high school level dropped by 4.59%. The low ability is mainly in optics, particularly optical instruments, indicating that students can only recognize the concept if they understand it. This study aims to determine the effect of inquiry-based learning on science literacy skills and Improvement in science literacy aspects. The research method used quasi-experimental with a nonequivalent control group design. The research population consisted of 199 students of grade XI at SMA Negeri 4 South Tangerang City, with a sample of 70 students: 35 students in class XI IPA 3 (experimental group) and 35 students in class XI IPA 4 (control group). The Mann-Whitney test results (Asymp Sig. 2-tailed < 0.05) showed a significant difference in science literacy skills between the experimental and control groups. The N-gain score indicated increased science literacy skills in the experimental group by 0.33 (medium category), while the control group was 0.10 (low category). Improvement occurred in the competence aspect by 0.52 and the knowledge aspect by 0.43 for the experimental group, while the control group in the competence aspect was 0.15 and the knowledge aspect was 0.27. Inquiry-based learning in this study has an effect and can improve students' science literacy skills.

***Keywords**: Competence; inquiry learning; optical instrument; scientific literacy, virtual laboratory.*

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INTRODUCTION

Science literacy is crucial in science education policy (Gumilar, 2021; Yacoubian, 2018; Sinatra & Hofer, 2016; Fensham, 2008). Science literacy is crucial in science education policy (Afnan, Munasir, Budiyanto, & Aulia, 2023; Elhai, 2023; World Economic Forum, 2016). Science literacy involves understanding science-related knowledge, critical thinking, problem-solving, and decision-making skills (Turiman, Omar, Daud, & Osman, 2012). The Program for International Student Assessment (PISA) defines science literacy as the ability to engage with issues and ideas related to science and literacy in knowledge and technology. The competence aspect of science literacy consists of three domains: 1) explaining phenomena scientifically, 2) evaluating and designing scientific investigations, and 3) interpreting data and evidence scientifically. The knowledge aspect of science literacy also comprises three domains: 1) content, 2) procedural, and 3) epistemic (OECD, 2019).

Despite its importance, science literacy in Indonesia still needs to improve, especially at the high school level (Komariyah & Nurlaela, 2023; Takda et al., 2023; Tulaiya, 2020; Irwan et al., 2019). The results of PISA 2022 showed that Indonesia's science literacy score dropped from 396 in 2018 to 383 (OECD, 2022). The 2022 National Assessment also showed a decline in science literacy at the high school level, from 53.85% to 49.26% (Kemdikbud, 2023). The lowest percentage was found in the competency indicator for evaluating and designing scientific investigations, which was 12.51% (Tulaiya, 2020). Students must often correct their interpretation of data, scientific evidence, and the epistemic knowledge aspect (Irwan et al., 2019).

Science literacy encompasses all fields of science, especially physics. One of the topics related to students' lives in the form of phenomena and technology is light and optical instruments. Yanti, Yuliati, & Wisodo (2019) research showed that high school students' science literacy skills in geometric optics content could only reach the nominal category. Yosef & Kanisius (2019) explained that science literacy ability in the nominal category means that students have recognized the related concept but still need clarification. The research by Warmadewi (2022) showed that only 5% of the research on optical instruments was conducted to measure science literacy skills.

Improving science literacy skills is crucial for students' lives as they will become scientifically literate citizens and impact all sectors, including self-improvement (Fortus, Lin, Neumann, & Sadler, 2022). The low science literacy skills of students are due to school learning that has not implemented inquiry activities and the lack of active student involvement in learning, as well as the minimal practice of student literacy (Takda et al., 2023; Fadilah, Isti, Amarta, & Prabowo, 2020; Tulaiya,2020; Fatmawati, 2016;). The gap in science literacy research is evident, especially in applying effective teaching methods like inquiry-based learning. This study aims to fill that gap by investigating the impact of inquiry-based learning on science literacy skills, particularly in the context of optical instruments. Literature supports the positive impact of inquiry-based learning on active student engagement and the Improvement of science literacy skills (Ahmad et al., 2023; Ida et al., 2022; Kang, 2022; Arieska et al., 2021; Destrilia et al., 2021).

The inquiry learning model is a learning process that acquires information through experiments based on questions using critical and logical thinking skills (Aprianty, Darmianty, & Khair, 2023). Each syntax in inquiry learning directly involves students in learning and develops science literacy. Inquiry learning helps students relate optical instrument material to daily life and stimulates them to connect understanding with its application (Ayo et al., 2018). PISA also highlights the importance of inquiry-based learning in science education to develop science literacy skills so students are ready to engage with science and technology in the future (Kang, 2022). Moreover, virtual laboratory activities combined with inquiry-based learning have positively impacted students' science literacy (Arieska Putri et al., 2021; Hamed & Aljanazrah, 2020; Alneyadi, 2019). This combination increases students' interest in science, critical thinking skills, decision-making, and problem-solving (Alneyadi, 2019; Turiman et al., 2012).

Combining inquiry-based learning with virtual laboratory activities is essential to improve high school students' science literacy in optical instrument material (M. S. Ahmad, Rahayu, & Sukarmin, 2023; Susanti & Ishafit, 2023). This research aims to determine the significant effect of inquiry-based learning on students' science literacy skills and improve all aspects of their science literacy. This research is necessary because it addresses crucial needs in education by providing practical teaching strategies that promote scientific understanding and prepare students for future challenges in science and technology.

This research introduces a virtual laboratory designed explicitly for the subtopics of optical instruments (eyes, lup, microscopes, telescopes, and cameras) as a new approach to learning. This virtual laboratory adjustment aims to improve students' scientific literacy skills more optimally. In addition, by combining inquiry-based learning, this research offers an innovative solution to overcome the problem of scientific literacy in science education, which has yet to be widely discussed in previous research.

METHOD

The research was conducted at SMA Negeri 4 South Tangerang City. The study was carried out from February 25 to March 19, 2024. This research uses a quasi-experimental method. The research design used is the Nonequivalent Control Group Design (Table 1). The experimental and control groups took a pretest and posttest. The treatment in an inquiry-based learning model was applied to the experimental group. The control group received the usual treatment used by the teacher, namely the conventional learning model (Creswell & Creswell, 2018).

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	X_1	O_4

The research population consists of all grade’s XI students at SMAN 4 Kota Tangerang Selatan in the even semester of the 2023/2024 academic year, totalling 199 students. The research sample was determined using a non-probability sampling technique through purposive sampling. Class XI IPA 3 students were assigned as the experimental group, totalling 35 students, and class XI IPA 4 as the control group, also totalling 35 students.

The measurement of science literacy skills is based on the PISA 2018 science framework, which includes competence and knowledge aspects focusing on optical instruments. The measurement of science literacy is also adjusted to the 2013 Curriculum used in grade XI. The instrument used to measure science literacy was produced through a rigorous process involving a series of tests and validations. The initial instrument consisted of 28 questions that had been validated by five experts with construct, material, and content validation. The results of the expert validation can be seen in Table 2.

Table 2. Results of Expert Validation

Aspect	CVI Score	CVI Category
Content	0.83	Appropriate
Construct	0.8	Appropriate
Language	0.92	Appropriate

Afterwards, it was tested on 30 grade XII students who had received optical instruments material. Validity, reliability, difficulty level, and discriminatory power were analyzed on the 28 questions using Anates V4. The results showed that 18 questions were valid with a correlation of 0.59, resulting in science literacy questions having a moderate correlation with moderate reliability (r_{kr} = 0.59). By adjusting the competency achievement indicators and question indicators, the questions were further qualified into 14 items consisting of 7 multiple-choice questions and seven essay questions, as seen in Table 3.

Table 3. Final Scientific Literacy Test

Sub-topic	Aspect		Question Number	Form of assessment
	Competency	Knowledge		
Eye dan Eyeglasses	Explain phenomena scientifically	Content	1	Open response
	Interpret data and evidence scientifically.	Procedural	2	Multiple choice
	Interpret data and evidence scientifically.	Epistemic	3	Open response
Magnifying glass	Explain phenomena scientifically	Procedural	4	Open response
	Interpret data and evidence scientifically.	Content	5	Multiple choice
	Evaluate and design scientific inquiry.	Procedural	6	Open response
Microscope	Explain phenomena scientifically	Epistemic	7	Open response
	Evaluate and design scientific inquiry.	Procedural	8	Multiple choice
	Explain phenomena scientifically	Epistemic	9	Multiple choice
Telescope	Explain phenomena scientifically	Content	10	Multiple choice
	Interpret data and evidence scientifically.	Epistemic	11	Multiple choice
	Interpret data and evidence scientifically.	Content	12	Open response
Camera	Explain phenomena scientifically	Procedural	13	Open response
	Evaluate and design scientific inquiry.	Procedural	14	Multiple choice

The research on optical instrument content was conducted over five meetings. A pretest was given as an initial test for both groups before applying the inquiry-based learning model to the experimental group. After each group received treatment in three meetings, both groups were given a posttest as a final test to determine the final Improvement in science literacy skills.

The treatment is given as an inquiry learning model combined with a virtual laboratory. The phases of inquiry learning are adapted from the phases proposed by (Donald & Paul, 2003). There are five phases: presenting a question or problem, formulating a hypothesis, planning and conducting an experiment, collecting and analyzing data, and drawing conclusions. Virtual laboratories are used to design, conduct experiments, and collect data (M. S. Ahmad et al., 2023).

The research data was analyzed following procedures. The data analysis technique included prerequisite tests such as normality tests and homogeneity tests for the experimental and control groups, as well as hypothesis testing for pretest and posttest data with the help of SPSS IBM Version 25. The Improvement in science literacy skills was calculated using the N-Gain score processed with Ms. Excel with categories seen in Table 4 (Hake, 2002).

Table 4. Criteria for N-Gain value

Range	Criteria
N-Gain $\geq$ 0.7	High
0.3 $\leq$ N-Gain $<$ 0.7	Medium
N-Gain $<$ 0.3	Low

RESULTS AND DISCUSSIONS

Table 5 shows the results of the prerequisite and hypothesis testing data. The results of the prerequisite test indicated that the experimental group data were normally distributed, while the control group data were not normally distributed. Both groups showed evenly distributed data. Subsequently, hypothesis testing was conducted using non-parametric statistics through the Mann-Whitney test. The pretest data showed no significant difference between the experimental and control groups before treatment. Meanwhile, the hypothesis test for posttest data showed a significant difference between the experimental and control groups. The difference in posttest data results was due to the different treatments given to the two groups.

Table 5. The Summary of Result Test

Component	Signification	Description
Normality Test Experimental Group	0.2	Normally Distributed
Normality Test Control Group	0.0	Not Normally distributed
Homogeneity	0.183	Homogeneous
Hypothesis pretest (*Mann-Whitney test*)	0.059 (Asymp.Sig2 tailed) > 0.05	There is no significant (H_o accepted, H_a rejected)
Hypothesis posttest (*Mann Whitney test*)	0,00 (Asymp.Sig2 tailed) > 0.05	It is significant (H_o rejected, H_a accepted)

Based on the hypothesis testing results, the experimental group that received the inquiry-based learning model significantly affected science literacy skills. The experimental group had a higher average posttest score. The pretest and posttest results of the experimental and control groups are shown in Figure 1.

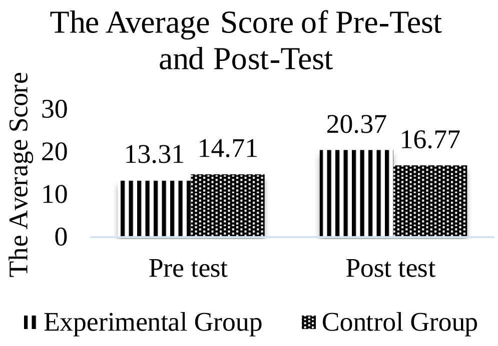


Figure 1. The Average Score Pretest and Posttest

Based on Figure 1, the pretest score of the experimental group was lower than that of the control group. After the inquiry-based learning model was applied, the posttest score of the experimental group increased. The posttest score of the experimental group was higher than that of the control group. The experimental group experienced a higher increase in science literacy competence than the control group, as seen in Figure 2.

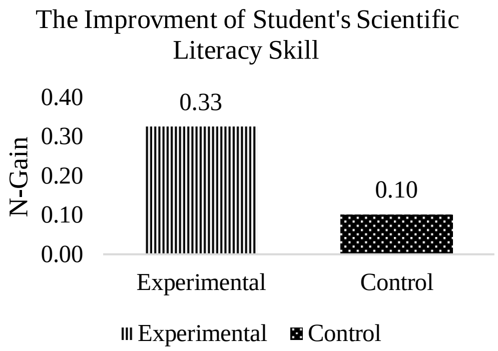


Figure 2. The Improvement of scientific literacy skills based on the N-Gain result

The N-Gain score for the experimental group was 0.33 (medium), while the control group had a score of 0.10 (low). The experimental group obtained the highest increase when using the inquiry-based learning model. Both groups experienced an increase in all aspects of science literacy skills. Figure 3 shows the N-Gain scores representing the increase in the competence aspect of science literacy skills. The highest increase in the competence aspect of the experimental group was in indicator K3, which is interpreting data and scientific evidence (N-Gain score 0.52, categorized as medium). In the control group, the highest N-Gain score was in indicator K1, which explains scientific phenomena (N-Gain score 0.15, categorized as low). Overall, the experimental group had the highest increase in all competence aspects.

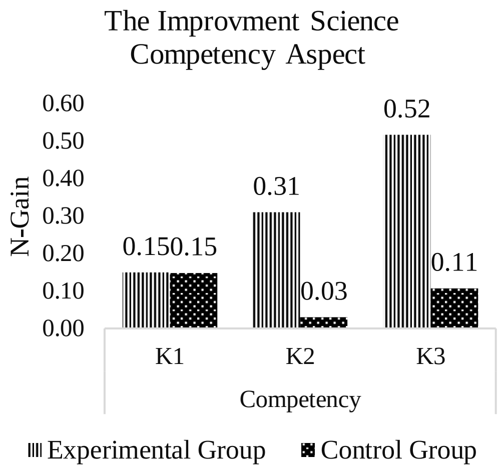


Figure 3. N-Gain Percentage for Competency Aspects

The increase in students' science literacy skills in the knowledge aspect for both the experimental and control groups is shown in Figure 4. The highest increase was in the content and epistemic indicators (in the experimental group with an N-Gain score of 0.43, categorized as medium). For the control group, the score was 0.27 (low category). In the knowledge aspect, the experimental group had the highest increase compared to the control group.

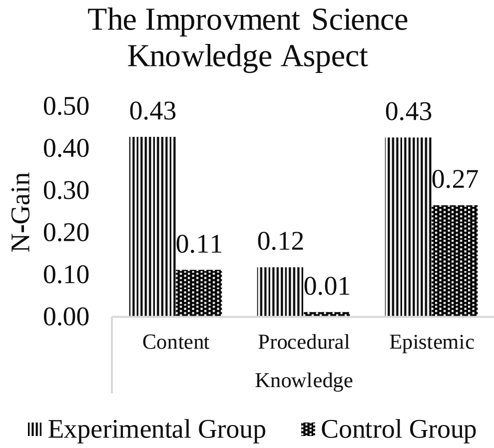


Figure 4. N-Gain Percentage for Knowledge Aspects

The increase in science literacy skills in the experimental group was due to applying the inquiry-based learning model. The inquiry-based learning model provides students with direct experience in thinking independently and discussing to find answers to given problems. According to Kang's research (Kang, 2022). The inquiry-based learning model positively affects the increase in science literacy skills. This model emphasizes the development of cognitive skills, enhancing problem-solving skills in answering questions based on scientific evidence (M. S. Ahmad et al., 2023)

One phase of inquiry-based learning, such as presenting questions or problems, formulating hypotheses, designing and conducting experiments, collecting and analyzing data, and drawing conclusions combined with virtual laboratories tailored to subtopics on optical instruments Donald & Paul (2003), affects the increase in science literacy skills. Students can develop knowledge and understanding by actively engaging in learning and asking and answering scientific questions, which is crucial for improving critical thinking. Students can also investigate potential outcomes by determining experimental procedures with the teacher as a facilitator. This is evident in the competence domain of interpreting data and scientific evidence, with the highest increase. In the student worksheet (LKPD) shown in Figure 5 for the data collection and analysis phase, the teacher guides the data analysis with questions; students must answer questions with the data obtained, as seen in the student worksheets (LKPD) in Figure 6. In this process, interpreting data into scientific answers occurs (Arieska Putri et al., 2021).

D. Collect and Analyze Data

Experiments according to the experimental procedures that have been designed and write down the data from your observations in the table provided below

Table 1. Observation Results of Experiment 1

Focal length: 80 cm

No	Object Distance	Shadow Result
1.	Exactly at the focus point	
2.	20 cm behind teh focus point	
3.	40 cm behind the focus point	
5.	20 cm in front of the focus point	
6.	40 cm in front of the focus point	

Table 2. Observation Results of Experiment 2

No.	Location shadow moment *Far Object*	Location shadow moment *Near Object*	Lens type the selected	Lens size the selected	Location after image lens selection
Eye 1 (Andi's eye condition)					
Eye 5 (Eye condition Andi's mother)					

To analyze the data above, answer the question below according to the experiment and the result of what you have done.

1. Based on the practical work you have done in experiment 1, make an analogy with the objects used in practice with the working principles of the eye and the process of forming images in the eye

Figure 5. One of the Inquiry Learning Syntaxes - Collecting and Analyzing data on Worksheet

Setelah merancang percobaan dan dikonfirmasi oleh guru, lakukan percobaan untuk mengumpulkan data sesuai dengan rancangan yang telah dibuat. Tanyakan kepada gurumu jika ada hal yang kurang dipahami dalam melakukan percobaan.

D. Mengumpulkan dan Menganalisis data

Lakukanlah percobaan sesuai dengan prosedur percobaan yang telah dirancang dan tulislah data hasil pengamatan kalian pada tabel yang telah disediakan di bawah ini!

Tabel 1. Hasil Pengamatan Percobaan 1

Panjang fokus : 80 cm

No	Jarak Benda	Hasil Bayangan
1.	Tepat pada titik fokus	tidak terhingga (diperbesar)
2.	20 cm di belakang titik fokus	diperbesar → real image / terbalik
3.	40 cm dibelakang titik fokus	diperbesar → real image / terbalik
5.	20 cm di depan titik fokus	diperbesar tegak → virtual image
6.	40 cm di depan titik fokus	diperbesar tegak → virtual image

Tabel 2. Hasil Pengamatan Percobaan 2

No.	Letak bayangan saat *Far Object*	Letak bayangan saat *Near Object*	Jenis lensa yang dipilih	Ukuran lensa yang dipilih	Letak bayangan setelah pemilihan lensa
Eye 1 (Kondisi mata Andi)	di depan retina	tepat pada retina	lensa cekung	-2,0 di	tepat pada retina
Eye 5 (Kondisi mata Ibu Andi)	tepat pada retina	di belakang retina	lensa cembung	+1,5 di	tepat pada retina

Untuk menganalisis data di atas, jawablah pertanyaan di bawah ini sesuai dengan percobaan dan hasil yang telah kalian lakukan.

1. Berdasarkan praktikum yang telah kalian lakukan pada percobaan 1, analogikanlah benda-benda yang digunakan dalam praktikum dengan prinsip kerja mata dan proses pembentukan bayangan pada mata

- figura pensil di analogikan sebagai objek
- lensa cembung dianalogikan sebagai lensa mata
- bayangan objek dianalogikan sebagai bayangan yang masuk ke retina.

Figure 6. Examples of Student Activities on Worksheet in the Collecting and Analyzing Data

The indicator for evaluating and designing scientific investigations in the experimental group experienced a significant increase. This is because inquiry-based learning especially in the phases of designing and conducting experiments with virtual laboratories requires students to determine experimental steps and tools and arrange them well to obtain valid information. Figure 7 shows that students must evaluate and design investigations using a microscope. This activity enables students to distinguish and evaluate (Nurmalasari & Hertanti, 2021). Virtual lab activities greatly help students in inquiry learning because they can visualize and explore abstract ideas. Students design their experiments to be able to solve their problems or questions (M. S. Ahmad & Rahayu, 2023; Abaniel, 2021).

The phases of inquiry-based learning, in addition to increasing competence, also affect students' knowledge aspects in learning optical instruments. Students can formulate questions based on daily phenomena, as shown in Figure 8. Students can discuss, formulate, and design hypotheses, conduct experiments to test hypotheses, and conclude explanations based on collected data, as found in research (Nurfitria & Hertanti, 2020). The content domain in the knowledge aspect experienced an increase, especially in indicators of finding and understanding phenomena related to content independently and actively, as found in Kusairi's research (Kusairi, Hardiyana, Suwasono, Suryadi, & Afrieni, 2021). An increase also occurred in the epistemic domain because students discovered new knowledge from experiments. Students naturally recheck to conclude the experimental activities and analyses (Nurfitria & Hertanti, 2020).

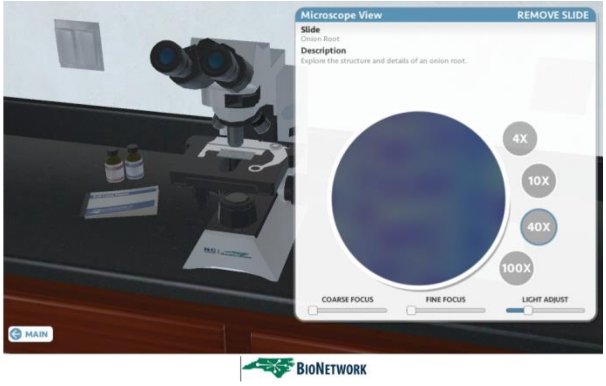
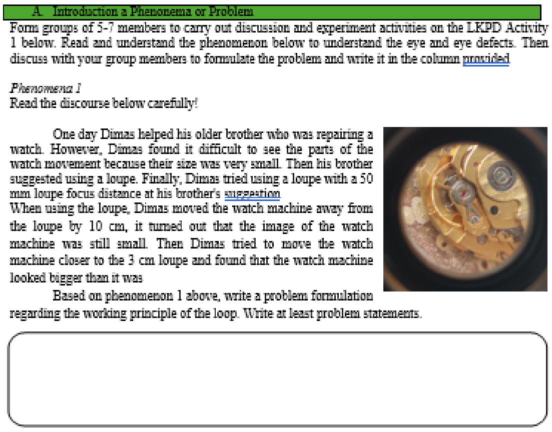


Figure 7. Example of using the Virtual Laboratory – Microscope – in Inquiry Learning



A. Introduction a Phenomena or Problem

Form groups of 5-7 members to carry out discussion and experiment activities on the LKPD Activity 1 below. Read and understand the phenomenon below to understand the eye and eye defects. Then discuss with your group members to formulate the problem and write it in the column provided

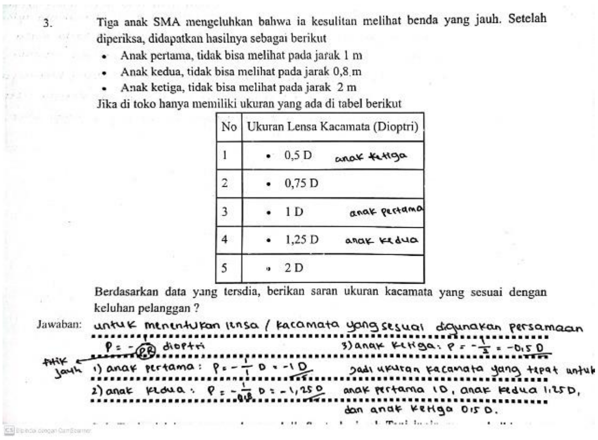
Phenomena 1
Read the discourse below carefully!

One day Dimas helped his older brother who was repairing a watch. However, Dimas found it difficult to see the parts of the watch movement because their size was very small. Then his brother suggested using a loupe. Finally, Dimas tried using a loupe with a 50 mm loupe focus distance at his brother's suggestion
When using the loupe, Dimas moved the watch machine away from the loupe by 10 cm, it turned out that the image of the watch machine was still small. Then Dimas tried to move the watch machine closer to the 3 cm loupe and found that the watch machine looked bigger than it was

Based on phenomenon 1 above, write a problem formulation regarding the working principle of the loop. Write at least problem statements.

Figure 8. Inquiry learning syntax – Identification Questions or Problems on Worksheet

Examples of questions to measure aspects of competence in interpreting data and scientific evidence and aspects of knowledge epistemic are shown in Figure 9. The questions contain the daily phenomena related to optical instruments. Students interpret the data presented and evaluate the knowledge gained through inquiry learning with virtual lab activities to make scientific explanations (Arieska Putri et al., 2021).



3. Tiga anak SMA mengeluhkan bahwa ia kesulitan melihat benda yang jauh. Setelah diperiksa, didapatkan hasilnya sebagai berikut
- Anak pertama, tidak bisa melihat pada jarak 1 m
- Anak kedua, tidak bisa melihat pada jarak 0,8 m
- Anak ketiga, tidak bisa melihat pada jarak 2 m

Jika di toko hanya memiliki ukuran yang ada di tabel berikut

No	Ukuran Lensa Kacamata (Dioptri)
1	• 0,5 D anak ketiga
2	• 0,75 D
3	• 1 D anak pertama
4	• 1,25 D anak kedua
5	• 2 D

Berdasarkan data yang tersdia, berikan saran ukuran kacamata yang sesuai dengan keluhan pelanggan ?

Jawaban: untuk menentukan lensa / kacamata yang sesuai digunakan persamaan
P = - 1/PR dioptri
titik jauh
1) anak pertama : P = - 1/1 D = -1 D
2) anak kedua : P = - 1/0,8 D = -1,25 D
3) anak ketiga : P = - 1/2 = -0,5 D
jadi ukuran kacamata yang tepat untuk anak pertama 1 D, anak kedua 1,25 D, dan anak ketiga 0,5 D.

Figure 9. Example of the question that measures students' scientific knowledge and scientific competency

Inquiry-based learning assisted by virtual laboratories helps students understand basic concepts and actively involves them in discovering principles of optical instruments, as it requires the application of scientific knowledge and scientific discovery performance and facilitates students' understanding of scientific concepts (Wen et al., 2020). Students' ability to explain scientific phenomena, evaluate and design scientific investigations, and interpret data and scientific evidence improves content, procedural, and epistemic knowledge (Arieska Putri et al., 2021). Based on these points, the inquiry-based learning model combined with virtual laboratories affects science literacy skills and can enhance every aspect of science literacy.

CONCLUSION

The inquiry-based learning model has a significant impact on science literacy skills. The final science literacy skills of the experimental group that applied the inquiry-based learning model were higher than the control group. Students experienced an increase in the medium category (0.33), and learning activities developed more positively. The Improvement in science literacy skills in the experimental group was evident in all aspects of science literacy (competence and knowledge). In the competence aspect, the indicator was interpreting data and scientific evidence. For the knowledge aspect, the indicators were content and epistemic.

Recommendations for researchers using the inquiry-based learning model, especially those aiming to improve science literacy skills, include considering that implementing the inquiry-based learning model requires more time than conventional learning models, thus requiring patience. Efficient and effective time management skills are essential. Students need time to adapt to learning using the inquiry model, so teachers must first practice as facilitators and be able to guide optimally.

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