



Developing Higher Order Thinking Laboratory (Hot-Lab) to Promote General Scientific Reasoning of Student-Teachers in Physics Practices

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Abstract – This study aims to develop physics practicum guidelines that can improve students' scientific reasoning. The development of practicum guidelines in this study was based on the principles of the Higher Order Thinking Laboratory (HOT-Lab). Using the ADDIE design, which consists of five stages: analyze, design, develop, implement, and evaluate, general physics practicum guidelines are developed in three parts, namely pre-practicum, lab, and post-practicum. The participants involved consisted of two groups: five experts and 88 students taking general physics courses. The pre-practicum stage is the part that distinguishes this practicum guideline from conventional practicum guidelines, where students are presented with "real-world problems" and opportunities to make hypotheses. The results showed that the practicum guideline products developed were deemed feasible and effective for developing students' scientific reasoning. This study shows that students' scientific reasoning for using practicum guidelines based on HOT-Lab principles is significantly higher than those who use conventional practicum guidelines. In conclusion, the guideline developed was valid, feasible, and effective in improving students' scientific reasoning. This study recommends considering the features of the HOT-Lab practicum activities to be used for similar practicum activities in other places or relevant courses.

Keywords: higher order thinking; laboratory; practical guideline; scientific reasoning

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I. INTRODUCTION

Scientific reasoning is one of the skills necessary to advance science and technology (Bao et al., 2022; Vo & Csapó, 2022). It is also helpful in overcoming complex problems with good scientific reasoning skills (Vo & Csapó, 2022; Bancong & Subaer, 2013). This competency can also assist someone in making careful decisions and developing scientific

abilities (Cuperman & Verner, 2019). Furthermore, scientific reasoning can also be a good predictor of learning success (Nieminen et al., 2012). This variable has also become one of the focuses in science learning, which continues to experience development (Bao et al., 2022). Asniar (2016) stated that students' ability to perform scientific reasoning showed unsatisfactory results. According to reports,

most students who enroll in university-level programs exhibit poor scientific thinking (Hrouzková & Richterek, 2021). Research conducted by Wilujeng and Wibowo (2021) revealed that the level of scientific reasoning of prospective physics teachers in online learning was at the concrete and transitional operational level. Nonetheless, several reports show that the scientific reasoning of students in Indonesia tends to be low (Khoirina et al., 2018; Mariana et al., 2018; Suryadi et al., 2020; Yediarani et al., 2019).

Several attempts have been made to develop scientific reasoning from the elementary and secondary education levels (Klemm et al., 2020; Koes-H & Putri, 2021) up to the university level (Göhner & Krell, 2020; Omarchevska et al., 2022; Owens et al., 2021). For example, studies combining hands-on learning and inquiry improved students' scientific reasoning (Graaf et al., 2019). Differently, Kant et al. (2017) and Omarchevska et al. (2022) used video modeling in learning. They found that students' scientific reasoning improved after learning. Erlina et al. (2018) implemented Evidence-Based Reasoning (EBR) in inquiry learning. Meanwhile, Koes-H & Putri (2021) applied STEM-PjBL to increase the increase in scientific reasoning of students. These studies show that learning interventions can improve scientific reasoning. Even so, these studies are still carried out in classical learning. Meanwhile, evidence regarding the development of scientific reasoning in

laboratory activities is still scarce. In addition, scientific reasoning is a domain that is closely related to students' abilities in a laboratory environment.

Learning in the laboratory in physics education is still only developing procedural practicum skills and concept proof. The implementation of such a practicum, according to Santiani (2013), is only limited to proving concepts and skills in using laboratory equipment. The practicum instructions are still in the form of cooking recipes (cookbook lab). Moreover, the steps students have to do during the implementation of practicum activities are more on proving the theory. This type of practicum is a verification practicum model. During the verification process, the practicum model certainly does not equip students with high-level thinking skills since students are not facilitated to determine. However, they were told which variables have changed and remained. Students are not involved in submitting hypotheses and predictions based on solid arguments (Wenning et al., 2011). Meanwhile, according to May et al. (2022), laboratory activities should be good in addition to developing experimental skills, student reasoning must also be developed. The existence of physics learning activities in the laboratory is expected that students can be directly involved in the learning process, so that students have long-term memory in remembering experiments conducted in the laboratory and can improve problem-solving skills (Krell et al., 2020). Therefore, it is

important to develop scientific reasoning in laboratory practicums.

Recently, practicum guidelines have begun to be directed at developing students' higher-order thinking skills. This model is the higher-order thinking laboratory (HOT-Lab) (Malik et al., 2019). The HOT-Lab framework is based on a combination of the Creative Problem Solving (CPS) and Problem-Solving Laboratory (PSL) models. The HOT-Lab stage consists of five stages: 1) understanding the challenges, 2) generating ideas, 3) preparing practicum activities, 4) conducting practicum activities, and 5) communicating and evaluating the results of the activities (Malik & Setiawan, 2016). Several studies have shown that the HOT-Lab model is effective in developing student competencies such as critical thinking skills (Setiawan et al., 2018; Setya et al., 2021), creative thinking (Safitri et al., 2019; Sapriadil et al., 2019), to the ability to communicate scientifically (Sapriadil et al., 2018). Therefore, this study aims to develop practicum guidelines with the term HOT-Lab and explore the effect of using HOT-Lab in improving the scientific reasoning of prospective teacher students.

II. METHODS

This study is a research and development with the ADDIE model (Branch, 2009). The ADDIE model consists of five sections: Analysis, Design, Development, Implementation, and Evaluation. In the

analysis phase, the research team determines the learning needs and describes some information related to the product that needs to be developed. At this stage, the participants filled out a questionnaire related to the practicum activities that had been carried out. The research team developed a prototype of the HOT-Lab practicum guidelines at the design stage. This prototype was discussed with the research team to understand the model. The next stage is the development stage, which is developing the HOT-Lab practicum guidelines, validated by experts and tested on a limited basis. The results of the validation and trials are used as information to revise the HOT-Lab practicum guidelines.

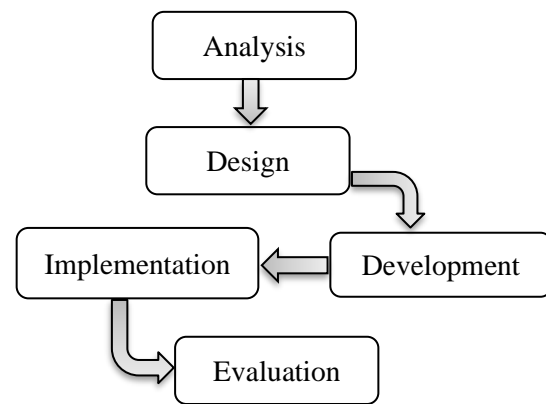


Figure 1. The stages of research and development methods ADDIE model

The implementation stage is the next stage, where the HOT-Lab practicum guidelines are applied to classes taking general physics lectures. The first class uses HOT-Lab practicum guidelines, and the second uses conventional ones. The first author is a teacher in the class. Each stage of this development

goes through an evaluation stage before proceeding to the next stage. The evaluation phase was carried out through focus group discussion (FGD) activities with the research team and several times with experts. FGDs are conducted online and offline.

This study involved students taking general physics courses for the 2022-2023 academic year of UIN Syarif Hidayatullah Jakarta. The research participants involved were five physics education experts and 88 students consisting of 12 male and 76 female students.

Test and non-test instruments are used to test the HOT-Lab practicum guidelines' validity, practicality, and effectiveness. Furthermore, questionnaires and tests were enrolled as data collection techniques. Preliminary study questionnaires were given to students who took general physics lectures at UIN Syarif Hidayatullah Jakarta. A physics education expert questionnaire was used to measure the developed guidelines' validity. The expert validation questionnaire assessed consisted of content, appearance, and language. In addition, students' response questionnaire regarding using the HOT-Lab practicum guidelines in general physics lectures to assess the practicality of the HOT-Lab practicum guidelines. The test used to measure scientific reasoning is in the form of

multiple choices adapted from the Lawson Classroom Test of Scientific Reasoning (LCTSR), an instrument with a general domain approach, based on Table 1.

Table 1. Types of scientific reasoning measured and number of items

Types of general domain scientific reasoning in LCTSR	Number of items (N=24)
Conservation	4
Proportional	4
Control of variables	6
Probabilistic	4
Correlational	2
Hypothetico-deductive	4

(Lawson, 1978)

The data analysis in this study, measuring product development validity, used the percentage of answers to all questions. If the results of the expert's assessment of the guideline product reaches a percentage of $\geq 75\%$ in each aspect of the assessment, then the e-Book is considered valid (Borich, 2008).

The practicality of developing the guidelines was measured using a student response questionnaire. The practicality percentage of the guidelines developed can be seen in Table 2. The practicality criteria used were 81-100% very feasible/practical, 61-80% feasible/practical, and 31-60% sufficiently feasible. Practical, 21-40% less feasible/practical, 0-20% category not feasible/practical (Bintiningtiyas & Lutfi, 2016).

Table 2. Students' response to the implementation of practicum guidelines

Aspect	Indicator
Quality of content and purpose	<ul style="list-style-type: none"> • Understandable instructions for the use • The learning objectives in the practicum guidelines are easy to understand • Pre-practicum stages are easy to understand • The core stages of practicum are easy to understand • Post-practicum stages are easy to understand • The real-world problems given are interesting • The choice of real-world problem solutions presented is clear • The relationship between experimental questions and practicum is clear
Technical quality	<ul style="list-style-type: none"> • The appearance of interesting practical guidelines • Is the language in the practicum guide informative and easy to understand • The images provided are clear and attractive
Quality of learning	<ul style="list-style-type: none"> • The real-world problems and questions that are presented stimulate your scientific reasoning • Does this practicum guide make the student more motivated to learn introductory physics practicum? • Practicum guidelines can be used independently • Overall, is this HOT-Lab practicum guide suitable?

The guidelines' effectiveness was seen to determine the achievement of learning objectives developed regarding scientific reasoning during practicum using different tests using non-parametric statistics Mann Whitney U (Field, 2013).

III. RESULTS AND DISCUSSION

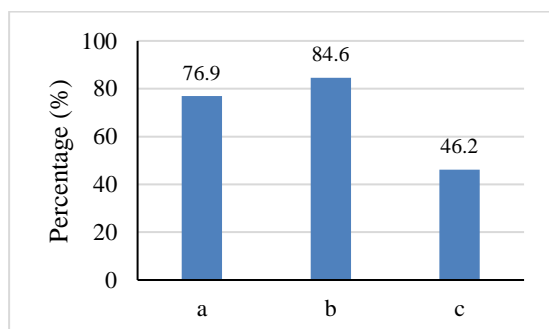
The first step to developing the HOT-Lab practicum guidelines is analysis. At this stage, there are two main things to do: conduct a needs analysis and review the literature. Needs analysis is carried out by providing a questionnaire containing questions related to the views of students who have programmed practicum courses related to practicum activities that have been carried out so far.

Students were asked questions about their views on the objectives of the practicum activities carried out so far. The questions are: "In your opinion, what are the important reasons for science practicum activities" and "In your opinion, what are the objectives of the practicum activities?" The survey was conducted on students who have been using conventional practicum guidelines. The results of the analysis show that practicum activities are not only carried out to develop motivation but also to develop scientific skills. Around 85% of respondents agreed that practicum is a vehicle for learning using a scientific approach. Through scientific methods, students can inquire to reveal the object being observed. This is in line with a study conducted by (Karatay et al., 2014) that the

attitude of prospective teacher students towards laboratory activities is quite positive.

Meanwhile, only about 38% believed practicums could generate motivation to learn science. Furthermore, related to practicum objectives, students have high expectations that practicum activities can assist them in developing competence in terms of skills, cognitive, and even affective aspects.

The survey also asked students' views regarding practicum guidelines used so far. The question is, "How has the basic physics practicum been used so far?" The tabulation of the results of this question is presented in Figure 2.



- Practicum guidelines tend to be used as a way to prove concepts, laws, or principles
- Practicum guidelines are in the form of detailed step-by-step recipes that must be carried out and followed by students during the implementation of practicum activities.
- Practicum guidelines contain elements of writing hypotheses and predictions before practicum

Figure 2. Student views regarding conventional practicum guidelines

Figure 2 shows that most participants considered that practicum activities were only a way to prove concepts, laws or principles (76.9%). This shows that the practicum activities carried out so far are still traditional.

Figure 1 also shows that most students (84.6%) said the practicum guidelines include detailed step-by-step recipes. In other words, the practicum guidelines are more verified. According to Shi et al. (2020) practicum activities like this make students' understanding not deep and they do not understand the experimental design carried out. This was confirmed by the participants' responses, which showed that only 46.2% indicated that the practicum activity provided an opportunity to write a hypothesis before the practicum activity. This contradicts students' expectations that practicum activities can develop scientific skills and reasoning. This kind of skill based on the literature can only be maximized through practicum activities that facilitate students with the stages of scientific discovery, such as submitting hypotheses.

There are two activities carried out in the design stage. The first activity is to design HOT-Lab practicum guidelines, and the second is to validate scientific reasoning instruments. The design of HOT-Lab practicum guidelines for general physics courses is presented in Figure 3.

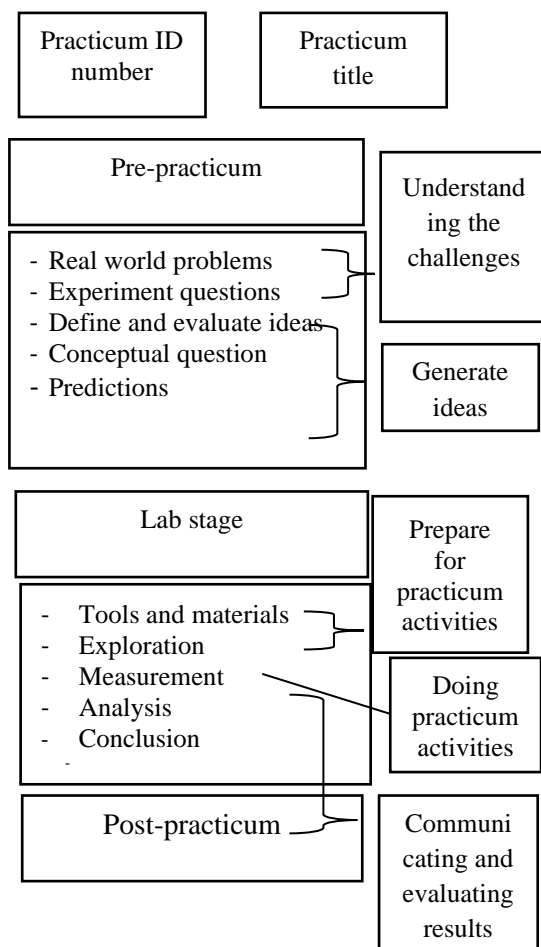


Figure 3. HOT-Lab guideline design

The practicum guidelines developed in this study are as many as seven practicum activities. The practicum activities are 1) practical use of basic measuring instruments; 2) friction force; 3) Archimedes; 4) expansion;

5) atwood planes; 6) momentum and impulse; and 7) calorimeter.

Experts validate HOT-Lab practicum guidelines regarding material content, language, and appearance. Comments given by experts are used as input to improve the product being developed. Some expert comments include "the questions presented are too contextual." Other comments regarding appearance include "the use of language should be improved." Quantitatively, product validity based on expert judgment is >75% or in valid category, as presented in Table 3.

Table 3. Product validity results based on expert assessment

Aspect	Percentage (%)	Category
Content	93.51	Valid
Appearance	93.33	Valid
Language	87.50	Valid

Table 3 shows the validity of the practicum guidelines based on five experts' opinions. After being accumulated, five experts stated that the HOT-Lab practicum guidelines developed were valid regarding content, appearance, and language. In detail, the input of Education experts is presented in Table 4.

Table 4. Expert input and improvement

HOT-Lab practical guideline stages	Use of basic measuring tools	Friction force	Expansion	Atwood's plane
Real world problem	Substitution of real-world problem case 1 to measure irregular objects, as well as adding	Revision and adjustment of problems and solutions provided.	Revision of the images displayed to suit the problems given, as well as	Adjustment of the introductory sentence given the case.

	solutions to cases 2.		reducing the cases given to 1 case.	
Experiment questions	Revision and reduction of questions with higher scientific reasoning.			Revision and reduction of questions that have the same context
Conceptual questions	Adjustments and additions to questions that cover every measurement of the primary measuring instrument that will be practiced.	Revision of questions with higher scientific reasoning.	Revision and addition of questions that further encourage students to do scientific reasoning.	Revision of questions and providing pictures for questions that require picture descriptions for the final answer.
Tools and materials	Determination of tools and materials adjusted to the experiments on each measuring instrument.			
Measurement	Revision and adjustment of the experimental results table.			
Analysis	Revision and adjustment of questions with higher scientific reasoning.	Revision of questions and provision of additional assignments for post practicum.	Revision of the problem by not only using one type of metal, in order to be able to compare the expansion between one type of metal.	Revision of questions that can improve students' scientific reasoning.

The next stage in developing practicum guidelines is implementation. Two groups of students have involved: the first group carried out practicum using HOT-Lab practicum guidelines, and the other group used conventional practicum guidelines. HOT-Lab is a form of student-centered practicum lecture. Using HOT-Lab in practicum activities can improve students' critical thinking skills (Setiawan et al., 2018; Setya et

al., 2021). Also, using HOT-Lab can help students solve everyday problems through investigative activities in the laboratory (Sutarno et al., 2019). Several studies have demonstrated the effectiveness of HOT-Lab in learning (Malik et al., 2019; Safitri et al., 2019; Setya et al., 2021).

Student responses to the products developed were measured using a questionnaire. Student response is measured in

three aspects: quality of content and objectives, quality of technique, and quality of learning. The percentage of student response scores in each aspect is presented in Table 5.

Table 5. Student response to product implementation

Aspects	Percentage (%)	Category
Quality of content and purpose	81.30	Very Practical
Quality of technique	79.51	Practical
Quality of learning	80.37	Practical
Average	80.39	Practical

Table 5 shows practical introductory physics HOT-Lab practicum guidelines. In general, the percentage of student responses to the products developed was 80.39 in the practical category. In other words, students can use HOT-Lab practicum guidelines practically in learning. Furthermore, the percentage of student responses in each aspect also shows promising results in the practical category. These results are in line with a study conducted by Shi et al. (2020) that students showed a positive attitude when using a non-verification practicum guide. This is interesting because a positive attitude in laboratory activities can reduce anxiety and increase student self-efficacy (Kurbanoglu & Takunyaci, 2021). The lowest percentage of student response scores from the three aspects is technical quality. This category has three indicators: display, language, and images. These three

things can be a concern in developing other HOT-Lab practicum guidelines in the future.

This study's HOT-Lab practicum guidelines were designed to improve students' scientific reasoning. Five physics education experts have validated this product on three aspects, namely content, appearance, and language. As a result, HOT-Lab practicum guidelines are feasible to use with valid categories for these three aspects. This HOT-Lab is equipped with features that support the improvement of student reasoning. The HOT-Lab guide consists of three parts: the pre-practicum stage, the Lab stage, and the post-practicum stage.

The HOT-Lab components are designed to improve student competence, especially in scientific reasoning. For example, in the pre-practicum stage, students were provided with "real-world problems," which were simple problems that students were familiar with. After that, they were asked to decide on a suitable solution. The challenges presented in learning can increase student motivation and enthusiasm (Aoyagi et al., 2020; Hung et al., 2015). Besides, as Wong et al. (2021) mentioned, training students to find solutions to a contextual problem can increase their competence.

At the Lab stage, HOT-Lab guidelines are also designed to develop students' scientific reasoning. Students are directed to determine practicum procedures. In offline practical activities, this phase trains student inquiry abilities. Training students to design

experiments can develop scientific reasoning, especially in controlling variables. Unfortunately, with activity restrictions still in place due to the Covid-19 pandemic, practicum activities must be carried out online. As a result, students' preparation for research procedures is limited by the applications used. In addition, to the limitations of the online experiment program, the design phase of this practicum is indeed a challenge for students. They were not used to designing practical steps because they had been provided in the practicum guidelines. Because the practicum topic was still the same as the previous year, many students made a practicum sequence by looking at the previous year's guidelines. This study anticipated this by providing scaffolding through the presence of a laboratory assistant. Students asked about the practicum design of the laboratory assistant. According to [Cwik and Singh \(2022\)](#), laboratory assistants significantly influence practicum activities in the physics laboratory.

After doing the practicum, students analyzed the data and make conclusions. This activity trains students' scientific reasoning abilities. This result aligns with [Marušić and Dragojević's \(2020\)](#) findings that scientific reasoning improves during experiments. At first, students recorded their results in a table of observations and then analyzed them. Students carried out this activity both in the experimental class and in the control class. The data analysis activity involves several aspects

of scientific reasoning; correlational, proportional, and probabilistic reasoning.

The two groups carried out the same seven practicum activities. At the end of the practicum activities, both groups were given a post-test related to scientific reasoning. The results of the scientific reasoning analysis are presented in Figure 4.

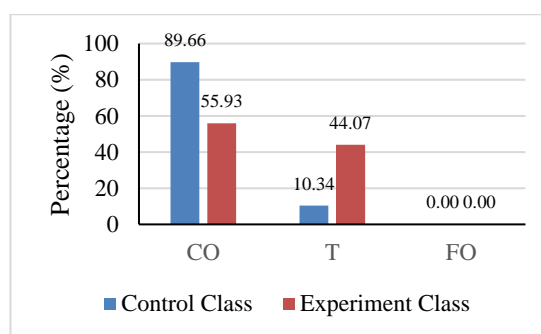


Figure 4. Distribution of students based on the level of general domain scientific reasoning

As Lawson explains, students who score below 25% on the LCTSR are classified as concrete operational reasoning (CO), and students who score between 25% and 58% are classified as transitional reasoning (T). Students who score above 58% are classified as formal operational reasoning (FO). Figure 3 shows that students' scientific reasoning tends to be low even though they have carried out a series of practicum activities. No participants were categorized at the formal operational reasoning (FO) level. Most participants were still at the level of concrete thinking (CO). As for the transition stage (T), a higher percentage of the students in the experimental group were at this level than in the control group.

Based on the type of scientific reasoning, participant scores for each type of scientific

reasoning in the experimental and control classes are presented in Figure 5.

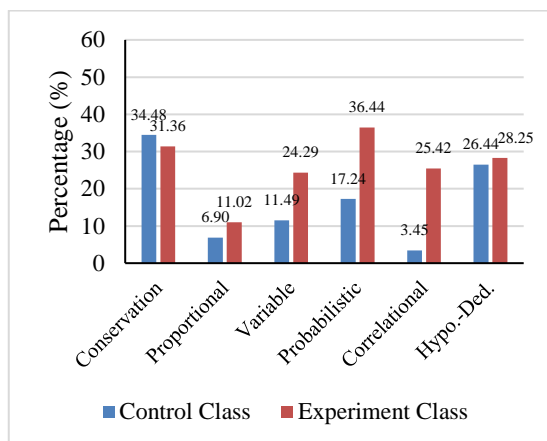


Figure 5. The average score for each type of general domain scientific reasoning

Figure 5 shows that experimental class students are better than control class students in almost all types of scientific reasoning. There are significant differences between the three types of scientific reasoning: correlational reasoning, probabilistic reasoning, and variable control.

Table 6. General domain scientific reasoning descriptive statistics (LCTSR)

Description	Experiment class	Control class
Ideal Score	100.00	100.00
Mean Score	26.86	18.04
Standard deviation	26.92	9.26
Maximum Score	27.25	46.15
Minimum Score	27.06	7.69

Table 6 displays an overview of students' scientific reasoning scores in general. The analysis results showed that the experimental

class's average scientific reasoning score (M=26.86; SD 26.92) was higher than that of the control class (M=18.04; SD 9.26). However, with an ideal score of 100, students' scientific reasoning in both the experimental and control classes is still low.

Furthermore, an inferential statistical analysis was carried out to determine whether statistical differences in scientific reasoning existed between the experimental and the control classes. The assumption test was carried out. First, the normality test analysis results are in Table 7.

Table 7. Normality of scientific reasoning data LCTSR (Domain General) experimental class and control class

Class	Shapiro-Wilk			Note
	Statistic	df	Sig.	
Experiment	.941	59	.007	Not normally distributed
Control	.845	29	.001	Not normally distributed

Table 7 shows the normality of general domain scientific reasoning data. The analysis results show that general scientific reasoning data is not normally distributed. In other words, the assumption of the data's normality is insufficient for analysis with parametric statistics. Therefore, an analysis was carried out using the Mann-Whitney U test. The analysis results using non-parametric statistics, Mann-Whitney U, are presented in Table 8.

Table 8. The results of the comparison test between the experimental class and the control class

	Experiment class	Control class
N	59	29
Median	23.08	15.38
IQR	20.08	11.54
U		529.50
Z		-2.95
Asymp. Sig. (2-tailed)		0.003

Table 8 shows that there are significant differences in the scientific reasoning of students in the experimental class and the control class ($p < 0.05$). The scientific reasoning of the experimental class (Mdn=23.08; IQR=20.08) was better than the scientific reasoning of the control class (Mdn=15.38; IQR=11.54). In other words, this study shows that using HOT-Lab in practice effectively develops students' scientific reasoning.

Students' scientific reasoning after using the HOT-Lab practicum guidelines significantly differs from conventional ones. Although the finding that an intervention can affect students' scientific reasoning is still being debated, this study's findings confirm previous findings showing that learning interventions can develop scientific reasoning (Erlina et al., 2018; Mahler et al., 2021; Omarchevska et al., 2022).

There are several primary differences between practicum with verification and HOT-Lab practicum guidelines. Practical

verification guidelines are like a recipe book or a cookbook experiment. Practicum, in this way, tends only to develop the ability to observe and make measurements. Meanwhile, formulating hypotheses and designing experiments are not accommodated (Bicak et al., 2021). With the structure of the HOT-Lab model implemented in this study, students can explore real problems and formulate hypotheses before the experiments are carried out. In addition, students were asked to design their experiments through discussion activities. Using active learning methods (experiments and discussions) allows students to master content better and perform evidence-based reasoning (Marušić & Dragojević, 2020). Furthermore, not only offline practicums, online learning that involves active student participation can improve student scientific reasoning (Parmin et al., 2022).

Another interesting finding in this study is that although students' scientific reasoning has progressed, students' scientific reasoning still tends to be low. This result was also found by Zulkipli (2020) in Malaysia, where even students' formal reasoning is still low. Furthermore, the reasoning is the most challenging component in explaining student-teacher candidates (Masters & Docktor, 2022). In our research, most students are still at the level of development of concrete thinking. The lowest reasoning is proportional reasoning. After observing 46 participants with an average age of 21.03 years, Lawson et al.

(1984) concluded that language internalization is necessary for someone to do proportional reasoning. Internalization of this language can be trained through activities giving arguments, but this proportional increase requires not a short time. Kwon and Lawson (2000) pointed out that plateau and spurt develop in early adulthood. This development causes a person to develop the ability to reject irrelevant information and accept relevant information. The implication is that in early semester lectures, students must be encouraged to develop progressively from thinking concretely to abstractly. Students can be given problems that are familiar and often observed towards problems that are not familiar or rarely observed.

There are several implications and limitations found in this study. Positive results when actively involving students in practicum activities have proven effective in developing students' scientific reasoning. Therefore, this study is beginning to change the structure of practicum activities carried out so far. Students are encouraged to develop competence through a series of practicums in the laboratory, not only by actively following practicum guidelines. Furthermore, even though this study is still limited in encouraging students to plan practicum procedures, further efforts in the future are essential to keep trying. The hope is that students can do sound scientific reasoning. Students are expected not only to be able to make claims but also to

provide logical formal explanations and even make the correct conclusions.

IV. CONCLUSION AND SUGGESTION

This study concluded that the HOT-Lab practicum guidelines are valid in content, presentation, and language based on expert judgment. The HOT-Lab practicum guide is equipped with features that facilitate student scientific reasoning development. The results of the developed product implementation show differences in students' scientific reasoning scores before and after the HOT-Lab practicum guidelines were used. Furthermore, there is a significant difference in scientific reasoning scores between groups of students using the HOT-Lab and conventional practicum guidelines. Thus, it can be said that the HOT-Lab practicum guidelines can be used in general physics learning to train students' scientific reasoning.

Although this study shows a positive effect between HOT-Lab and scientific reasoning, there are several suggestions that need to be considered in developing future practicum guides. First, the design of real-world problems must be made carefully to familiarize and excite students. Second, students also need to get more attention when preparing the steps for practicum activities. Lastly, there needs to be an initial orientation when a guide like this is first implemented. It may take time for students to adjust to a new guide like this model.

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