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Designing of Virtual laboratory on Thermal Expansion

Dina Rahmi Darman[1,2], Andi Suhandi[1*], Ida Kaniawati[1], Achmad Samsudin[1], Firmanul Catur Wibowo[3]

[1] *Department of Science Education, Universitas Pendidikan Indonesia, Indonesia*
[2] *Department of Primary Teacher Education, Universitas Negeri Jakarta, Indonesia*
[3] *Department of Physics Education, Universitas Negeri Jakarta, Indonesia*

**Correspondence Author:* andi_sh@upi.edu

ABSTRACT
This research aims to produce a virtual laboratory that can be used in teaching physics about thermal expansion. This research uses Design Development Research (DDR) with the ADDIE development model. The development results produce virtual laboratory characteristics consisting of two experiments, three independent and control variables, namely the type of material and length of the cylindrical rod, and changes in temperature, as well as the dependent variable, namely temperature. change in cylinder rod length. Data collection is carried out by asking for validator responses to the virtual laboratory that has been developed. The validators consist of five physics lecturers who are experts in learning media and physics concepts. Validation data is processed using the average percentage of expert responses. The virtual laboratory aspect of thermal expansion validation results in quality, appearance and interactivity was 96%, 93% and 92.5% with very valid criteria. The validation results for all aspects conclude that the virtual laboratory on thermal expansion is very valid with a value of 93.8% and can be used for physics learning.

Keywords: *virtual laboratory, thermal expansion, and learning physics*

INTRODUCTION

Science is an activity carried out by scientists to obtain knowledge about natural phenomena (Rini & Aldila, 2023; Sanjaya et al., 2021;Wibowo, Sanjaya, et al., 2022). Science discusses ways to acquire and use this knowledge through products, processes, and scientific attitudes (Snow & Dibner, 2016). Science discusses natural phenomena arranged systematically based on the results of experiments and observations and those carried out by scientists (Coccia, 2020). It can be concluded that science is knowledge, or a collection of concepts, principles, laws, and theories formed through a systematic creative process based on a scientific attitude carried out by someone to uncover the secrets of the universe.

Science in the learning process is not enough to be given to students through information transfer (Siswanto et al., 2023). However, it needs to be taught by involving various thinking abilities and process skills following the nature of science (Wibowo et al., 2017). One part of science that needs to be taught following the nature of science is learning physics using a laboratory (Permana et al., 2021). Physics learning using a laboratory facilitates students learning physics according to the nature of science (Rini & Aldila, 2023; Berland et al., 2016).

One of the problems in learning physics using a laboratory is the unavailability of physics laboratory equipment that can support learning following the nature of science, especially in microscopic concepts. The problem of the unavailability of laboratory equipment for physics learning above can be overcome by developing a virtual laboratory (Wibowo et al., 2019).The virtual labs allow students to carry out virtual investigations as when students do experiments using fundamental tools (Wibowo, Setiawan, Darman, et al., 2019)

Virtual labs are proven to improve the quality of education from traditional to modern education. Virtual labs can also enhance the teaching experience (Daineko et al., 2017). Virtual labs can be a solution to overcome the limitations of natural laboratories in the form of remote labs. The virtual laboratory allows students to visually explore and experiment with complex processes as a substitute for direct experiments in the laboratory (Grodotzki et al., 2018).

The virtual labs also have various benefits as a substitute for a natural laboratory in the form of low investment costs, easy maintenance at low cost, can be replicated as needed, can enhance active learning, provides new challenges for students to develop various skills, and provides a new paradigm in learning (Hernández-de-Menéndez et al., 2019). So, it can be concluded that the virtual laboratory is the right choice to overcome the problem of the absence of lab equipment and the lack of lab equipment in natural labs. In addition to the benefits above, the virtual laboratory provides a fun experience for students when applied to learning activities. The virtual laboratory application also motivates passive students to be more active in learning (Bogusevschi et al., 2020). Other findings also show the positive impact of using the virtual laboratory in learning by increasing student learning outcomes. Besides that, further findings provide recommendations for using virtual labs as an alternative to natural (El Kharki et al., 2021).

The results obtained after the COVID-19 pandemic show that virtual labs can be widely accepted and in demand by students. Virtual labs can be used with natural laboratories and complement each other without prejudice to physical laboratories in learning models that combine direct and online learning (Vergara et al., 2022). Virtual labs and physical laboratories do not show significant differences in student learning outcomes, so that they can be combined in learning (Kapici et al., 2019).

The availability of virtual laboratories related to abstract and invisible phenomena has various benefits, including being able to help natural physics educators teach (Wibowo, Setiawan, Alizkan, et al., 2019).Then the virtual laboratory on microscopic physics material can increase students' understanding of abstract physics concepts (Wibowo, Sanjaya, et al., 2022). Furthermore, virtual labs on microscopic material can improve students' problem-solving skills when applied to physics learning (Wibowo, Budi, et al., 2019). Based on his description above, it can be concluded that virtual labs on both real and abstract contextual material can have a positive impact in improving various skills, making passive learning active, and facilitating students to discover concepts as scientists work through activities of designing experimental designs, manipulating variables, making measurements, and finding relationships between variables.

One of the abstract physics concepts requiring laboratory learning is thermal expansion. Thermal expansion, when viewed microscopically, is related to the naked eye is the increase in the object's length when given heat energy (Khachan, 2018). When viewed microscopically, the material is composed of many particles that are constantly vibrating. When the temperature increases, the vibration speed increases, thus causing the space requirements between particles to increase as well. This is what causes the object's length to increase when it expands.

This phenomenon of thermal expansion can be observed in various incidents in everyday life, such as the increase in the length of the cable when it is heated during the day, marked by the curvature of the electric cable between two electric poles, the reduction in the size of the railway gap when it is hot during the day, the shrinking of the concrete bridge joints which were initially tenuous in the morning, the breaking of a glass filled with boiling water due to a sudden temperature change. Although this expansion phenomenon can be seen directly, the magnitude of the length increase for every one-degree temperature increase is very difficult to measure. This is because the expansion process causes an increase in length of a very tiny order with each increase in temperature. Because the order of the material's expansion is very tiny, it is not easy to measure it directly. This phenomenon is also not supported by the absence of measuring instruments that can be used to measure very tiny orders of thermal expansion.

Based on the results of observations on physics learning on the concept of expansion at universities and schools, it was found that learning was still limited to observing expansion symptoms by the naked eye. In addition, experiments on thermal expansion are still limited to investigating the relationship between heat and changes in water volume due to expansion (Wagner et al., 2021). In addition, the test experimental devices that can be carried out are still limited to thermal expansion in the form of 3D printing of polymeric materials, which uses expensive tools to investigate the thermal expansion of some polymeric materials, which is still tricky to do (Rădulescu et al., 2022). In addition, based on tracing the availability of lab equipment at lab equipment manufacturers, namely PUDAK and PASCO, information was obtained that expansion lab equipment was costly, resulting in the unavailability of this lab equipment in university and school laboratories. Based on these findings, it is concluded that the concept of thermal expansion requires a virtual laboratory to solve the limitations of experimental tools on this concept.

The results of the analysis of the availability of a Virtual laboratory on heat expansion material at PhET provide information that no virtual laboratory on heat expansion material is available at the PhET link https://phet.colorado.edu. In contrast, the virtual laboratory on thermal expansion is not available. Based on these findings, it can be concluded that previous researchers have never developed a virtual laboratory on thermal expansion even though the virtual laboratory on thermal expansion is a virtual laboratory that is needed and urgent to be developed as a learning medium for students to teach the concept of thermal expansion following the nature of science.

Based on the explanation above, an idea emerged to overcome the unavailability of laboratory equipment regarding thermal expansion by innovating to develop a virtual laboratory. So the findings above are the background for creating a virtual laboratory on thermal expansion to produce a virtual laboratory that has yet to exist as a novelty from this research.

The general formulation of the problem is a Virtual Laboratory (VL) about how thermal expansion can support physics learning for prospective physics teacher students. With the following research questions: 1) What are the characteristics of virtual laboratory products regarding thermal expansion developed to support physics learning for physics teacher students? and 2) What is the validity of virtual laboratory products regarding thermal expansion generated for physics learning in physics teacher students?

This research aims to produce a virtual laboratory product on thermal expansion that is valid and can be used for physics learning for prospective physics teachers. This research is development research that uses products whose validity is measured based on content validity using experts who assess the level of product validity. The structure of this article includes research methodology, consisting of methods and stages of virtual laboratory development research on expansion, results, and discussion of the resulting virtual laboratory products consisting of virtual laboratory characteristics on thermal expansion and virtual laboratory validation results on thermal expansion.

METHODOLOGY

The research method used in developing virtual laboratory products regarding thermal expansion is Design and Development Research (DDR). DDR is a study of making products and tools in the form of design, development, and evaluation processes that are carried out systematically. DDR includes the creation of new products and tools as well as improved models of existing tools. This study includes instructional and non-instructional tools and products (Richey & Klein, 2014).The DDR used uses the ADDIE model, which consists of four stages of the five complete ADDIE stages. These stages are the analysis, design, development, and evaluation stages, which are carried out simultaneously with the other three stages (Md Shukri & Ariffin, 2019). The development of the virtual laboratory on thermal expansion is described in full in Figure 1.

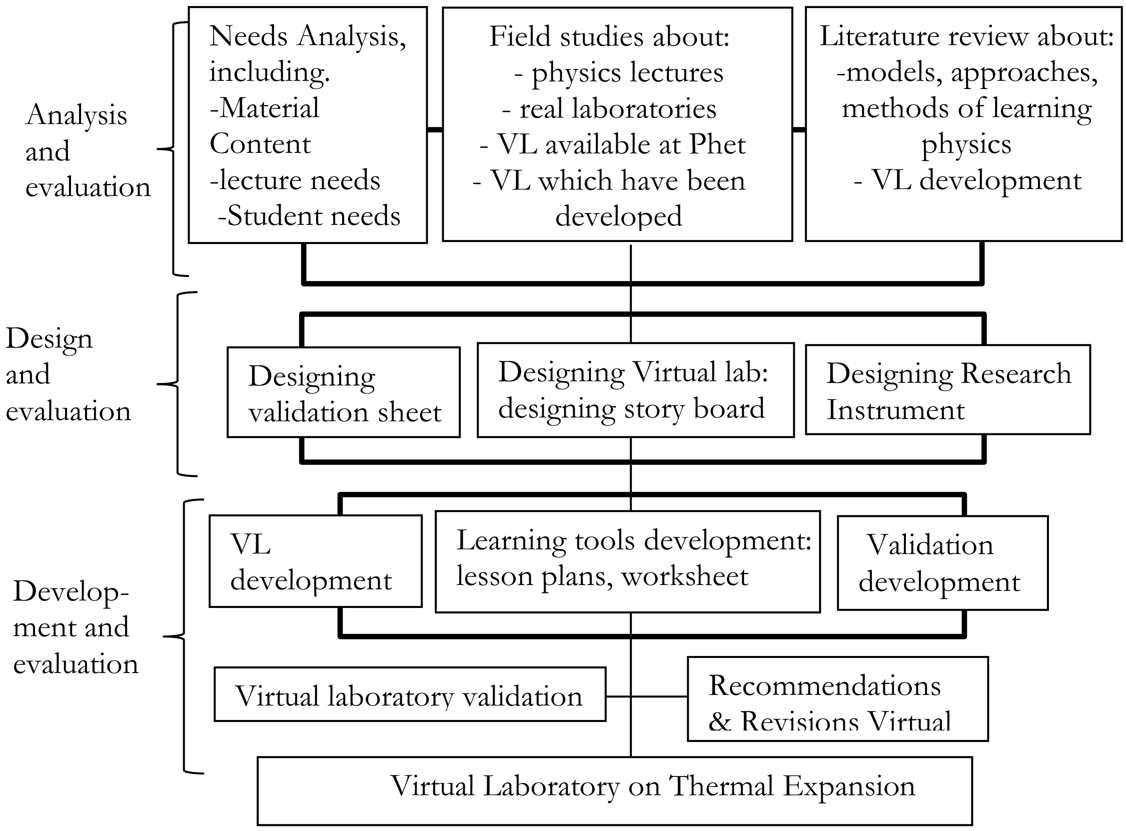

Figure 1. Development of Virtual Laboratory on Thermal Expansion

Based on the purpose of this study, namely, to produce a virtual laboratory on thermal expansion that can be used in physics learning, the research stages are carried out in Figure 1. The first stage is the analysis stage. At this stage, a needs analysis study, preliminary study, and literature review were carried out to support the development of a virtual lab. At this stage, the research subjects used were physics education students, physics education lecturers, and teachers. A needs analysis study was conducted to determine the needs of student learning media. For data collection, interviews were conducted with students and physics education lecturers. They also observed the availability of laboratory equipment to support learning.

The design stage is the second stage of virtual laboratory development on thermal expansion. At this stage, a virtual laboratory storyboard design was created regarding thermal expansion. Besides that, the design of the instrument used for the virtual laboratory regarding thermal expansion was also carried out, and the design of the expert validation sheet was to obtain suggestions for improving the virtual laboratory from experts.

The third stage is the development of the virtual laboratory on thermal expansion which is the development stage. At this stage, all designs that have been designed in the form of storyboards are created and developed into finished products, namely virtual labs on thermal expansion, learning tools in the form of worksheets and lesson plans, as well as validation sheets are also created. At this stage, a validation process was also carried out using validation sheets for physics experts who mastered physics learning content and media. The virtual laboratory validation instrument was developed based on a modified multimedia mania rubric developed by ISTE's hyperSIG and refined by the multimedia mania team at North Carolina State University (NCSU) and the virtual laboratory development rubric by other researchers (Wibowo, Setiawan, Alizkan, et al., 2019b; Masril et al., 2018). The results of the validator's responses are processed using the average percentage of the validator's responses by dividing the sum of all scores on each statement by the number of questions and validators.

The validators for this virtual laboratory development research are five physics lecturers who are experts in developing learning media and are experts in physics concepts. They master good learning media and appropriate physics concepts. They were asked for consideration because their research field was learning media. To find out the validation criteria based on the validator's response to the virtual laboratory about expansion interpreted with the Average Validation Response (AVR) criteria in Table 1.

Table 1. Virtual Laboratory Validation Criteria

AVR (%)	Validation Criteria
0< AVR<25	Very Less
25≤AVR<50	Less
50≤AVR< 75	Valid
75≤AVR<100	Very Valid

(Wibowo et al., 2019b)

Based on Table 1, the expected virtual laboratory validation results are valid and very valid. In addition to the criteria in Table 1, input and recommendations from the validators were also obtained, written on the validation sheet as a basis for revisions to the virtual laboratory so that a virtual laboratory regarding expansion was obtained, which was valid for use in physics learning.

RESULT AND DISCUSSION

Developing a virtual laboratory on thermal expansion goes through 4 stages. The results obtained at the needs analysis stage found that the laboratory equipment in physics learning was incomplete, so several topics that should have been taught using the laboratory could not be carried out. Thermal expansion is a topic requiring practical tools in the laboratory. Based on the results of an interview with one of the lecturers, information was obtained that practicum tools on thermal expansion were yet to be available in the laboratory because they were expensive. Based on a search of a Pasco laboratory equipment manufacturer located in Roseville, California, United States, and available at https://www.pasco.com/, thermal expansion equipment is available at very high prices. In addition, in Indonesia, PUDAK produces thermal expansion lab equipment. The search (https://www.pudak-scientific.com/) taught me that laboratory equipment for length expansion is costly.

The results of the analysis of the availability of virtual labs that previous researchers have carried out found that several virtual labs that have been developed include the topics of force (Zhuoluo et al., 2019), optics (El Kharki et al., 2021), electricity (El Kharki et al., 2021), light-wave (Wibowo, Anggraini, et al., 2022), optical geometry-light (Wibowo, Darman, et al., 2022), ohm's law and mechanics (El Kharki et al., 2021), energy kinetic (Sari et al., 2019), isobaric (Rani et al., 2019), dynamic electricity (Wibowo, Setiawan, Darman, et al., 2019), thermodynamic (El Kharki et al., 2021), electric circuit (Sapriadil et al., 2019), heat transfer (Wibowo, Budi, et al., 2019), measurement (Rasheed et al., 2021) (Jannati et al., 2018) and magnetic (Price & Price-Mohr, 2019), nuclear physics (Šiđanin et al., 2020), kirchhoff laws (Rosdiana et al., 2019), Geometrical Optics (Erdoğan & Bozkurt, 2022; Wibowo, Anggraini, et al., 2022).

Based on these findings, it can be concluded that a virtual laboratory on expansion has never been developed by researchers before. Then the results of the virtual laboratory analysis are available online at PhET. Provides information that the new heat and thermo material provides simulations about diffuse, intro gas, gas properties, energy forms and changes, and state of matter. In comparison, the virtual laboratory on thermal expansion is not available.

After it was found that the virtual laboratory on thermal expansion was a virtual laboratory that was needed and urgently developed, the design phase was carried out. At this stage, a virtual laboratory storyboard design was created regarding thermal expansion. The storyboard consists of the initial display of the virtual lab, the display after the virtual laboratory regarding thermal expansion, and the results after measurement. Each view of the storyboard explains a guide at the development stage.

The virtual laboratory development stage is carried out by creating a virtual laboratory based on the storyboard that was designed in the previous stage. Development of a virtual laboratory on thermal expansion using Corel Draw software for making materials in the form of objects to be used in virtual labs and Adobe Animate for making virtual laboratory media (Animation and Coding). The results of the virtual laboratory development on expansion consist of the characteristics of the virtual laboratory on thermal expansion and the virtual laboratory validation results on the thermal expansion.

1. Characteristics of the virtual laboratory about expansion

The virtual laboratory about expansion is designed to be flexible to be used anywhere and anytime. This virtual laboratory can also be used repeatedly by students. Students can explore the virtual laboratory independently and discover the concept of expansion and the relationship between variables in the virtual laboratory. No guidelines for using the virtual laboratory or practical instructions are provided so that this virtual laboratory can be used in various types of practicums, depending on the experimental design chosen by the lecturer or teacher. If the lecturer or teacher wants to learn with one of the models, then the lecturer and teacher can adjust the use of this virtual laboratory by adding their own student worksheets adapted to the model.

The virtual laboratory on expansion consists of "practicum 1" and "practicum 2," as shown in Figure 2.

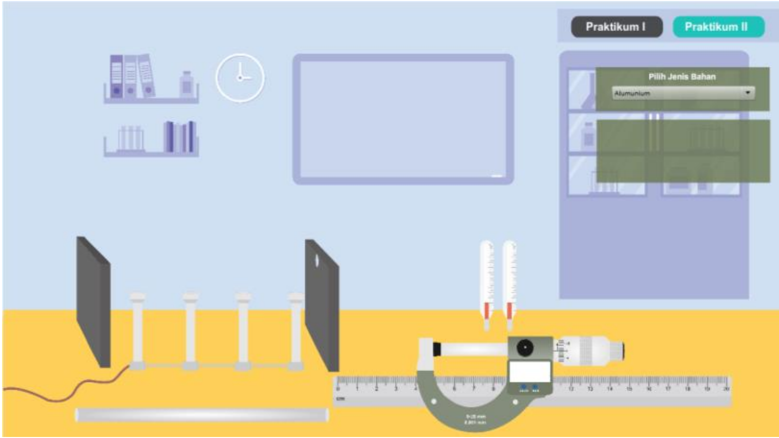

Figure 2. Initial Display of The Virtual Laboratory on Thermal Expansion in the "Practicum 1"

Based on Figure 2, there are two parts to the virtual lab's initial appearance of expansion. The "practicum 1" section displays a lab atmosphere like a real lab in general, as shown in Figure 2. There is an experiment table and experimental tools on the table and in cupboards, books, wall clocks, and blackboards. The table provides experimental tools for thermal expansion that can be selected before experimenting, consisting of a cylinder rod holder, a cylinder rod, a ruler, a screw micrometer, and a thermometer. The cylinder rod comprises ten materials, as shown in Figure 3.

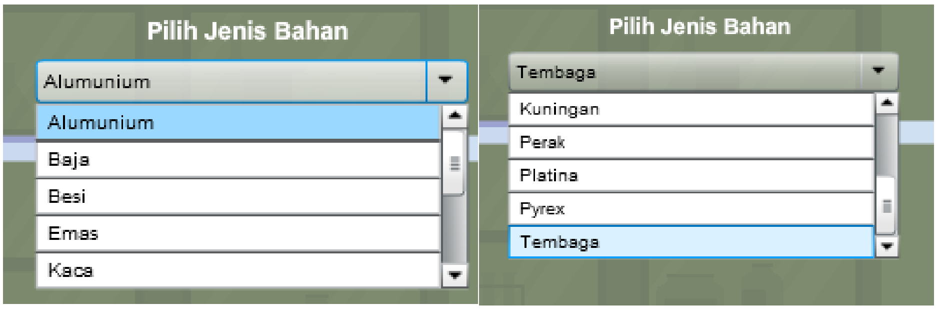

Figure 3. Types of Materials Used in The Virtual Laboratory on Thermal Expansion.

The types of materials used in the virtual laboratory regarding thermal expansion, based on Figure 3. consist of aluminum, steel, iron, gold, glass, brass, silver, platinum, pyrex, and copper. If the student chooses one of the materials, the display of the cylinder bar will adjust to the selected material.

In the virtual laboratory on thermal expansion, students design their experiments by selecting the tools and materials provided. The tools provided can be moved around to prepare a series of experimental tools by hovering over one of them and clicking, then holding it until the desired position. Of all the tools described earlier, there is one tool whose position cannot be moved, the cylinder rod holder, because it is fixed to make it easier for students to do experiments. If the student is right in assembling the experimental tool, a "start" button will appear to start the investigation with the virtual lab, as shown in Figure 4.

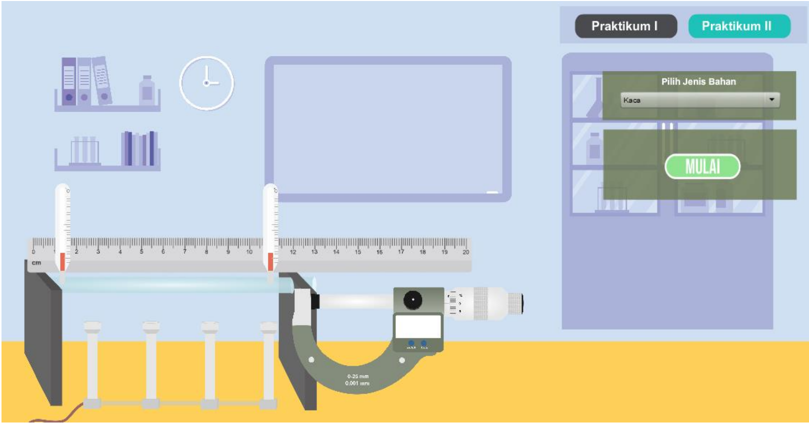

Figure 4. Virtual Laboratory on Thermal Expansion Circuit to Start the Investigation

Based on Figure 4, the position of the digital screw micrometer is placed at the right end of the cylinder rod, which aims to measure the increase in the length of the cylinder rod because the left end of the rod holder is made fixed. The virtual laboratory on thermal expansion cannot simulate if the students are wrong in assembling the tools, so students must put the experimental tools in the correct position.

Virtual laboratory on thermal expansion simulating the addition of long material from an initial temperature of 20^0 C. The virtual laboratory display of heat expansion, when measurements are simulated, can be seen in Figure 5.

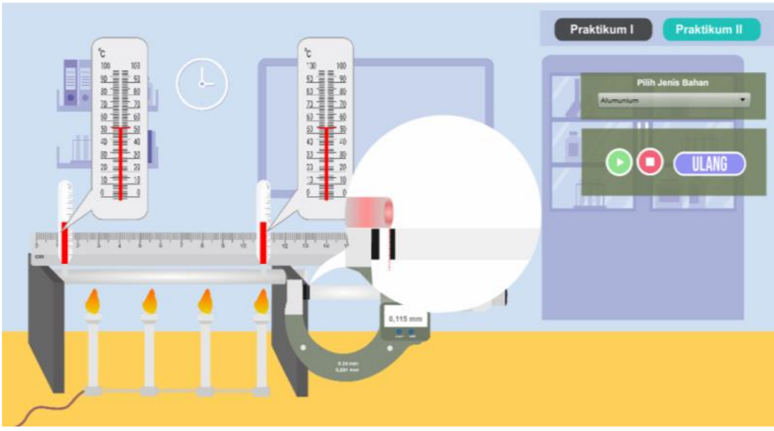

Figure 5. The Virtual Laboratory on Heat Expansion When Measurements are Simulated.

Figure 5 shows the scale on the thermometer, the scale on the screw micrometer, and the increase in the length of the cylinder material is automatically zoomed in to make visualization more transparent. The temperature and the increase in the length of the cylinder rod will continue to increase until the desired final temperature. The student clicks the "stop" symbol (red) to reach the final temperature. The virtual laboratory will stop when the "stop" button is clicked. To continue at a higher temperature rise, click the "mulai" symbol (green) without repeatedly assembling the tool. The digital screw micrometer will automatically calculate the increase in the length of the cylinder rod for every 1 C increase in temperature. The initial look of the virtual laboratory regarding the expansion of the "practicum 2" section is almost the same as the appearance of the "practicum 2" section presented in Figure 6.

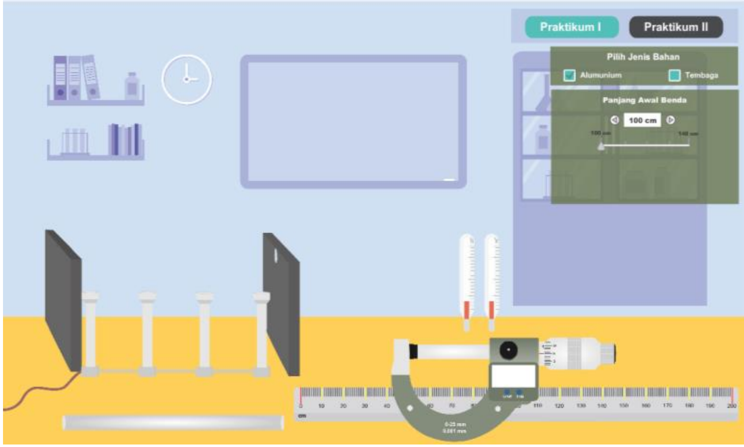

Figure 6. Initial View of The Virtual Laboratory on Thermal Expansion in The "Practicum 2" Section

Figure 6 shows that the difference between "practicum 1" and "practicum 2" is only in the choice of cylinder rod material. In "practicum 2," only two-cylinder material choices: aluminum and copper. Another difference is that "practicum 2" provides a choice of cylinder rod length, consisting of five choices, namely 1m, 1.1m, 1.2m, 1.3m, and 1.4m. While the tools for "practicum 2" are the same as "practicum 1," namely rod holders for expansion, cylinder rods, thermometers, and screw micrometers. Display of the virtual laboratory "practicum 2" regarding heat expansion when measurements are simulated in Figure 7.

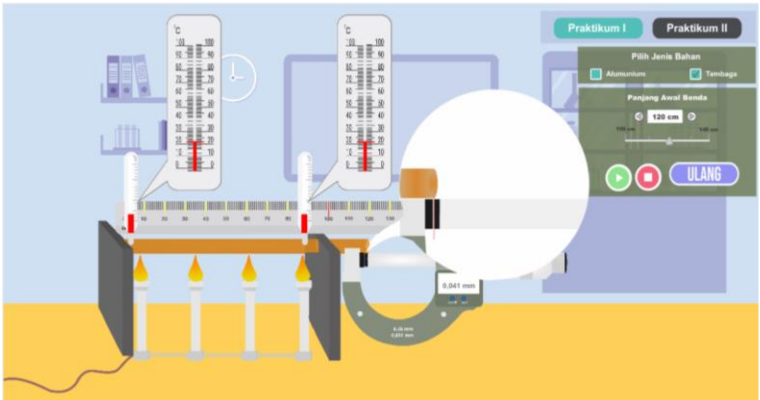

Figure 7. View of the "Practicum 2" When Measurements are Simulated.

Based on Figure 7 can be seen that the running of the virtual laboratory in "practicum 2" is the same as the running of the simulation in "practicum 1". There is no difference between how to operate, stop, and repeat measurements in the "Practicum 2" and "Practicum 1" virtual laboratory.

2. Virtual laboratory validation results regarding expansion

The virtual laboratory validation of expansion involves five physics education experts who are experts in physics teaching and learning media The virtual laboratory validation regarding expansion uses a validation rubric that assesses four aspects: virtual laboratory content quality, virtual laboratory appearance, and virtual laboratory interactivity. The validator response consists of four answer choice criteria. Indicators for the assessment aspect of the expert validation instrument are presented in Table 2.

Table 2. Indicators for Validation Instrument

Aspect	Sub Aspect
Quality	1. Visualization of tools and materials
	2. Systematic arrangement of experiments
	3. Conformity of measurement results with theory
	4. The relevance of the concept with visualization
	5. Compatibility of the virtual heat expansion lab with the curriculum
Display	1. Quality of virtual laboratory visualization
	2. Use of backgrounds
	3. Image selection
	4. Color composition
	5. Design layouts
	6. Typography
Interactivity	1. Ease of selecting the practicum menu
	2. Ease of selection of tools and materials
	3. Ease of preparation of tools and materials
	4. Ease of use navigation buttons
	5. Clarity of navigation button links to other pages
	6. Accuracy of response to orders

Based on Table 2, the expert validation aspect consists of 3 main parts with 17 indicators. The quality of the content relates to the quality of the visualization of the virtual laboratory produced following the concepts and needs and the contextual virtual laboratory measurements following the theory of physics. Aspects of the virtual laboratory display relate to image selection, design color composition, and virtual laboratory typography. To obtain a virtual laboratory that has a harmonious, harmonious, balanced appearance and attracts students. The interactivity aspect of the virtual laboratory relates to user convenience in using the virtual laboratory in learning such as the ease of selecting menus, tools, and materials and preparation of tools and materials. Besides that, virtual laboratory interactivity is also related to good navigation and the accuracy of virtual laboratory responses to user commands.

The validation expert results obtained that the Average Validator Response (AVR) in the virtual laboratory quality aspect was 96%, in the virtual laboratory display aspect was 93%, and in the interactivity aspect was 92.5%. Based on AVR value criteria, according to Wibowo (2019b), if the AVR value for a learning media is $75 \leq AVR < 100$, then the media is in very valid criteria. So, the three aspects of the virtual laboratory regarding expansion, namely the quality, appearance, and interactivity, are very valid criteria. Overall, the virtual laboratory aspect regarding expansion obtained an AVR score of 93.8%, also within the very valid criteria. Based on these results, the virtual laboratory on expansion proves the accuracy and precision of the virtual laboratory in carrying out measurements like a real laboratory in carrying out its measurement function.

There are various inputs from the validator to improve the virtual laboratory regarding expansion. Based on the inputs from the validator, a revision was made to the virtual lab, namely the systematic preparation of experiments was made more flexible, all measuring instrument scales were clarified so that they were easy to read, repaired the virtual laboratory part that covered the ruler scale, improved the magnification display of the increase in length of the material scale so that it could be seen more clearly. Then the unbalanced virtual laboratory layout is corrected. The thermometer image is also fixed with a thermometer scale. The size of the writing on the ruler scale, which is less visible, is also fixed. The virtual lab's interactivity has also been improved to make the arrangement of tools and materials more flexible. Then, improvements were made to the sensitivity of the navigation buttons that were not functioning correctly, and improvements were made to the accuracy of the virtual lab's response to user commands. After revising the virtual laboratory about expansion, a virtual laboratory about expansion is obtained, which is valid and can be used in physics learning. This virtual laboratory can be a medium for students to understand the expansion process with expansion practicums. Students can measure the increase in the length of materials as the temperature increases. This virtual laboratory can also be used as a demonstration tool for lecturers when teaching in class. This virtual laboratory can also be used in various practicum designs tailored to lecturers' and students' needs and conditions.

CONCLUSION

The resulting virtual laboratory about the expansion consists of the characteristics and validation of the virtual laboratory about the expansion. The virtual laboratory characteristic of expansion consists of two experimental parts: "practicum 1" and "practicum 2". Experimental equipment and materials include thermometers, screw micrometers, expansion stands, and cylindrical rods. The cylinder rod comprises aluminum, steel, iron, gold, glass, brass, silver, platinum, pyrex, and copper. Students can choose three independent variables: the type of cylinder rod material, temperature changes, and the initial length of the cylinder rod. In comparison, the dependent variable students observe is the change in the length of the cylinder rod. Based on the results of the validation, it shows that the virtual laboratory on expansion is valid and can be used for learning physics. The average results of the validation of experts on aspects of quality, aspects of display, and aspects of interactivity are 96%, 93%, and 92.5, which are in the very valid category. Overall, the virtual laboratory aspect regarding expansion obtains a percentage value of 93.8%, with a very valid category for physics learning. Although the virtual laboratory for this expansion is very valid, further research is still needed to see the impact of implementing this virtual laboratory in various physics and innovative laboratory learning models on various thinking skills, achievement, and student learning outcomes.

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