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Investigating the Impact of Research-Based Learning on Conceptual Understanding in Thermal Conduction

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Abstract: This study investigates the impact of research-based learning on students' conceptual understanding of thermal conduction. The research employed a one-group pretest-posttest design involving 20 pre-service physics teachers enrolled in a thermodynamics course. The research instrument used was a conceptual understanding test administered before and after implementing research-based learning. The Shapiro-Wilk normality test indicated that both pre-test and post-test data were normally distributed ($p > 0.05$). A paired samples t-test revealed a significant difference between pre-test and post-test scores (Sig. (2-tailed) = 0.000 < 0.05), suggesting that research-based learning effectively enhanced students' conceptual understanding. Furthermore, the N-Gain analysis resulted in a score of 0.71, categorized as high, indicating a substantial improvement in students' conceptual mastery. These findings suggest that research-based learning is an effective instructional approach in teaching thermal conduction, fostering deeper conceptual comprehension among students.

Keywords: Conceptual understanding; Pre-service physics teachers; Research-based learning; Thermal conduction

Introduction

Understanding the concept of conduction is a crucial aspect of physics learning, particularly in the field of thermodynamics, which is closely related to everyday life, from designing energy-efficient buildings to utilizing thermal technologies. Heat conduction describes how heat moves from one object to another or from one part of an object to another through direct contact between particles (Anam et al., 2020; Tipler & Mosca, 2007). A thorough understanding of conduction and its rate is essential, not only to enhance students' scientific understanding but also as a foundation for various practical applications.

Although this concept has high relevance in real life, in practice, students often face difficulties in understanding it. The first reason is that students have difficulty visualizing conduction occurring through interactions between particles at the microscopic level (Jones & Kelly, 2015). Heat transfer through conduction is not easy to visualize, especially when talking about real objects in everyday life. For example, it is difficult for students to understand how heat moves from a hotter side to a cooler side through a wall layer or other solid objects. Physics concepts like this are often considered abstract and difficult to imagine (Ornek et al., 2008).

Although this concept has high relevance in real life, in practice, students often face difficulties in understanding it. The first reason is that students have difficulty visualizing conduction occurring through interactions between particles at the microscopic level (Jones & Kelly, 2015). Heat transfer through conduction is difficult to visualize, especially when talking about real objects in everyday life. For example, it is difficult for students to understand how heat moves from a hotter side to a cooler side through a wall layer or other solid objects. Physics concepts like this are often considered abstract and difficult to imagine (Ornek et al., 2008).

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Secondly, many students struggle to relate heat conduction theory to practical situations (Niss, 2012; Duch, 1997), primarily because conventional teaching methods (such as lectures and exercises) often emphasize memorizing formulas without providing opportunities to see the concepts in action (Ornek et al., 2008; Pavkov-Hrvojević & Bogdanović, 2019). As a result, students' understanding is often abstract and detached from practical contexts (Niss, 2012), which can hinder their ability to apply physics concepts in real-life situations. In other words, for many students, conduction is often learned theoretically through formulas and concepts, rarely given the opportunity to conduct experiments that allow them to directly observe heat transfer through conduction. Without direct experience, these physics concepts often feel abstract and difficult to grasp (Bray & Williams, 2020; Doucette & Singh, 2021). Therefore, a learning design is needed that allows students to be directly involved through scientific activities that can help overcome this difficulty by providing a more in-depth, real experience (Johari, 2018).

If students' lack of understanding of conduction continues without effective intervention, the impact could be quite broad, both in educational contexts and in real-life applications. In the short term, students will continue to struggle to grasp the basic concepts of heat transfer, resulting in them simply memorizing formulas without truly understanding the underlying physical principles (Eichenlaub & Redish, 2019). This reduces their ability to analyze and solve problems related to conduction, both in laboratory experiments and in everyday situations. In the long term, this lack of in-depth understanding can lead to low competitiveness of graduates in science and technology. Unless learning solutions are found to address this issue, physics education will remain theory-oriented without equipping students with the scientific and experimental thinking skills necessary for both the academic and professional world.

In this context, instructors must be innovative in fostering a learning environment that engages students. Learning seems to require something more organized, such as hands-on experiments, practical experiences, or mental exercises. According to Cirenza et al. (2018) and Hofstein et al. (2007), students who follow this learning model are expected to provide a comprehensive understanding and scientific explanations based on their observational activities. Student understanding is one of the most important aspects of the learning process (Phanphech et al., 2019; Treagust & Duit, 2018). Simply put, Redish et al. (1999) state that understanding physics concepts is a crucial part of physics learning. One effort considered strategic in helping students understand physics concepts is developing and implementing research-based learning.

In this context, research-based learning presents itself as an innovative learning method that directly engages students in the research process, where they are invited to design, conduct, and analyze experiments relevant to the topic being studied (Tungkasamit, 2019). This approach gives students an active role, encouraging them to engage directly in data collection and scientific analysis. In research-based learning, students function not only as recipients of information but also as researchers who learn through direct experience (Nursofah et al., 2018; Daryanes & Sayuti, 2023; Maulidiya et al., 2023). By providing students with opportunities to conduct experiments on conduction, they not only understand the related formulas or theories but also gain a deeper understanding of how heat transfers in real-world conditions. This process is expected to significantly improve students' conceptual understanding and strengthen their ability to apply physics concepts in various contexts. According to Usmeldi et al. (2017), research-based learning integrates research into a meaningful learning process and promotes student-centered learning (Brew & Saunders, 2020; Perdana et al., 2025; Kowalczuk-Waledziak et al., 2025). Real-world challenges provide the foundation for research-based learning, providing students with an environment to acquire important knowledge and concepts related to the subject while also developing problem-solving strategies and skills (Hidayatul et al., 2020; Lestari et al., 2025; Gita et al., 2024; Astuti, et al., 2024; Nurhayati et al., 2023; Ernawati et al., 2023; Etherington, 2011).

Research-based learning on the topic of conduction is still underexplored. Research-based learning studies specifically on the concept of conduction are still rare, so this study has the potential to be a new contribution to enriching the study of physics learning. This research can contribute to seeing how research-based learning on the topic of conduction affects students' conceptual understanding. Therefore, this article aims to provide an overview of students' understanding of thermodynamics courses, especially on the topic of conduction, as a result of the application of research-based learning. Through research experiences, students have the opportunity to learn the topic of conduction not only from lecture materials but also from research practices, which include literature searches, hypothesis formulation, data collection, data analysis and testing, and conclusion.

Method

This research is a pre-experimental study using a one-group pretest-posttest design, which involves administering treatment to a sample class to determine the changes that occur (Sugiyono, 2019). The research procedure begins with a pretest administered to the sample class. After the pre-test is completed, the next step is implementing research-based learning. The final stage is administering a post-test to the sample class.

The sample in this study used a total sample. Total sample is a sampling technique in which the entire population in a particular group is used as a research sample (Sugiyono, 2019). This method is used when the population is relatively small and allows all members of the population to be included in the study. In the context of this research, which involved all 20 students of the Physics Education Study Program, Faculty of Teacher Training and Education, University of Palangka Raya, who were taking the Thermodynamics course, the total sampling method was very appropriate because the population was relatively small without the need for random sampling or stratification techniques.

Table 1. Stages of Research-Based Learning Applied to the Topic of Conduction

Stages	Description	Learning activities
Identify the basic problem	Students identify problems related to conduction in a room. These problems can include how heat transfer occurs through the walls, floor, or roof of the room, as well as influencing factors such as material type, thickness, and temperature differences.	Initial observations of conduction phenomena in the surrounding environment, group discussions to raise issues related to conduction, and formulating problems that can be researched further.
Inventory of supporting aspects of research	Students conduct an inventory of aspects that support research, including designing experiments and selecting the necessary equipment and materials.	Identifying the variables to be studied (e.g., temperature differences, material types, material thickness); developing an experimental design; Determining the tools and materials needed; Formulating a research hypothesis.
Reference collection	Students collect reference data related to conduction to understand aspects that support their research. Reference sources can come from books, scientific journals, academic websites, or other relevant media.	Search for valid and relevant sources of information for the research.
Data collection and analysis	Students conduct experiments based on a pre-designed plan. The collected data is then analyzed to answer the research problem.	Conduct experiments in small groups by following the designed protocol; Record the results of measurements of temperature, time, and other factors that affect conduction; Measure the conduction rate in a miniature model of a room measuring 146 cm x 120 cm x 80 cm consisting of several components, for example, glass, zinc, wood, and aluminum with a certain thickness; Analyze data using statistical methods or physics calculations.
Reporting results	Students compile research reports and conduct meta-literacy to reflect on the understanding they have gained.	Compiling reports, presenting research results in the form of presentations or class discussions, reflecting on the research process, and connecting research results with real-world phenomena.

Table 2. Indicators in the Test

Conceptual understanding indicators	Conceptual understanding test indicators	Question number	Aiken's V
Students are able to explain the basic concept of heat conduction.	Explain the mechanism of heat transfer through conduction.	1 2	1.00 1.00
Students are able to analyze the factors that influence the rate of conduction.	Analyze the relationship between thermal conductivity, cross-sectional area, thickness, and temperature difference.	3	0.75
Students are able to compare the rate of conduction in various materials.	Compare the thermal conductivity of several different materials.	4	0.75
Students are able to interpret experimental results related to the rate of heat conduction.	Analyze experimental data on the temperature of a material.	5	1.00

Data on students' understanding of the conduction material was obtained using a test instrument developed by the researcher. The test instrument consisted of essay questions consisting of five questions related to the conduction material. The test instrument used in this study was validated through expert review by two physics lecturers. The validation process was carried out by providing the instrument to the two experts to be assessed based on relevance, clarity, and suitability to the learning indicators. Then, the assessment results were analyzed using the Aiken validity coefficient to assess the level of agreement between experts regarding the quality of the test instrument (Utami et al., 2024; Safitri et al., 2025). The analysis showed that most of the test items had Aiken's V values ≥ 0.75, indicating good content validity (Nabil et al., 2022). These validation results confirm that the test instrument is of good quality for measuring students' understanding of heat conduction in this study. Table 2 presents an overview of the indicators in the test and the results of expert validation.

Data were collected before (pretest) and after (post-test) students participated in the learning. The data obtained were then analyzed using MS Excel for calculations and IBM SPSS version 24 for statistical analysis. Analysis of the test results was carried out using a paired t-test to determine whether there were significant differences in the treatment given by the researcher (Sudaryono, 2019). Before conducting the paired t-test, the researcher first conducted a normality test to determine whether the data were normally distributed or not. If the data were normally distributed, a paired sample t-test would be used. Meanwhile, if the data were not normally distributed, a non-parametric test would be used. Next, a normalized gain test (N-Gain) was conducted to determine the increase in students' conceptual understanding after being given the treatment. This increase was taken from the pretest and posttest scores obtained by the students. The results of the N-Gain calculation were grouped into several categories as presented in Table 3.

Table 3. Interpretation of N-gain Calculation Results (Hartanto et al., 2023)

N-Gain scores	Improvement categories
<g> < 0.3	Low
0.3 ≤ <g> ≤ 0.7	Medium
<g> > 0.7	High

Result and Discussion

Research-based learning has been implemented in lectures on the topic of conduction with the aim of improving understanding. This approach engages students in an independent research process, from problem formulation and experimental design to data collection and analysis, and finally to conclusion (Usmeldi, 2016; Priantari et al., 2022). Furthermore, research-based learning is combined with projects to provide a more practical learning experience. After the implementation of the learning, an analysis was conducted to measure the effectiveness of research-based learning in improving students' conceptual understanding. Data were collected through pretests and posttests, then analyzed using statistical tests to determine the significance of differences in learning outcomes. Furthermore, the N-Gain calculation was used to determine the extent of improvement in students' conceptual understanding after participating in research-based learning. The results of the statistical analysis are shown in Table 4.

Table 4. Statistical data Analysis from the Pre-test and Post-test

Components	Pretest	Posttest
N	20	20
Average value	36.40	81.60
N-Gain		0.71 (High)
Shapiro-Wilk Normality Test		
Significance (Sig.α = 0.05)	0.053	0.076
Conclusion	Normal distribution	Normal distribution
Paired samples test		
Significance (Sig.α = 0.05)	Asymp. sig. (2-tailed) = 0.000 < 0.05	
Conclusion	There is a significant difference	

Based on the output results in Table 4, it is known that the Shapiro-Wilk significance value for the pre-test and post-test variables is greater than 0.05, so it can be concluded that both variables are normally distributed. Based on the output table "paired samples test" in Table 4, it is known that the Sig. (2-tailed) value is 0.000 < 0.05, so it can be concluded that there is an average difference between the pre-test and post-test learning outcomes, which means there is an effect of the implementation of research-based learning in improving students' understanding of the topic of conduction. The N-Gain of 0.71 indicates that the increase in students' conceptual understanding after participating in research-based learning is included in the high category. With an N-Gain value of 0.71, research-based learning that has been applied to the topic of conduction can be said to be effective in improving students' understanding.

The results of the N-Gain analysis for each question item in Table 5 show an increase in students' conceptual understanding after participating in research-based learning on the topic of conduction. Question item number 1 has the highest N-Gain (0.84), which indicates that the concept tested in this question is easier for students to understand after research-based learning. Question item number 2 (N-Gain 0.65) and question number 3 (N-Gain 0.60) have N-Gain in the medium category, which indicates that students' understanding of the concept tested has increased. Question item number 4 (N-Gain 0.72) and question item number 5 (N-Gain 0.73) are in the high category, indicating that the concept tested is quite well understood after the implementation of research-based learning.

Table 5. The N-Gain Analysis for Each Question

Indicators	Item number	N-Gain	Improvement categories
Students are able to explain the basic concept of heat conduction.	1	0.84	High
	2	0.65	Medium
Students are able to analyze the factors that influence the rate of conduction.	3	0.60	Medium
Students are able to compare the rate of conduction in various materials.	4	0.72	High
Students are able to interpret experimental results related to the rate of heat conduction.	5	0.73	High

Research-based learning, in the context of this study, has a positive impact on students' understanding of the topic of heat conduction. One of the main reasons research-based learning is effective is that this approach allows students to be directly involved in the research process, which encourages them to understand concepts more deeply and apply them (Budi et al., 2024; Liu & Li, 2011). In the research-based learning model, students are not only recipients of information but also active researchers. In the context of heat conduction, research-based learning allows students to design experiments, conduct measurements, and directly observe how changes in temperature and material properties affect the rate of conduction (shown in Figure 1). These hands-on activities allow them to see the application of physical laws in real-world situations and clarify concepts they may have previously only understood abstractly (Marcelina & Hartanto, 2021). Active involvement in the learning process allows them to experience moments of enlightenment when abstract concepts become more concrete and meaningful, increasing students' enthusiasm and engagement in learning (Rizaldi & Fatimah, 2023; Parisoto et al., 2014).

The results of this study support the findings of several other studies that demonstrate the importance of research-based learning about student understanding and learning patterns. Brew et al. (2020) found that research-based learning successfully enables teachers to revitalize their usual learning patterns. Ramahwati (2016) found that research-based learning allows students to practice searching, collecting, and processing data, and drawing conclusions, which helps them gain a better understanding. Research conducted by Tungkasamit (2019) also found that through research-based learning, students practice investigating material by finding, proving, collecting, analyzing, and drawing conclusions appropriately based on the collected data. Nursofah et al. (2018) and Daryanes et al. (2023) found that research-based learning can construct students' knowledge through practice through a series of observation and analysis activities.

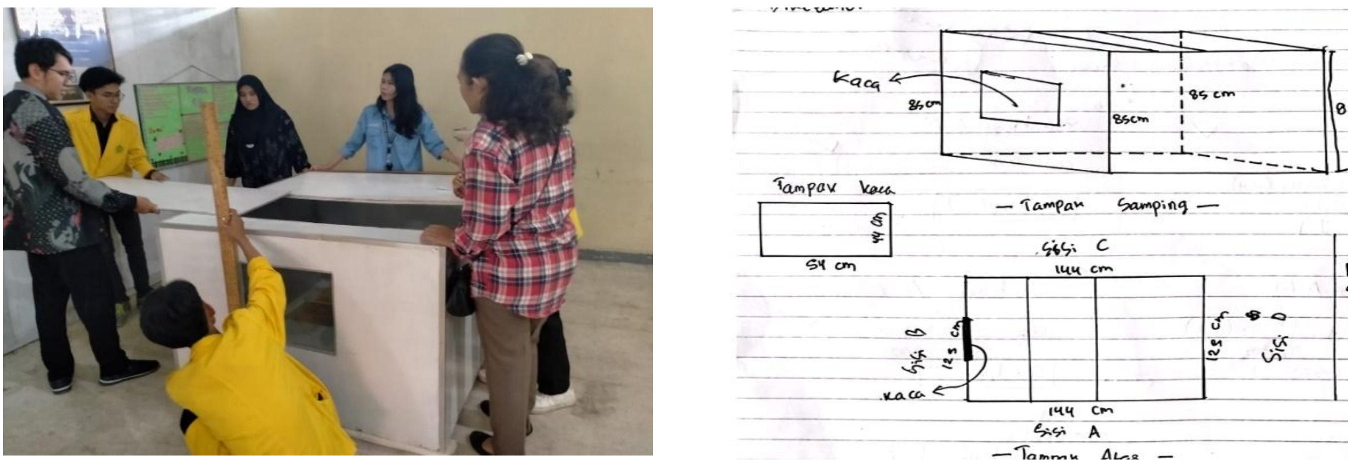

Figure 1. Documentation of student activities and experimental designs in research-based learning

Research-based learning also encourages collaborative work among students. In the project, students work in groups to discuss problem formulation, collect data, and analyze results. This collaborative process not only enriches perspectives as each member can share knowledge and experiences (Arifin et al., 2022) but also trains scientific communication skills (Rattanaprom, 2019), such as the ability to present findings and critically discuss the data obtained. Thus, students not only understand the concept of conduction theoretically but also develop soft skills essential for research and professional practice.

Another interesting note from this study is the change in students' understanding of the implementation of research-based learning, through an analysis of student responses in the pretest and posttest. This comparison provides an overview of the extent to which students have improved in explaining concepts related to conduction. One example is presented in Table 6. The narrative in Table 6 is based on students' written answers on the answer sheet.

Table 6. One Example of a Student's Answer in the Pre-test and Post-test

Indicators	Question	Answers on the pre-test	Answers on the post-test
Students are able to explain the basic concept of heat conduction.	Two objects, a block of wood and a metal plate, are placed in the same room for several hours. When you touch the two objects, the metal feels colder than the wood. Explain the reason for this difference in temperature sensation. Is the metal cooler than the wood? Provide a scientific reason for your answer.	Yes. Metal feels colder than wood because metal has a lower temperature than wood. After all, heat flows from the cold metal to the hand, so the hand feels cold. (Student 03)	No, metal and wood that have been in the room for a long time have the same temperature. However, when touched, metal feels colder than wood. This happens because metal conducts heat faster than wood, or metal has a higher thermal conductivity than wood. When the hand touches the metal, the heat from the hand is immediately absorbed, so the hand loses a lot of heat in a short time and feels cold. In contrast, wood conducts heat more slowly, so the heat from the hand is not transferred much. As a result, the hand still feels warm when touching the wood, even though the temperature of the wood and metal is the same. (Student 03)

Based on the pre-test answers, it appears that, in general, students' initial understanding of conduction is the belief that metal feels colder than wood because metal has a lower temperature than wood. After all, heat flows from the cold metal to the hand, making the hand feel cold. Answers like this were also found in a study conducted by Anam et al. (2020) and Sözbilir (2003). This initial understanding is thought to be due to students' sensory experiences (Resbiantoro & Setiani, 2022), where students rely on tactile sensations without understanding the mechanisms of heat transfer. Furthermore, another cause is an incomplete understanding of conduction (Acar et al., 2010), where students do not understand that metal conducts heat faster than wood, so more heat from the hand is transferred to the metal in a short time.

After intervention through research-based learning, changes in student understanding were observed. For example, students understood that metal and wood in the same room have the same temperature, but metal feels colder because it conducts heat from the hand faster than wood. In other words, metal absorbs heat from the hand more quickly, causing a more intense cold sensation. With the research-based learning, students not only understand the concept of thermal conductivity theoretically but are also able to connect it to everyday experiences and apply scientific methods to test and correct their understanding. This eliminates misconceptions and equips them with better critical thinking skills in understanding physical phenomena (Brew & Saunders, 2020). The results of a study by Usmeldi et al. (2017) argue that the application of research-based learning is an effective way to improve student understanding. Furthermore, research by Narahaubun et al. (2020) discusses improving the quality of learning through research-based learning that provides a good understanding for students.

Another important note from this study is that lecturers play a key role in the success of research-based learning by engaging students in the collection and processing of information. Dobber et al. (2017) stated that the role of lecturers is crucial to the successful implementation of research-based or inquiry-based learning. Although lecturers sometimes provide information through lectures and textbooks are used as sources, there is an emphasis on students learning to find and process these resources themselves. In research-based learning in the classroom, teachers often act more like coaches, guiding students as they develop questions and problems, helping students find, read, sort, and evaluate information, giving students opportunities to draw conclusions, and providing time and opportunities for students to communicate their results. The classroom climate and environment consistently encourage students to express opinions, solve problems, and think at a higher level. Kudryashova et al. (2016) stated that modern teachers must shift their vision of the teacher's role from a transmitter of knowledge to a multi-role educator who can engage students in the process of independently acquiring knowledge and developing skills.

Conclusion

The results of this study indicate that the implementation of research-based learning on the topic of conduction is effective in improving students' understanding. The Shapiro-Wilk normality test confirmed that the pre-test and post-test data were normally distributed. The paired samples test yielded a significance value of 0.000 (<0.05), indicating a significant difference between the pre-test and post-test results. In addition, the N-Gain value of 0.71 is included in the high category, indicating that students experienced a significant increase in conceptual understanding after participating in research-based learning. Thus, research-based learning can be considered an effective approach in supporting students' understanding of the concept of conduction. Based on the process and results of this research-based learning study, the researchers recommend several things. This study still has limitations in measuring the effectiveness of research-based learning without comparing it with other learning methods. Future research is recommended to use an experimental design with a control class implementing a specific learning method. This will allow for a more comprehensive comparison of the effectiveness of research-based learning in improving student understanding. Furthermore, the number of participants in this study was limited, so broader research involving more participants is needed to increase the validity and generalizability of the research findings. Measurement of conceptual understanding only used pre-tests and post-tests in the form of written questions. In addition to written tests, understanding evaluation can be combined with interviews, analysis of student reflective journals, or project-based assignments to obtain a more comprehensive picture.

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Formal analysis, writing—review and editing, G.S.B.; Conceptualization, methodology, investigation, writing—original draft preparation, G.S.B. and T.J.H.; validation, review and editing, F.F., E.T., and M.F.M; supervision, review and editing, G.S.B. and F.F. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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