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Easy, Simple, Lower Cost -Heat Transfer Kit: A Case Study of Implementation and Student Response

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ABSTRAK

Masih rendahnya literasi sains di Indonesia memacu kita untuk mencari solusi bagi peningkatan kualitas pembelajaran sains, salah satunya dengan mendorong pembelajaran berbasis keterampilan sains. Pembelajaran dengan metode praktikum, eksperimen, atau praktek langsung adalah salah satu penanda bahwa pembelajaran tersebut sudah berbasis keterampilan sains. Namun pelaksanaan praktek langsung masih berbenturan dengan ketersediaan peralatan laboratorium yang belum memadai. Penelitian ini memberikan penjelasan tentang alat eksperimen yang sederhana, mudah dibuat dan relative murah untuk mempelajari topik panas dan perpindahannya, khusus pada jenjang sekolah menangah keatas. Pada studi ini diberikan deskripsi pembuatan alat dan penjelasan konseptual secara fisika serta bagaimana partisipasi siswa saat pembelajaran dengan model *Discovery Lerning* berbantuan kit eksperimen perpindahan panas sederhana. Penelitian ini merupakan studi kasus yang menjelaskan partisipasi siswa secara kualitatif berdasarkan observasi dan wawancara non struktural selama proses pembelajaran berlangsung. Hasil dari penelitian ini diperoleh bahwa siswa dapat berpartisipasi secara aktif selama pembelajaran, mulai dari pada saat merakit alat eksperimen, hingga melakukan percobaan secara berkelompok. Siswa dapat mengamati secara langsung proses perpindahan kalor secara konduksi, konveksi dan radiasi. Pengalaman langsung ini mendorong siswa untuk lebih memahami konsep tentang perpindahan panas, yang terlihat dari kelancaran siswa saat menjelaskan hasil percobaan di depan kelas. Media pembelajaran berupa Kit Perpindahan Panas Sederhana, dapat dijadikan alternatif untuk guru dalam menyelenggarakan pembelajaran berbasis pendekatan keterampilan sains, untuk meningkatkan partisipasi siswa dan pemahaman konseptual siswa terutama pada topik perpindahan panas.

Kata kunci: Praktikum; Perpindahan kalor; Discovery learning; Kit eksperimen, Studi kasus.

ABSTRACT

The low level of scientific literacy in Indonesia has prompted efforts to improve the quality of science education, particularly through the promotion of science process skills. Practical activities such as experiments and hands-on investigations are indicators of science skill–based learning. However, their implementation is often limited by the lack of adequate laboratory equipment. This study introduces a simple, low-cost experimental kit designed to facilitate the teaching of heat and its transfer processes, specifically for the senior high school level. The study describes the kit construction, provides conceptual explanations of the underlying physics, and examines student participation during learning activities conducted with the Discovery Learning model. A case study approach was employed, with qualitative data collected through classroom observations and informal interviews. The findings indicate that students actively engaged throughout the learning process, from assembling the kit to conducting group experiments. They were able to directly observe heat transfer phenomena through conduction, convection, and radiation. This hands-on experience enhanced their conceptual understanding, as reflected in their ability to confidently explain experimental results during class discussions. The study concludes that the Simple Heat Transfer Kit can serve as an effective alternative medium for teachers to implement science skill–based learning, thereby improving both student participation and conceptual comprehension, particularly on the topic of heat transfer.

Keywords: Hands on activity, Heat transfer, Discovery learning, Experimental kit, Case study.

INTRODUCTION

Scientific literacy remains a critical challenge in Indonesia, with national and international assessments consistently revealing gaps in students' ability to understand and apply scientific concepts (Kemendikbud, 2019; OECD, 2019). This concern has prompted educational reforms emphasizing the development of science process skills through inquiry-based learning and hands-on investigations (Baroudi & Helder, 2021; Kadir et al., n.d.). Research demonstrates that practical activities, including experiments and laboratory work, are essential indicators of effective science skill-based learning, fostering deeper conceptual understanding and scientific reasoning (Alda et al., 2025; Kabapınar et al., 2025; Lester et al., 2014). However, the implementation of such activities in Indonesian schools is frequently constrained by inadequate laboratory facilities, limited equipment availability, and budget restrictions, particularly in rural and underserved areas (Malik et al., 2020; Risdiyani et al., 2025; Sparrow et al., n.d.).

Recent systematic literature reviews reveal persistent gaps in hands-on science education implementation globally. Despite evidence demonstrating positive impacts of practical work on student motivation and academic success (Oliveira & Bonito, 2023; Yilmaz et al., 2024). Significant barriers continue to prevent widespread adoption of hands-on approaches in physics education. Studies indicate declining interest in physics at secondary levels, with traditional teaching methods failing to engage students effectively (Steidtmann et al., n.d.).Teachers face substantial challenges in implementing laboratory approaches, including insufficient resources, inadequate professional development, and time constraints (Cortes et al., 2024). Furthermore, there exists a considerable evidence-practice gap, where research findings on effective hands-on learning fail to translate into actual classroom implementation (Zhang et al., 2022). This gap is particularly pronounced in developing countries, where systemic factors such as large class sizes, limited infrastructure, and teacher preparation programs inadequately address practical work implementation (Muhamad Dah et al., 2024). The integration of the flipped classroom and PBL models can be applied to materials other than Linear Motion to improve conceptual, procedural, and metacognitive knowledge

Instructional aids will made student easier to understanding and applying physics concepts(Masta & Silaban, 2024). The lack of hands-on activities in physics education represents a multifaceted challenge that extends beyond simple resource limitations. Recent research identifies critical gaps in understanding how to effectively scale successful hands-on programs from pilot implementations to system-wide adoption, particularly in resource-constrained environments (Al-Kamzari & Alias, 2025). Current literature lacks comprehensive frameworks for curriculum integration that address time constraints and standardized testing pressures while maintaining content coverage (Oliveira & Bonito, 2023; Shernoff et al., 2017) . Additionally, insufficient research exists on cost-effective solutions that provide sustainable alternatives to expensive commercial laboratory equipment, limiting accessibility for schools with budget constraints (Cortes et al., 2024; Holland & Davies, 2020). The COVID-19 pandemic further highlighted gaps in maintaining practical learning experiences in diverse educational settings, emphasizing the need for adaptable, low-cost solutions that can function across various implementation contexts (Hoang et al., 2021; Yilmaz et al., 2024).

In this study, we described the simple, easy to assembly and low-cost instructional kit to facilitate student hands on activity in heat transfer topic. We extended our previous study, which report improvement in conceptual understanding and presents good criteria in user responses through learning assisted by easy-simple-lower cost heat transfer (ESL-HT) (Aruan et al., 2024). Subsequently, clearing the conceptual representation of heat transfer in visual diagram and illustration. How student participated during learning process assisted by ESL-HT experiment kit? Through using case study approach. This study focused on qualitative explanation based on non-structured interview and observation data. The explanation study could become guidelines and motivated teachers to facilitated the similar hands on activity in class (Arini & Darmayanti, 2022), particularly in heat transfer topic.

METHODS

1. Research Approach, Participants Time and Location

This study employed a case study design to investigate the application of a simple heat transfer experimental kit in physics learning. The research was conducted at SMA Swasta Pondok Daun, Jakarta, during the even semester of the 2024 academic year, specifically in June 2024.

2. Participants

The implementation took place over two learning sessions within the heat transfer topic, involving 26 students of grade XI Science B.

3. Data Collection

Data were collected through classroom observations, student worksheets, and informal interviews. These instruments were used to capture student participation, conceptual understanding, and classroom dynamics during the implementation of the experimental kit. Triangulation of data sources was applied to ensure the reliability of the findings. The researcher acted as a facilitator and observer, guiding students in using the experimental kit while ensuring that the learning process followed the discovery learning model.

4. Instrument

The instruments used in this study consisted of observation sheets, interview guides, and student worksheets. Observation sheets were designed to record student participation and engagement during the learning process, while interview guides supported the collection of qualitative data regarding student experiences and perceptions. Student worksheets were used to assess students' understanding of heat transfer concepts. In addition, teacher observation sheets were employed to validate classroom implementation and to triangulate data from different sources.

5. Data Analysis

The collected data were analyzed qualitatively using descriptive methods. Observation notes and interview transcripts were coded to identify patterns of student participation and conceptual understanding. Student worksheets were reviewed to evaluate learning outcomes, while teacher observation sheets provided supporting evidence. The integration of these data sources allowed for a comprehensive interpretation of student engagement and learning processes.

6. Learning Stage

The learning process was carried out using the Discovery Learning model, consisting of six stages (Chusni et al., 2020). In the Stimulation stage, students were introduced to open-ended questions about heat transfer to trigger curiosity. During Problem Statement, they identified related issues and formulated hypotheses. In Data Collection, students conducted experiments with the heat transfer kit and gathered supporting information. The results were then analyzed in the Data Processing stage, followed by Verification, where hypotheses were tested against experimental findings and theoretical concepts. Finally, in Generalization, students concluded the principles of conduction, convection, and radiation, which were formulated into general rules applicable to daily phenomena.

RESULTS

The results of this study consisted of two part: kit description and student participation.

A. Kit Description

Kit description consisted the ESL-HT in three part: conduction, convection and radiance heat transfer demonstration learning tools.

1. Simple Heat Conduction Demonstrator

In the conduction experiment using the ESL-HT kit, students first prepared the necessary tools and materials. The mosquito electric repellent device was connected to the power supply to serve as the heat source. A small piece of candle wax was then placed on the iron plate, either at the center or at one end of the plate. After a few minutes of heating, the candle wax gradually melted, indicating the transfer of heat through conduction along the metal plate. The elapsed time from the initial heating to the melting point of the wax was recorded as experimental data. This simple setup provided students with observable and measurable evidence of heat transfer by conduction.

Figure 1 presents the arrangement of heat conduction demonstrator kit. The developed tool was utilized to demonstrate the mechanism of heat transfer through conduction. The tools and materials included scissors, a knife, a ruler, adhesive tape, cardboard, mosquito coil, candle, butter, and an iron plate. The experimental setup for the ESL–HT Heat Transfer Kit was constructed using simple, low-cost materials that are easily accessible for classroom implementation.

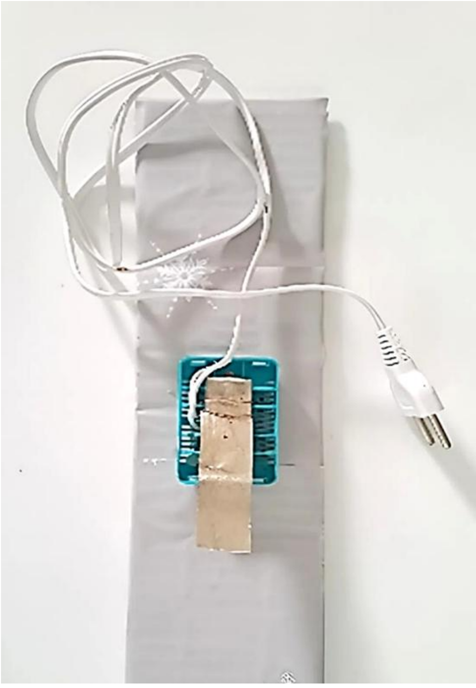

Figure 1. Heat Conduction Demonstration

A similar leraning media, but utilizing a Bunsen burner as the heat source, was previously employed by Bahar et al. Learning natural sciences in the field of physics, especially heat-conducting materials has proven to be effective and its benefits can be seen by participants because they were able to increase their understanding of concepts related to the material provided (Bahar et al., 2024).

2. Simple Convection Tube

In the convection experiment using the ESL-HT kit, students began by preparing the required tools and materials. A candle was first lit inside the convection tube to act as the primary heat source. Subsequently, a mosquito coil was ignited within the same tube to generate smoke. Care was taken to ensure that no openings were present other than the two outlets at the top of the tube, so that the smoke flow was clearly directed. Once the mosquito coil produced sufficient smoke, students observed the movement of the smoke as it rose through the chimney outlets. The visible flow patterns of the smoke provided direct evidence of heat transfer through convection within the tube system.

Figure 2 Simple Convection Tube

Figure 2 presents the arrangement of simple convection tube. The developed tool was utilized to demonstrate the mechanism of heat transfer through convection. The tools and materials consisted of scissors, a knife, a ruler, a match, adhesive tape, glue, candles, mosquito coil, and plasticine. The experimental kit was developed using simple and low-cost materials that were easily accessible for classroom practice.

Similar study, observed heat convection transfer by burning a sheet of paper was previously employed by Alaria et al. The percentage of students' mastery in the convection transfer experiment reached 80% overall, with scores of 78% in the cognitive domain, 85% in the affective domain, and 81.25% in the psychomotor domain (Alaria et al., 2023).

3. Simple Thermoscope

A simple thermoscope was utilized to demonstrate heat transfer through radiation. In the radiation experiment using a simple thermoscope, students first prepared the required apparatus, including a U-tube thermoscope, a stopwatch, and a ruler. The initial alcohol level in both arms of the U-tube was carefully measured and recorded. A lit candle was then placed near the bulb of the thermoscope to provide a source of heat. As the candle burned, students observed the changes in alcohol level within both arms of the tube. Measurements of alcohol height were taken at different time intervals, and the differences between the two arms were systematically recorded in the observation table. The gradual increase in alcohol height demonstrated the effect of radiant heat transfer, as the heated bulb caused expansion and movement of the liquid in the U-tube.

Figure 3 presents the arrangement of simple thermoscope. The tools and materials employed included scissors, a knife, a ruler, matches, adhesive tape, cardboard, glue, candles, black plastic bubble wrap, alcohol, a light bulb, transparent tubing, plasticine, and red synthetic dye. The experimental kit for demonstrating heat transfer mechanisms was constructed using simple, low-cost, and easily accessible materials.

Figure 3 Simple Termoscope

Similar study, observed heat convection transfer by approaching hand in to a light of candle was previously employed by Alaria et al. The radiance heat transfer activity achieving 85% of students reaching mastery. At this stage, the assessment results showed a marked improvement, with cognitive scores increasing to 90%, affective scores to 93.75%, psychomotor performance to 90.75%, and teacher observation results reaching 95.3%The percentage of students' mastery in the convection transfer experiment reached 80% overall, with scores of 78% in the cognitive domain, 85% in the affective domain, and 81.25% in the psychomotor domain (Alaria et al., 2023).

B. Students Participation during Discovery Learning Assisted By ESL-HT Experiment Kit

The classroom implementation of discovery learning using the ESL-HT experimental kit revealed that students were actively engaged in exploring the principles of heat transfer. At the beginning of the session, students were stimulated with open-ended questions and problems that encouraged them to investigate how heat is transferred in daily life phenomena. Guided by these prompts, they formulated problem statements by identifying specific issues, such as why wax melted only at certain points in the conduction experiment, why smoke emerged only from the chimney above the lit candle in the convection tube, and how radiation from a flame influenced the rise of liquid in a simple thermoscope.

Following this stage, students collected data through hands-on experiments with the ESL-HT kit. Figure 4 presents student activity while using conduction heat demonstrator kit. In the conduction activity, they observed how heat from an electric mosquito repellent device was transmitted through a metal plate, leading to the melting of candle. Once assembled, the apparatus was connected to an electrical power source, which supplied energy to the electric mosquito repellent device. The heated device then transferred thermal energy by conduction to the attached metal plate, causing small pieces of wax placed on its surface to melt. This observation confirms that the tool effectively illustrates the principle of heat transfer by conduction in a simple and direct manner.

Figure 4. Students Observed Heat Conduction Phenomena

Figure 5 presents student activity while using convection heat flows through demonstrator kit. In the convection activity, they investigated how heated air currents directed the flow of smoke inside the convection tube. The convection tube was employed to examine heat transfer through convection. The process was visibly indicated by the flow of smoke emerging from the tube's chimney, which occurred as the air inside the tube was heated by the burning candle placed beneath it.

Figure 5 Students observing the flow of heating fluid from simple convection tube

Figure 6 presents student activity while using radiance tranfer mechanism through demonstrator kit. In the radiation activity, they recorded changes in the thermoscope as absorbed heat from the candle flame caused a rise in the liquid column. The process was observed as the glass bulb absorbed heat emitted by the burning candle, leading to a rise in temperature. This temperature increase was indicated by the upward movement of the alcohol level within the tube.


Figure 6 Student Hands on Activity on Radiance Phenomena

All results were documented in student worksheets. The collected data were then processed and analyzed, allowing students to classify observations according to the type of heat transfer and to connect their findings with theoretical concepts.

The collected data were then processed and analyzed, allowing students to classify observations according to the type of heat transfer and to connect their findings with theoretical concepts. Verification of their initial hypotheses showed that conduction requires direct physical contact, convection involves fluid motion driven by temperature gradients, and radiation transfers energy without a medium. Finally, students generalized their findings into broader principles, concluding that the ESL-HT kit provided an effective medium to observe, analyze, and internalize the abstract concepts of conduction, convection, and radiation. This process not only reinforced their conceptual understanding but also highlighted the role of hands-on experimentation in supporting discovery-based learning.

C. Triangulation

The results of this study were obtained through triangulation of data collected from observation, interviews, and documentation. Observation showed that students actively participated in assembling and experimenting with the heat transfer kit, demonstrating enthusiasm and collaborative engagement. Interviews with students confirmed that the direct experience of observing conduction, convection, and radiation improved their conceptual understanding and increased motivation to learn. Documentation in the form of students' reports and experiment records further supported these findings, as students were able to describe heat transfer processes accurately and connect them with real-life examples. The consistency of data across these three sources strengthens the conclusion that the use of the simple heat transfer kit in a Discovery Learning setting effectively enhanced students' participation and conceptual understanding of heat transfer phenomena. Table 1 shows the triangulation table.

Table 1 Triangulation Table

Theme/Claim	Observation (Evidence)	Interview (Evidence)	Documentation (Evidence)	Convergence	Strength	*Notes*
Student participation and collaborative engagement increased	Students actively assembled and experimented with the kit; visible enthusiasm; collaborative work observed	Students said hands-on activity kept them engaged and willing to participate	Reports actively participated during learning activity	Partial	High	Observation strong; documentation silent on participation
Conceptual understanding of conduction, convection, and radiation improved	Students set up and ran experiments demonstrating the three modes (indirect indicator of understanding)	Students reported that directly observing the three modes clarified concepts	Reports accurately described heat transfer processes	Agree	High	Interviews and documentation align; observation is indirect
Overall effect: the ESL-HT kit in Discovery Learning enhanced participation and understanding	Strong evidence of active, collaborative participation	Strong evidence of increased understanding and motivation	Accurate descriptions and real-life connections in student artifacts	Agree	High	Convergent support across sources for core claim

CONCLUSION

This study demonstrated that the use of the ESL-HT experimental kit effectively enhanced students' conceptual understanding of heat transfer mechanisms—conduction, convection, and radiation—through active engagement in discovery learning–based activities. The learning process encouraged students to identify problems, collect and analyze data, verify hypotheses, and formulate general principles, resulting in improved participation and higher-order thinking skills. The quantitative results confirmed that students achieved a high level of mastery, with notable improvements across cognitive, affective, and psychomotor domains, supported by positive teacher observations. These findings indicate that experimental kits integrated into discovery learning not only facilitate deeper comprehension of physics concepts but also foster active learning and scientific inquiry skills.

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