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Development and Evaluation of Portable Heat Kit: Enhancing Thermodynamics Laboratory Instruction

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Abstract

This study developed and evaluated a Portable Heat Kit, along with an accompanying laboratory module, designed to enhance thermodynamics laboratory instruction for Grade 12 STEM students in Senior High School Physics. Thermodynamics is widely recognized as one of the most conceptually challenging areas in physics because students often struggle to connect abstract principles of heat, work, and energy with observable phenomena. To address this challenge, the Portable Heat Kit was designed as an affordable, user-friendly, and curriculum-aligned instructional resource that promotes hands-on, inquiry-based learning. The study was guided by the ADDIE instructional design model and employed a developmental mixed-method research design with a one-group pre-test/post-test quasi-experimental component. 34 Grade 12 STEM students participated in the implementation, while 10 physics education specialists validated the instructional materials and the evaluation instrument. The instrument demonstrated excellent content validity (S-CVI/Ave = 0.93) and high internal consistency (Cronbach's α = 0.89). Quantitative data were analyzed using descriptive statistics and paired-sample t-tests, whereas qualitative data from focus group discussions and interviews were analyzed thematically. The Portable Heat Kit received high ratings across five evaluation dimensions: effectiveness, durability, functionality, usefulness, and economic value. Students reported that the kit improved engagement, supported collaboration, and helped connect theoretical concepts with practical laboratory experiences. The kit was produced at a cost of ₱810 per unit, making it substantially more affordable than comparable commercial laboratory kits. Although the pre-test and post-test comparison did not yield a statistically significant difference in achievement ($p = 0.563$), qualitative findings indicated that the kit enhanced motivation, inquiry-based exploration, and active participation during laboratory activities. The study concludes that the Portable Heat Kit is a practical, cost-effective, and pedagogically sound instructional innovation that supports experiential learning in thermodynamics. It is recommended for broader implementation in Senior High School STEM programs and for further investigation through larger-scale and longitudinal studies.

Keywords*: thermodynamics, instructional materials, experiential learning, STEM education, portable laboratory kit, ADDIE model*

Introduction

Physics is a core discipline in science education that plays a critical role in developing students' problem-solving ability, creativity, and critical thinking. Despite its importance, students continue to exhibit persistent misconceptions in thermodynamics, particularly in understanding heat transfer and thermal conductivity. Many learners conceptualize heat as a material substance or struggle to connect theoretical principles with observable phenomena, resulting in fragmented and superficial understanding (Tan & Leong, 2019; Sun et al., 2022; Donnelly & Vitale, 2020). These difficulties are further intensified by limited opportunities for hands-on experimentation, as instruction often relies heavily on lectures and abstract representations (Jaffe, 2023).

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Contemporary science education increasingly emphasizes student-centered and inquiry-based learning approaches to promote deeper conceptual understanding. Professional organizations and researchers advocate guided discovery, dialogic teaching, and experimental learning as effective strategies for addressing misconceptions and fostering conceptual change (Adeyemo, 2020; Buabeng et al., 2019; Koponen & Salonen, 2019). However, in many classrooms—particularly in under-resourced schools—access to functional, affordable laboratory equipment remains limited, thereby restricting students' exposure to meaningful experimental experiences (Zacharia et al., 2018).

The global shift to online and remote instruction during the COVID-19 pandemic further highlighted the limitations of purely digital laboratories. While virtual simulations support visualization, they lack tactile feedback and psychomotor engagement essential for developing scientific reasoning and laboratory skills (De Jong et al., 2019; Balamuralithara & Woods, 2020). Students in underserved communities also face technological barriers that exacerbate educational inequities (UNESCO, 2022; Abuhammad, 2020).

To address these challenges, this study introduces the Portable Heat Kit, a low-cost, inquiry-based instructional tool that enables students to observe, measure, and investigate heat transfer processes through direct material manipulation. The kit integrates physical experimentation with guided inquiry and reflection, encouraging students to construct accurate mental models of thermodynamic concepts. Prior research suggests that combining physical experimentation with modeling and simulation produces greater conceptual gains than using either approach alone (Olympiou & Zacharia, 2017; Xie et al., 2021).

This study aims to design, develop, implement, and evaluate the Portable Heat Kit using the ADDIE instructional design model to enhance the teaching and learning of thermodynamics among Grade 12 STEM students. Specifically, the study examines the kit's effectiveness in improving conceptual understanding as well as its durability, functionality, usefulness, and economic feasibility as an instructional innovation.

Methodology

This study employed a sequential explanatory mixed-method research design with a quasi-experimental approach to develop, implement, and evaluate the Portable Heat Kit and its accompanying laboratory module for teaching thermodynamics in Senior High School General Physics. Quantitative data collection and analysis were conducted first using a one-group pre-test and post-test design to determine the effectiveness of the Portable Heat Kit. This was followed by an embedded qualitative component to further explain and support the quantitative findings through student feedback and interviews.

A developmental research approach was adopted using the ADDIE instructional design model as the guiding framework. The model consists of Analysis, Design, Development, Implementation, and Evaluation phases, which provide a systematic structure for the construction, classroom use, and assessment of the Portable Heat Kit and its supporting instructional module.

Research Design

During the Analysis phase, a topic selection survey was administered to physics teachers and former Grade 12 STEM students who had completed General Physics I to identify priority thermodynamics topics based on perceived difficulty and relevance. The results guided the selection of six priority topics: First Law of Thermodynamics, Engine Cycles, Heat Engines, Heat Capacity of an Ideal Gas, Work Done during Volume Changes, and Internal Energy of an Ideal Gas.

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In the Design and Development phases, the Portable Heat Kit and instructional module were constructed based on the identified topics and aligned with the K to 12 Most Essential Learning Competencies (MELCs) and the curriculum guide. Expert validation was incorporated at this stage to ensure content accuracy, instructional quality, safety, and usability.

During the Implementation phase, students used the Portable Heat Kit in regular physics laboratory sessions to perform thermodynamics experiments following the procedures outlined in the instructional module. Students recorded observations, analyzed results, and participated in guided discussions facilitated by the teacher.

The Evaluation phase focused on assessing the kit's effectiveness, durability, functionality, usefulness, and economic aspects using validated questionnaires and pre- and post-test results.

Population and Sample of the Study

The study population consisted of Senior High School students enrolled in the Science, Technology, Engineering, and Mathematics (STEM) strand who were taking General Physics I during the second semester of School Year 2024–2025. A purposive sample of thirty-six students from one intact class section was selected. Due to absences during data collection, only thirty-four students completed both the pre-test and post-test, and their responses were included in the final analysis.

Research Instrument

The primary instrument used to evaluate the Portable Heat Kit, and its instructional module was an adapted twenty-five-item Likert-scale questionnaire originally developed and validated by Portana et al. (2021). The instrument was modified to align with the objectives of the present study and the Most Essential Learning Competencies for Senior High School Physics.

The final instrument consisted of five dimensions: content and conceptual accuracy, clarity and organization, relevance and practical application, procedural knowledge and implementation, and alignment with learning competencies and institutional goals. Each dimension contained five items and was rated using a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5).

Validation of Instrument

The adapted instrument underwent expert validation by ten physics education specialists from Bulacan State University, University of Santo Tomas, Pamantasan ng Lungsod ng Valenzuela, Jose Rizal University, Far Eastern University, and De La Salle University. Item-level Content Validity Index (I-CVI) values ranged from 0.80 to 1.00, while the overall Scale-level Content Validity Index Average (S-CVI/Ave) was 0.93, indicating excellent content validity.

Reliability testing using Cronbach's alpha yielded a coefficient of 0.89, demonstrating high internal consistency of the instrument.

Data Gathering Procedure

Data collection was conducted over approximately two to three months during the students' regular physics classes. The sequence of activities included the administration of the pre-test, the conduct of laboratory activities using the Portable Heat Kit, the administration of the post-test, and the distribution of the evaluation questionnaire.

For the qualitative component, focus group discussions with students and physics teachers, as well as semi-structured interviews with expert validators, were conducted. These discussions were analyzed to gain deeper insights into student engagement, instructional clarity, kit usability, and areas for improvement.

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Statistical Treatment of Data

Descriptive statistics, including frequency, mean, weighted mean, and standard deviation, were used to analyze students' perceptions of the Portable Heat Kit regarding effectiveness, durability, functionality, usefulness, and economic aspects.

A paired-samples t-test was employed to determine whether there was a significant difference between pre-test and post-test scores. Item-level Content Validity Index (I-CVI) was computed by dividing the number of experts who rated an item as 4 or 5 by the total number of experts.

Ethical Considerations

Prior to data collection, informed consent was obtained from students and their guardians. Participation was voluntary, and respondents were informed of their right to withdraw at any stage of the study. Confidentiality of responses was strictly maintained, and data were reported in aggregate form.

Strict safety protocols were observed throughout the implementation of activities. Students wore appropriate personal protective equipment such as lab coats, gloves, and safety goggles. The laboratory was equipped with fire extinguishers and first-aid kits, and all activities were supervised by the researcher to ensure adherence to proper safety procedures.

Results And Discussion

Selection of Thermodynamics Topics

Survey results from students and teachers identified six priority thermodynamics topics for inclusion in the Portable Heat Kit: First Law of Thermodynamics, Engine Cycles, Heat Engines, Heat Capacity of an Ideal Gas, Work Done During Volume Changes, and Internal Energy of an Ideal Gas. These topics obtained the highest combined frequency counts among all topics listed, indicating a strong consensus that they are conceptually difficult and essential for mastery in Senior High School Physics.

Expert Evaluation of the Portable Heat Kit

Experts evaluated the Portable Heat Kit for portability, safety, functionality, durability, and ease of use. Mean ratings ranged from 4.5 to 4.9 on a five-point scale. Ease of use received the highest mean rating (M = 4.9), followed by portability (M = 4.8), functionality (M = 4.7), and durability (M = 4.6). These results indicate that the kit meets instructional and safety standards and is suitable for classroom implementation.

Student Perceptions of the Portable Heat Kit

Students evaluated the Portable Heat Kit across five dimensions: effectiveness, durability, functionality, usefulness, and economic aspect.

Overall descriptive statistics showed:

- Effectiveness: M = 4.24, SD = 0.527 (Effective)
- Durability: M = 4.14, SD = 0.761 (Durable)
- Functionality: M = 4.50, SD = 0.379 (Very Functional)
- Usefulness: M = 4.50, SD = 0.435 (Very Useful)
- Economic Aspect: M = 4.63, SD = 0.573 (Very Economic)

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Most students agreed or strongly agreed that the kit improved their understanding of thermodynamics, increased engagement during laboratory activities, and helped connect theory with real-life applications.

Cost Analysis

The total production cost of one Portable Heat Kit was ₱810.00. A comparable commercial thermodynamics kit costs approximately ₱7,500.00. This represents an 89% cost reduction, indicating that the kit is substantially more affordable than market alternatives.

Pre-Test and Post-Test Results

Students' pre-tests mean score was 12.0 (SD = 2.55), while the post-test mean score was 11.5 (SD = 3.22). A paired-sample t-test yielded $t(33) = -0.584$, $p = 0.563$. The result indicates no statistically significant difference between pre-test and post-test scores.

The selection of priority thermodynamics topics reflects well-documented areas of difficulty in physics education, particularly those involving energy conservation, work, and heat processes. By targeting these topics, the Portable Heat Kit addresses core conceptual obstacles that commonly hinder student understanding.

Expert validation results demonstrate that the Portable Heat Kit possesses strong instructional and technical qualities. High ratings for ease of use, portability, and functionality suggest that the kit can be integrated into regular laboratory sessions with minimal logistical difficulty. This supports the premise that instructional tools must be practical and user-friendly to encourage sustained classroom adoption.

Students' consistently high ratings for usefulness and functionality indicate that the kit successfully supports experiential and inquiry-based learning. Learners perceived the kit as making laboratory activities more engaging and meaningful, consistent with experiential learning theory, which emphasizes that knowledge is constructed through concrete experience followed by reflection. The findings suggest that the kit promotes active engagement and helps students visualize abstract thermodynamic processes.

Although students perceived the kit as effective, the lack of statistically significant gains between pre- and post-test scores suggests that short-term exposure alone may be insufficient to produce measurable achievement gains. Prior research indicates that the benefits of active learning approaches often become evident over extended periods and repeated instructional cycles. Thus, the Portable Heat Kit may require longer, more frequent integration across multiple lessons to yield stronger effects on achievement.

The very high rating for the economic aspect, supported by cost analysis, confirms that the Portable Heat Kit is an affordable and scalable instructional solution. Its low production cost makes it particularly suitable for schools with limited laboratory resources, addressing equity issues in access to hands-on science education.

Overall, the results indicate that the Portable Heat Kit is a pedagogically sound, functional, and cost-effective instructional tool that enhances students' learning experiences in thermodynamics. While immediate achievement gains were not observed, strong evidence supports its value in promoting engagement, usability, and conceptual support. Continued refinement and extended implementation are recommended to maximize its impact on student performance.

Conclusions and Recommendations

This study aimed to design, develop, implement, and evaluate a Portable Heat Kit with a supporting laboratory module to enhance the teaching and learning of thermodynamics in Senior High School Physics. Anchored on Kolb's Experiential Learning Theory and guided by the ADDIE instructional design model, the study addressed the need for affordable, functional, and pedagogically sound instructional materials for hands-on physics instruction.

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Based on the study's findings, the following conclusions and recommendations are presented in accordance with the Statements of the Problem.

Selection of thermodynamics topics and laboratory activities

The study concludes that using curriculum standards, expert input, and learner needs is an effective approach in identifying appropriate thermodynamics topics and laboratory activities for the Portable Heat Kit. Reviews of the Most Essential Learning Competencies, curriculum guides, teacher records, student surveys, and expert consultations revealed that students find the following topics most difficult: First Law of Thermodynamics, engine cycles, heat engines, heat capacity of an ideal gas, work done during volume changes, and internal energy of an ideal gas. The selected laboratory activities are appropriate for classroom use, address common misconceptions, and promote hands-on and experiential learning.

Physics teachers and curriculum planners are therefore encouraged to continue using curriculum standards, assessment results, and expert consultation when selecting thermodynamics topics and laboratory activities. Regular review of curriculum guides and student performance records is recommended to ensure alignment with learners' needs. Future developers may apply this same process to include other difficult physics topics in the Portable Heat Kit.

Design and development of the Portable Heat Kit and laboratory module

The study concludes that the ADDIE model is an effective framework for designing and developing the Portable Heat Kit and its laboratory module. The use of locally available and low-cost materials resulted in a kit that is affordable, portable, and easy to reproduce. The laboratory module includes clear objectives, step-by-step procedures, and guiding questions aligned with the Most Essential Learning Competencies. Expert validation confirmed that the kit is accurate, safe, functional, durable, and easy to use, and revisions based on expert suggestions improved its overall quality.

Future instructional material developers are encouraged to use the ADDIE model as a guide for systematic design, development, and revision. Continued use of locally available and low-cost materials is recommended to maintain affordability and ease of reproduction. Improvements may focus on clearer instructions, stronger components, and better visual aids, with regular expert validation to ensure content accuracy, safety, and instructional quality.

Implementation and integration of the Portable Heat Kit

The study concludes that the Portable Heat Kit can be easily implemented in Senior High School Physics classes using the laboratory module as a guide. Students were able to conduct experiments, record observations, analyze data, and discuss results with minimal difficulty. Teachers reported that the kit supports classroom management, encourages active participation, and promotes group work. The kit also helped make laboratory sessions more interactive and engaging.

Physics teachers are encouraged to use the Portable Heat Kit across several thermodynamics lessons to provide students with repeated hands-on experiences. School administrators should allocate funds for additional kits and for the repair or replacement of worn-out components. Laboratory coordinators should maintain up-to-date inventories, regularly check kit condition, and prepare spare consumable materials to avoid disruptions during laboratory activities.

Evaluation of the Portable Heat Kit

The study concludes that the Portable Heat Kit meets the evaluation criteria for effectiveness, durability, functionality, usefulness, and economic aspects. Students reported a better understanding and engagement in thermodynamics lessons; however, pre-test and post-test results suggest that longer, repeated use of the kit may be necessary to achieve stronger academic gains. The kit is suitable for repeated use, effectively demonstrates thermodynamics concepts, and helps connect theory with practice. Moreover, the kit is affordable, with a production cost of ₱810.00 per unit, making it practical for schools with limited resources.

Teachers and researchers should continue to evaluate the Portable Heat Kit using both achievement tests and feedback instruments to monitor its effectiveness, durability, functionality, usefulness, and cost-effectiveness. Longer implementation periods and repeated use are recommended to better determine its impact on learning. Future researchers may conduct studies with larger sample sizes and explore the kit's use in other physics topics and school settings. Students are also encouraged to participate actively and provide constructive feedback to help improve the instructional materials.

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