Applying Problem-Based Learning in Thermodynamics to Enhance Comprehension of Physics Concepts and Argumentation Skills

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Abstract: To effectively teach the complex concept of thermodynamics, appropriate and innovative teaching methods are needed to ensure a correct and in-depth understanding. This study aims to evaluate the application of the Problem-Based Learning (PBL) model in teaching thermodynamics to enhance students' comprehension of concepts and argumentation skills. The research utilized a quasi-experimental design with a pretest-posttest non-equivalent control group. Of the 50 participants, two distinct groups were formed through purposive sampling. A total of 27 participants underwent PBL instruction, while the remaining 23 participants received conventional learning instructions. The results revealed that students who were taught thermodynamics using the PBL model exhibited significant improvement in both conceptual understanding and argumentation skills compared to the control group. These participants displayed high engagement in tackling thermodynamic problems. PBL taught them how to argue comprehensively, emphasizing the cultivation of ‘how to think’ rather than just ‘what to think’ in addressing thermodynamic challenges. Based on these findings, this study recommends that physics educators consider incorporating PBL as a teaching strategy to bolster students' conceptual understanding and argumentation skills in thermodynamics.

INTRODUCTION

The ability of prospective students to think critically emerges when the learning process in the classroom fosters patterns of interaction and communication that prioritize active knowledge formation (Thomas, 2009). Feedback frequency correlates with an enhanced ability of prospective students to comprehend specific physics concepts (Huang & Chuang, 2008). Notably, thermodynamics stands out as a pivotal physics concept to bolster students’ aptitude. However, the intricacy of thermodynamics, laden with several abstract notions, challenges prospective physics teachers in grasping its depth (Nurdyansyah & Fahyun, 2016).

Historically, while human curiosity about the nature of learning has been longstanding, systematic investigations into this phenomenon only emerged in the nineteenth century (Yadav et al., 2011). Various theories surfaced, proposing mechanisms underlying learning. In today's context, the proliferation of knowledge, evolving student profiles, and swift technological advances mandate students to foster self-directed learning, time management, and profound knowledge acquisition. Traditional
methods, rooted in positivist perspectives, often fall short in schools, resulting in students' inability to actualize or apply their knowledge pragmatically. Consequently, the educational sphere has witnessed the emergence and evolution of numerous pedagogical strategies to optimize learning outcomes. Contemporary educational paradigms, influenced by post-positivist and interpretive ideologies, center around constructivist theories. These theories posit students as central to the learning experience, empowering them to actively construct their knowledge base, perceptions, and behaviors, contingent upon their sociocultural milieu (Schmidt et al., 2007). This social constructivist viewpoint asserts that meaning formation is intertwined with an individual's social context, with learning being modulated by culture and language. In educational settings, this perspective manifests through methodologies such as problem-based learning, cooperative learning, project-based learning, situated learning, cognitive apprenticeship, and context-based learning.

A pertinent pedagogical model in this regard is Problem-Based Learning (PBL), recognized for augmenting student engagement, comprehension, and long-term retention (Baran & Sozbilir, 2018). PBL endeavors to galvanize students into constructive actions, facilitating autonomous knowledge construction.

Existing research underscores the efficacy of PBL in elucidating diverse physics concepts, including solids (Shahsavar et al., 2020), pressure (Gurses et al., 2015), Newtonian mechanics (Celik et al., 2011), gases (Caserta et al., 2021), electricity (Ryberg, 2013), and properties such as absorption, surface tension, viscosity, and conductivity (Huilgol, 2021). Such investigations illuminate PBL's potency in rectifying misconceptions, fostering positive scientific dispositions, and enhancing cognitive skills, including problem-solving and creativity. Drawing from this empirical foundation, it becomes evident that PBL is instrumental in fortifying comprehension across multiple physics domains. Consequently, this study aims to evaluate the efficacy of PBL in thermodynamics instruction for prospective students, with a focus on enhancing their understanding of physics concepts and fostering robust scientific argumentation.

THEORETICAL SUPPORT

Theoretical Problem-Based Learning (PBL)

Research on various learning models has been extensively conducted, shedding light on invaluable insights for the educational landscape. The dawn of 21st-century education highlights the nexus between learning and the multifaceted challenges of the real world. Such a learning paradigm emphasizes harnessing individual intelligence, whether in isolation or within group dynamics, to grapple with relevant, contextual, and significant challenges. In this landscape, students, the primary stakeholders, are propelled to immerse themselves in these problems, navigating and devising solutions that resonate with their daily experiences. Problem-Based Learning (PBL) emerges as a highly pertinent learning model in this context. PBL is characterized as an instructional approach wherein problems form the central focus, aiming to enhance problem-solving capabilities, subject knowledge, and self-regulated learning (Hmelo-Silver, 2004). As delineated by Wahyu & Prasetyo (2021), PBL encompasses three distinct traits. Firstly, the instructional trajectory commences with a problem, anchoring problem resolution as the fulcrum of the learning experience. Secondly, students bear the onus of crafting strategies and orchestrating solutions that resonate with their daily experiences. Problem-Based Learning (PBL) emerges as a highly pertinent learning model in this context.
information dispensers but as facilitators. They scaffold the learning journey, probing with thought-provoking questions and proffering pedagogical support as students embark on their problem-solving odyssey. Such attributes necessitate astute pedagogical skills and judicious planning, ensuring that the instructional endeavor is both effective and impactful.

**Conceptual Understanding**

Understanding concepts is a cornerstone of learning objectives, especially in disciplines such as physics. The essence of understanding extends beyond the rote memorization of content; it emphasizes the ability to interpret and internalize the core ideas and principles. In their study, Tatar & Oktay (2011) found that conceptual learning proves more substantial than merely quantitative learning when it comes to fostering a genuine understanding of student concepts. Therefore, educational experiences should prioritize meaningful learning, ensuring students delve deeper into concepts rather than scratching the surface.

Tatar & Oktay (2011) also highlighted the utility of concept maps as a nuanced evaluation tool to assess such meaningful learning. Concept maps are underpinned by four foundational aspects: propositions, hierarchy, cross-links, and illustrative examples. A proposition, as delineated by Shephard (2012), is a unit that binds multiple concepts, presenting statements about objects or events. This can be viewed as the nexus of meaning within the map, elucidating how various concepts interrelate. In the context of this research, the proficiency of prospective students in understanding physics concepts will be gauged through their capability to construct coherent and insightful concept maps.

**Scientific Argumentation Skills**

Scientific argumentation can be conceptualized as the validation or refutation of ideas based on reasoned assertions that echo knowledge, methodologies, and intrinsic values (Simon et al., 2006). It encompasses the formulation and endorsement of explanations pertaining to scientific phenomena. As proposed by Setyani et al. (2021), arguments strive to authenticate conclusions that counter specific claims, acting as foundational premises.

Classroom activities within the sciences often act as catalysts, enabling the genesis of these arguments. Activities commonly involve questioning, model development and utilization, data interpretation, and the application of evidence and rational justifications (Aydin, 2014). This pedagogical trajectory stimulates students to forge and evaluate arguments, integrating claims, evidence, and reasoning. Here, claims articulate statements or deductions. In contrast, evidence constitutes empirical data buttressing these claims, with reasoning weaving in pertinent scientific principles to bolster claims via relevant evidence (Marx et al., 2004). To ascertain the robustness of these arguments, researchers employ scientific concepts, critically evaluating the claims, evidence, and the underlying rationale (Marx et al., 2004). Open-ended queries frequently serve as tools to gauge the depth and quality of scientific arguments (Simon et al., 2006). In the context of this study, post the learning engagement, the researchers leverage an inventive framework to assess prospective students' prowess in scientific argumentation.

Within physics education, myriad studies employing the PBL learning model have been orchestrated across various topics. Prominent among these are solids, pressure, Newtonian mechanics, gases, motion and force, electricity, absorption, surface tension, viscosity, and conductivity (Tatar & Oktay, 2011). This burgeoning interest among scholars underscores the allure and relevance of
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the PBL model. However, a conspicuous lacuna exists in its application to thermodynamics — an area intrinsically intertwined with daily life experiences. This study, therefore, embarks on a journey to discern the efficacy of PBL in amplifying the comprehension of physics concepts and nurturing the scientific argumentative skills of its candidates.

METHOD
Research Design

This research employs a Quasi-Experimental method, specifically utilizing a Non-Equivalent Control Group Pretest-Posttest design. Within this framework, participants are bifurcated into two distinct groups: the experimental group, which engages in learning via the Problem-Based Learning (PBL) model, and the control group, which presumably uses traditional teaching methods.

Prior to the introduction of the PBL model, both cohorts undergo a pre-test. This initial assessment is designed to gauge their foundational understanding of physics concepts and their proficiency in scientific argumentation, particularly in relation to thermodynamics. Subsequent to the conclusion of the thermodynamics lecture sessions, a post-test is administered to all participants. This serves to measure the comparative efficacy of the PBL model by examining the extent of knowledge acquisition and skills development in both groups, thereby providing insights into the effectiveness of this pedagogical approach.

Participants

The participants of this study comprised 50 students enrolled in the Physics Education Study Program at the Institut Pendidikan Indonesia. Selection of these participants was executed using the Purposive Sampling Method, a technique that prioritizes the alignment of participants with specific research objectives. Consequently, twenty students were earmarked as the experimental group, receiving instruction via the Problem-Based Learning (PBL) model. In contrast, the remaining twenty students constituted the control group, experiencing a more traditional, direct learning approach. Notably, all participants were engaged in their fourth semester of the program and were concurrently enrolled in the thermodynamics course.

Research Instrument

In this study, the researchers developed three research instruments. The first instrument assesses the understanding of physics concepts in the context of thermodynamics. This instrument employs a concept map to measure understanding. For this purpose, researchers assembled a series of concepts (15-20 concepts) pertinent to thermodynamics. These concepts are presented to students, who are then tasked with constructing a concept map. The validity and reliability of this instrument are confirmed through evaluations by two experts in the field of physics. The second instrument measures scientific argumentation skills. It was devised in the form of five open-ended questions, encompassing all concepts of thermodynamics taught. Similar to the first instrument, this tool’s validity was affirmed by a physics lecturer. The third instrument evaluates students’ perceptions of the Project-Based Learning (PBL) model’s application in thermodynamics lectures.

Before embarking on the PBL approach (experimental group), students are introduced to PBL and its stages through presentations and videos. They will engage with the PBL model over four sessions, each lasting 100 minutes. Topics to be covered include the thermodynamic system (types of systems, system boundaries, surroundings), heat or temperature, energy conservation (energy conversion and degradation), and atomic
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energy concepts (energy conservation, internal energy, macro and micro energy). The PBL process in each problem scenario consists of six steps: encountering the problem, planning the learning, data collection, formulating a solution, presentation, and assessment.

**Data Collection and Analysis**

Three types of data will be collected in this research: scores for understanding the concept, scores for scientific argumentation skills, and interview transcripts. Scores for understanding physics concepts are derived from both pre-test and post-test results, using the concept map test instrument. These scores are determined by comparing the students’ concept maps with the standard concept maps developed by the researchers, based on specific rubrics. Subsequently, these scores are standardized to a scale of 0-100.

Similarly, the scores for scientific argumentation skills are acquired from both pre-test and post-test results, utilizing instruments designed to assess these skills. The scoring process, standardized to a 0-100 scale, involves comparing students’ answers against rubrics developed by the researchers. The analysis of scores from both understanding of concepts and scientific argumentation skills is conducted in two ways: the T-Test and Normalized Gain (N-Gain). The T-Test is used to evaluate the differences in average scores between the experimental and control groups. In contrast, N-Gain assesses the effectiveness of the learning process by comparing the performance of the experimental group to the control group.

**RESULT AND DISCUSSION**

The study collected data from a total of 50 students, split into two groups: 27 students in the experimental class and 23 students in the control class. Both classes underwent a pre-test and post-test. The results are presented in Table 1.

<table>
<thead>
<tr>
<th>Information</th>
<th>Experiment Class</th>
<th>Control Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>Total students</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Ideal Score</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>The Highest Value</td>
<td>1.52</td>
<td>3.72</td>
</tr>
<tr>
<td>The Lowest Value</td>
<td>0.52</td>
<td>2.43</td>
</tr>
<tr>
<td>Average</td>
<td>0.83</td>
<td>2.38</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.34</td>
<td>0.69</td>
</tr>
<tr>
<td>Average Score Percentage of Ideal Score</td>
<td><strong>16.08%</strong></td>
<td><strong>65.47%</strong></td>
</tr>
</tbody>
</table>

The analysis results from the research are as follows: Based on the normality test of the pre-test data for the experimental class, L max is found to be 0.1453, which is less than the L table value of 0.1601. For the control class, L max is 0.1776, which is also less than the L table value of 0.1830. Both cases indicate that the data distribution is normal. In analyzing the pre-test results, we used the t-test to determine the difference in initial abilities between the two classes, as their data variances are homogeneous. The calculated t-value is 0.3902, which is less than the t table value of 2.3426. This means there is no significant difference in the initial abilities between students who were taught using the Problem Based Learning model and those taught with the conventional model. Additionally, for the post-test normality test of the experimental class, the L max value is 0.1143, which is less than the L table value of 0.1546. For the control class, L max is 0.1417, which is less than the L table value of 0.1847, confirming that the data distribution for both is normal.
Table 2. Percentage of N-Gain.

<table>
<thead>
<tr>
<th>No</th>
<th>Category</th>
<th>Experimental Class</th>
<th>Control Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Students</td>
<td>Percentage</td>
</tr>
<tr>
<td>1</td>
<td>High</td>
<td>7</td>
<td>26.00</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>20</td>
<td>74.00</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Amount</td>
<td>27</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Based on Table 2, it can be concluded that the experimental class experienced an increase in students' argumentation skills at a moderate level, as evidenced by the average N-gain value. In contrast, the control class experienced a slight increase in the quality of scientific argumentation skills, which was reflected in the average N-gain value.

Table 3. Results of Students' Scientific Argumentation Skills.

<table>
<thead>
<tr>
<th>No</th>
<th>Indicator</th>
<th>Experimental Class</th>
<th>Control Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% Category</td>
<td>% Category</td>
</tr>
<tr>
<td>1</td>
<td>Interpretation</td>
<td>87.50 High</td>
<td>73.96 High</td>
</tr>
<tr>
<td>2</td>
<td>Analysis</td>
<td>91.60 High</td>
<td>35.42 Medium</td>
</tr>
<tr>
<td>3</td>
<td>Evaluation</td>
<td>71.60 High</td>
<td>53.13 Medium</td>
</tr>
<tr>
<td>4</td>
<td>Inference</td>
<td>68.30 High</td>
<td>30.21 Low</td>
</tr>
<tr>
<td>5</td>
<td>Explanation</td>
<td>45.00 Medium</td>
<td>21.88 Low</td>
</tr>
<tr>
<td>6</td>
<td>Self Regulation</td>
<td>22.50 Low</td>
<td>21.88 Low</td>
</tr>
</tbody>
</table>

The students in the experimental class have achieved high-level argumentation skills in the areas of interpretation, analysis, evaluation, and inference. For the explanation indicators, they have nearly attained medium-level argumentation skills. However, in the self-regulation indicators, they have not yet reached a satisfactory level of argumentation skills, remaining in the low category.

In the control class, the percentage results for students' argumentation skills across six indicators are as follows: interpretation is at a high category with 73.96%, analysis and evaluation are at a medium category with 35.42% and 53.13% respectively. Meanwhile, inference, explanation, and self-regulation are in the low category, with percentages of 30.21%, 21.88%, and 21.88%, respectively. Consequently, we can deduce that students in the control class have achieved high-category argumentation skills in interpretation. For the analysis and evaluation indicators, students are nearing medium-category skills. However, for the inference, explanation, and self-regulation indicators, students have not yet reached satisfactory argumentation skills, falling into the low category.

During the course of the lessons, students generally preferred studying individually. In the initial meeting, the learning process unfolded as usual. This included presenting material designed to enhance their argumentation skills. Students were posed with problems, and these were demonstrated both through simple media and video presentations. After presenting the material, the researcher provided practice questions. Students were tasked with solving these, writing their answers on the blackboard, and then explaining their thought process to their peers.

The subsequent lesson employed the Problem-Based Learning model. Here, students engaged in group learning. Once groups were formed, the instructor provided Student Worksheets (LKPD) for group activities. Before embarking on the LKPD tasks, the instructor posed a problem rooted in...
real-life scenarios to be addressed during the lesson.

However, there were challenges during the instructional process. A pressing concern was the limited time available. Additionally, the students' waning interest in physics made the application of the learning methods challenging. On the brighter side, when the classroom environment was conducive, students were more receptive, participated actively, and were easily guided through the learning journey (Ismail et al., 2018; Sutrisno et al., 2020).

The learning process in the conventional or control class began with an initial test (pre-test). This was followed by the core learning phase, which took place over three sessions and progressed without issues. Upon completion of the lessons, students were given a final test (post-test). Throughout the learning sessions, students typically worked individually. From the first to the third meeting, the learning process proceeded as usual. Instructional materials were provided to hone the students' argumentation skills. These materials presented problems through demonstrations using simple mediums like broadcasts or interactive video lectures. After the presentation of the material, the researcher gave the students practice questions. They were required to solve these, write their answers on the blackboard, and then elucidate their thought process to the class.

However, the process wasn't without its challenges. A notable issue was that some students displayed a diminished interest in learning physics. Nevertheless, it was observed that with a conducive classroom environment, students could effectively engage in and be smoothly guided through the learning process (Nurdiansyah & Amalia, 2018; Park & Ertmer, 2007).

The Problem-Based Learning (PBL) model exhibits significant differences when compared to the conventional learning model. This distinction is evident from the average scores obtained by students in the post-test: the experimental class recorded an average score of 2.38, while the control class posted an average of 1.60. The outcomes derived from six indicators of student argumentation skills in both classes showed variations in percentages and categories. Among these six indicators, two – the interpretation indicator (high category) and the self-regulation indicator (low category) – were consistent across both classes. This data suggests a shift in understanding after implementing PBL across three topics: conservative energy, thermodynamics, and heat laws.

Upon integrating PBL into the primary subjects of conservative energy and heat transfer, an enhancement in comprehension was noted. In the domain of conservative energy, 76% of students grasped the first law of thermodynamics - the principle of energy conservation - as it pertains to both closed and open systems. It is universally acknowledged that energy remains conserved; no known process contravenes the first law of thermodynamics. Thus, any occurring process must inherently adhere to this law. For instance, a hot coffee cup placed in a cooler room will inevitably lose heat. Such an event aligns with the first law of thermodynamics since the energy the coffee relinquishes is equivalently absorbed by the surrounding air.

Furthermore, 70% of students demonstrated a clear understanding of heat-related content. They recognized that energy could traverse the boundary of a closed system in two distinct ways: as heat and work. Practical experiences, such as observing a cold soda can warming up when left on a table or a hot
baked potato cooling down, reinforce this concept. When an object with a certain temperature is situated within a different ambient temperature, energy exchange ensues between the object and its surroundings until thermal equilibrium is attained, i.e., until they both equilibrate at a shared temperature. This energy transition always proceeds from the hotter entity to the cooler one. Once temperature parity is achieved, this energy transition ceases. This energy exchange is identifiable as heat transfer. Heat is delineated as the energy variant transferred between two systems (or a system and its environment) due to a temperature differential. It is crucial to note that heat transfer can only materialize due to a temperature disparity; therefore, two systems at identical temperatures cannot engage in heat exchange.

The adaptation of the Problem-Based Learning (PBL) paradigm should be contingent upon the learners' developmental stages (Haatainen & Aksela, 2021; Raha yu & Suana, 2022). Investigating the nuances of these adaptations and the means by which PBL components can be scaffolded for diverse learners are pivotal research areas. Moreover, 'just-in-time' direct instruction could be beneficial; a timely lecture might assist students grappling with specific issues that necessitate distinct informational inputs. As Bransford et al. (2015) posited, PBL can foster a "time for telling". However, integrating this into a student-centric learning environment remains a challenge. There is an imperative need for evidence elucidating which PBL components are vital for specific outcomes, guiding educators in tailoring PBL to their unique contexts.

One significant barrier to the wider adoption of PBL is the scarcity of adept facilitators. Given that facilitating a larger group of students is challenging (Park & Ertmer, 2007), strategies such as procedural facilitation, scripted collaboration, and structured journaling might be instrumental in tailoring PBL to various contexts. Adjustments in the PBL activity framework may also be made to tailor PBL for specific instructional goals. Technology's role in customizing PBL for specific courses is also significant.

Incorporating the PBL model within a thermodynamics course offers the potential for enhanced understanding of physics concepts and the bolstering of scientific argumentation, though it does come with its set of challenges. These encompass the potential lack of foundational knowledge in thermodynamics among some students, which necessitates either pre-assessments or the provision of supplemental resources, given the engagement-centric nature of PBL. Furthermore, the approach demands significant time allocations for deep problem-solving and dialogues, which, in the face of curriculum limitations, calls for strategic time management. The success of PBL also heavily rests on the facilitator's adeptness in guiding discussions and promoting critical thought, highlighting the need for specialized faculty training. Additionally, the assessment within PBL environments is nuanced, with traditional examination methods often falling short in grasping the entirety of students' understanding, urging the adoption of aligned assessment tools like rubrics and group projects. Lastly, given the collaborative essence of PBL, potential complications in group dynamics, such as unequal participation or conflicts, require educators to proactively provide guidance, establish clear expectations, and monitor group interactions to ensure a fruitful learning environment (Baran & Sozbilir, 2018;
Haatainen & Aksela, 2021; Kamil et al., 2019).

This study presents several limitations. Firstly, the sample size might not accurately represent the broader population, which could constrain the generalizability of the results. Moreover, the use of self-reported data introduces potential biases that might affect the study's accuracy. It's also worth noting that findings specific to a thermodynamics course may not be universally applicable across different subjects. Furthermore, the success of PBL is strongly influenced by the facilitator's expertise.

For subsequent studies, it would be advantageous to utilize a larger and more diverse sample to enhance result generalizability. Undertaking longitudinal research could shed light on the enduring impacts of PBL. It would also be beneficial to assess PBL's efficacy across a variety of academic disciplines and explore how technological integration might augment the PBL experience. Delving into group dynamics and considering alternative assessment techniques within the PBL framework would further enrich our understanding.

CONCLUSION
The implementation of the Problem-Based Learning (PBL) model in a thermodynamics course yielded notable differences in student performance compared to the conventional learning method. Specifically, students in the experimental class demonstrated higher levels of argumentation skills across various indicators, with particular strengths in interpretation and notable deficiencies in self-regulation. This effectiveness, however, was tempered by challenges such as time constraints, students' waning interest in physics, and the necessity of a conducive learning environment. On the other hand, the control class, relying on traditional teaching methods, revealed less consistency in argumentation skills across different indicators. The success of PBL in enhancing comprehension was particularly evident when applied to topics like conservative energy and heat laws, with students showcasing an improved grasp of complex thermodynamic principles. However, the successful adaptation of the PBL paradigm largely hinges on various factors, including facilitator proficiency, effective group dynamics, and alignment with students' developmental stages. The study's limitations, such as potential biases from self-reported data and questions of generalizability, underline the need for more expansive future research. This research should delve deeper into the nuances of PBL across various disciplines, the integration of technology, and alternative assessment techniques to fully capture its educational potential.

ACKNOWLEDGMENT
The authors wish to express gratitude to the Ministry of Education, Culture, Research, and Technology for providing the grant and to the Institut Pendidikan Indonesia for supplying the essential facilities during the research and manuscript preparation process.

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