

Enhancing Students' Critical Thinking in Thermodynamics through Long Bumbung Local Wisdom-Based Physics Comics

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ABSTRACT

This study aims to develop and assess the impact of the Long Bumbung comic, based on local wisdom, in enhancing critical thinking skills in thermodynamics. The research used a quasi-experimental method with 120 students across six eleventh-grade classes of SMA Sahabatqu Yogyakarta. The researchers randomly selected two classes of 60 students each for the intervention. The research employed the R&D method with the 4D model. The results showed that the Long Bumbung comic was highly feasible, with positive feedback from experts on its material, learning, and language aspects. Critical thinking skills improved more in the experimental group, with an N-gain of 0.64 compared to 0.53 in the control group. Student interest was notably high, with 83.33% expressing enthusiasm for the comic. This finding underscores the comic's effectiveness and appeal as a culturally relevant educational tool, enhancing critical thinking and engagement.

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INTRODUCTION

Critical thinking skills assist students in expressing opinions to solve various problems systematically. The ability to think critically as an indicator of the higher-order thinking skill, is essential for students when it comes to problem-solving (Sayekti et al., 2019). To improve critical thinking skills, students can be trained by starting to read critically, observing critically, and giving examples to provoke questions (Setiawati & Senam, 2018).

Critical thinking is a vital skill in the learning process, as it influences a student's ability to engage actively and understand complex material. However, the current educational practices often fail to foster this skill effectively, leading to a significant variation in students' critical thinking abilities and, consequently, their academic

performance. Research indicates that students' engagement in asking questions, problem-solving, and providing justifications is generally low, reflecting their limited critical thinking abilities (Nasihah et al., 2018).

This gap in critical thinking is further supported by (Wiyoko, 2019), who states that many students still exhibit low levels of critical thinking. The disparity in critical thinking skills among students results in varying levels of activity and understanding during the learning process (Suana et al., 2019). There is a direct correlation between students' critical thinking abilities and their comprehension of material concepts. Students with higher critical thinking skills tend to better understand and master the subject matter. School institutions also need to equip students in the learning process to

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develop thinking skills, such as critical thinking, decision-making, and problem-solving. Despite this, educators often neglect the importance of nurturing critical thinking skills in their teaching methodologies.

The application of inappropriate learning media will make learning less meaningful. So, there is a need for innovations in the learning process that can involve students directly in learning. This innovation can be in the form of learning media developed by teachers by looking at the school situation and students' abilities (Nisrina et al., 2017). Learning media can also be developed by empowering local culture or utilizing the latest technology (Fani & Tranggono, 2023). To compete in the era of the industrial revolution, Indonesia must improve the capabilities and skills of its human resources through education (Sunarno, 2018). This effort can be supported by utilizing technological advances developed in the Industrial Revolution 4.0 to improve the quality of education so that lessons are not only given during class hours but also provide opportunities for students to study outside school hours (Nisa et al., 2018). The thinking intelligence of students is also required to be developed as widely as possible to deal with technological developments in the world of education to be able to survive in the era of the Industrial Revolution 4.0 (Ennis, 2018). In addition, the development of the world requires a person to develop his knowledge capacity. However, educators more often apply mathematical thinking patterns than deep concepts in teaching and learning activities (Erlangga et al., 2021). This issue makes it difficult for students to understand physics (Saifullah & Wartono, 2016).

Several things make it difficult for students to understand physics, one of which is less contextual physics learning (Saifullah & Wartono, 2016), so physics material is less related to students' daily lives (Sa'diah et al., 2021). The questionnaire results revealed that 55% of students reported that teachers rarely linked physics learning with local

wisdom. As a result, students struggled to grasp abstract physics concepts. The nature of physics is inherently connected to daily life (Artiawati et al., 2018). To make physics more relevant to students' everyday experiences, contextual learning should be applied (Erlangga & Saputro, 2018). Therefore, incorporating local wisdom into learning as contextual education is essential.

In Yogyakarta, Central Java, and its surroundings, bamboo cannons are commonly known as "*Bumbung*." In other places, this game is known by the names of bamboo guns, bamboo firecrackers, and others (Ramadhan et al., 2019). Furthermore, this Long Bumbung game is usually played by boys when commemorating religious/traditional holidays and enlivening the month of Ramadan (fasting) ahead of the holiday. The game is rarely found in the surrounding environment due to the emergence of many modern games that have replaced local games. The explosion process produced by Long Bumbung can be closely related to the concepts of physics, including thermodynamics. The workings of the Long Bumbung are shown in Figure 1.

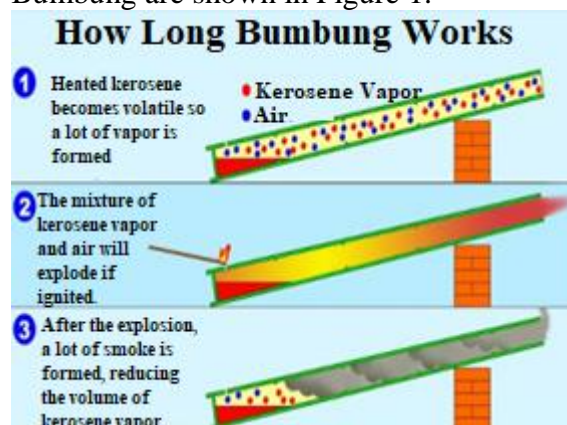


Figure 1. How the Long Bumbung Works

Figure 1 explains the working mechanism of a Long Bumbung (bamboo cannon) in three main steps, which can be related to the principles of thermodynamics. First, when heated, kerosene vaporizes inside the bamboo cannon, forming a mixture of kerosene vapor and air. According to the first law of thermodynamics, which deals with energy conservation, the heat energy

supplied is converted into the internal energy of the vapor mixture. Second, the mixture of kerosene vapor and air will explode when ignited, demonstrating the second law of thermodynamics, which states that energy transfer increases the entropy of an isolated system. The rapid combustion generates a significant amount of energy, causing an explosive reaction. Third, after the explosion, a large amount of smoke is produced, reducing the volume of kerosene vapor inside the bamboo cannon. This process illustrates the third law of thermodynamics, where the system approaches a state of equilibrium as the energy is dissipated in the form of heat and sound, and the cannon returns to a lower energy state filled with smoke.

Learning media that incorporate technology positively influence students by offering more varied and personalized learning schedules, accommodating different learning styles, and enhancing overall learning effectiveness (Keller et al., 2017). Integrating technology into education can create engaging and enjoyable learning environments, yet many educators remain unaware of how to fully utilize this potential (Nuwairah et al., 2018). Despite the rapid advancement of information technology, its use in education still lags behind, as teachers often underutilize it as a learning tool (Valtonen et al., 2017). To maximize the learning process, especially in physics, it is essential to adopt technology-driven media. For instance, physics comics combine compelling narratives with visualizations of physics concepts, enabling students to grasp the material more effectively while enjoying the learning experience (Oliinyk, 2021).

Comics have certain advantages when applied to physics learning. Comics contribute to students' enjoyment of science in sound material (Kim et al., 2017). Physics comics show good achievement in helping students understand physics concepts (Aeni & Yusupa, 2018). This shows a positive value, that comics can be a suitable medium for learning physics. Using physics comics by looking at the conditions of students and

schools provides a better value for maximizing learning (Putri & Ananda, 2020). The condition of the school or students can be seen according to the local culture of each region. Local culture or local wisdom can make learning media more contextual to apply (Sa'diah et al., 2021). However, in its development, comics are rarely integrated into physics learning.

Previous studies on the development of physics comics have primarily focused on improving problem-solving abilities (Annisa et al., 2020), observational skills (identifying and defining) (Husna et al., 2024), creative thinking (Sari et al., 2020), mathematical representation ability and creative thinking (Permata et al., 2020), and critical thinking ability (Rosdiana & Kholiq, 2021), however, to the best of the researcher's knowledge, no research discusses the development of physics comics based on Long Bambung local wisdom to improve student's critical thinking ability on thermodynamic material.

This study aims to develop and assess the impact of local wisdom-based Long Bambung comics on improving thermodynamic critical thinking skills. Integrating local wisdom into educational comics not only fills a void in the literature but also offers a culturally relevant approach that can encourage deeper engagement and more effective development of critical thinking.

METHODS

This research is development research to produce learning media in the form of local wisdom-based physics comics. It focuses on using the long tube concept in the context of sound material, aiming to increase students' critical thinking skills. This study uses an experimental research method with a quasi-experimental design in a quantitative research approach.

The instruments used were adjusted to the indicators of critical thinking, namely basic clarification, giving reasons for a decision, concluding, further clarification, and conjecture and coherence to measure the

impact of using the physics comic media. The design used in this study was a non-equivalent posttest control group design (Sugiyono, 2019). This research was conducted at Sahabatqu Yogyakarta Senior High School in the odd semester of 2020/2021. The product was developed using the 4D (Figure 2) model, which includes Define, Design, Develop, and Disseminate (Sugiyono, 2019).

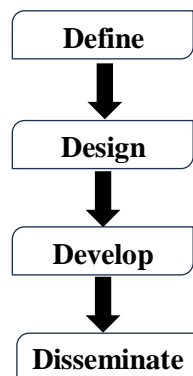


Figure 2. 4-D Procedures

The population in this study were all eleventh-grade students at SMA Sahabatqu Yogyakarta, which consisted of six classes with 120 students. The sampling was carried out randomly. The experimental class 1 (class XI MIPA 2) was taught using a problem-based learning model, while the experimental class 2 (class XI MIPA 1) was taught using a direct learning model. The instruments used in this study consisted of lesson plans, student worksheets, learning model implementation sheets, and student learning activity sheets.

A validator first validated the instruments used by researchers in conducting research. First, the content validity was carried out. Inferential statistical analysis was used to test the truth of the proposed hypothesis. Before carrying out inferential analysis, prerequisite test analyses were carried out, including normality tests and data homogeneity tests, with the help of the SPSS program. If the prerequisite test meets normal and homogeneous criteria, then parametric statistics are used for inferential analysis; if it does not meet normal and homogeneous

criteria, then nonparametric statistics will be used (Suharsimi, 2018).

RESULTS AND DISCUSSION

Product Development

The interview process revealed that students had difficulty understanding physics material. Some students did not understand the material well before entering practicum activities (Rohanah et al., 2019). In addition, the use of PowerPoint and computer-based practicum tools showed the use of technology in learning. The smartphone display was not optimal.

The process of identifying the concept of physics was carried out on the phenomenon of the Long Buntung local wisdom. The process of determining the material was also carried out by analyzing the concepts of physics according to the problem of research variables to achieve the suitability of cases or storylines in physics comic media related to achieving learning objectives. Comics are arranged to include characters that support the reader's interest (Aeni & Yusupa, 2018). Character aspects applied in comics are culture, humor, and Smartbots.

Physics comics present examples of physics problems and their discussion. Example questions are made so that students can immediately get an idea of the application of the concept of sound to the problem (Hanson et al., 2017) so that they have information that can strengthen the concepts of physics they get from reading comics. Product validation was done to assess research instruments, such as questions and lesson plans. The validity of the physics comic, problem instruments, and lesson plans was evaluated by media experts, physics teachers, and expert peer reviewers. The results of the validation assessment of physics comic media, problem instruments, and lesson plans were used for evaluation and revision. The researchers evaluated and revised the comic at this stage according to the validator's assessment and suggestions. The product can be seen in Figure 3.

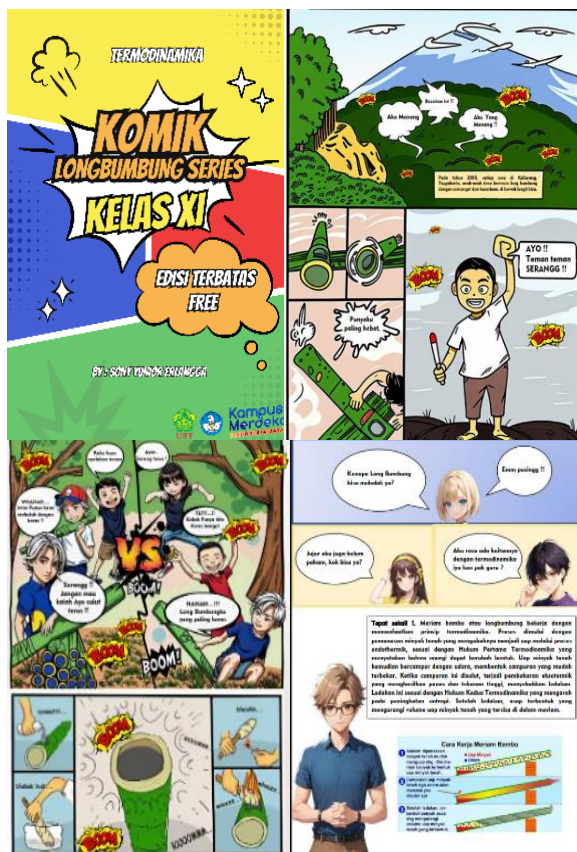


Figure 3. The Comic Product Based on Local Wisdom

Product Trials

The data on critical thinking skills was obtained through a written test with 12 questions. These questions represented 12 sub-indicators of the five indicators of critical thinking. The five indicators include 1) giving a simple explanation, 2) building basic skills, 3) making a conclusion, 4) clarifying/further explanation, and 5) strategy and tactics (Rahmawati, 2014). All pretest and posttest data obtained came from two classes: the experimental and control classes. Each class has the same number of students, namely 30 students. Before learning, a pretest was conducted to determine the extent of the student's initial abilities in the control and experimental classes. Then, a posttest was carried out after learning to determine the effect of learning using the developed comic. The Pretest and Posttest questions given are shown in Table 1.

Table 1. The Recapitulation of Students' Critical Thinking Ability through Pretest between Control Class and Experiment Class

Component	Pretest	
	Control	Test
Total	30	30
Maximum	78.38	81.08
Minimum	56.76	51.37
Average	67,97	63.15
Standard Deviation	5.57	7.35
Sig. Conclusion	0.144	0.253
	Normal	Normal
Sig.	0.201	
Conclusion	Homogeneous	
Sig. In conclusion	0.006	
	significantly different	

The results of the pretest calculations for the control and experiment classes were tabulated first. The pretest was administered to the control class and the experimental class. The recapitulation of the results of the pretest data of the control and experimental classes can be seen in Table 1. From the pretest results, control and experimental class students' initial critical thinking skills differed significantly (Hidayaturrohman et

al., 2017). Therefore, the next step was calculating the N-gain value. The difference in critical thinking skills between the control and experimental classes can be seen through N-gain calculations. The N-Gain graph is shown in Figure 4.

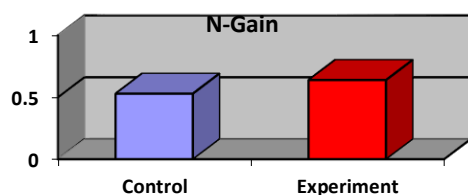


Figure 4. Average N-gain Scores

The analysis of experimental and control class scores shows that the experimental and control classes experienced increased critical

thinking skills, as indicated by a higher N-gain value in the medium category. However, the N-gain value in the experimental class was greater than that in the control class. Therefore, the comic based on the Long Bumbung local wisdom improved critical thinking skills compared to using PowerPoint (Widyawati & Prodjosantoso, 2015). The results of calculating the N-gain value are shown in Table 2.

Table 2. The Average Value of Each Aspect of Critical Thinking in the Control Class and Experimental Class

NO	Aspect Indicator	Control Class		Experimental Class	
		Average N-gain	Category	Average N-gain	Category
1	Gives a simple explanation	0.390	moderate	0.689	moderate
2	Building basic skills	0.59	moderate	0.54	moderate
3	Concluding	0.41	moderate	0.50	moderate
4	Make more advanced explanations	0.83	High	0.85	High
5	Set strategy and tactics	0.50	moderate	0.60	moderate

Based on Table 2, the experimental class's N-gain value is greater than that of the control class. Both classes experienced an increase marked by the N-gain value, which was categorized into three categories: the high category, the medium category, and the low category (Syarifudin et al., 2021).

This improvement in critical thinking skills is related to using the comic based on the Long Bumbung local wisdom. The Long Bumbung (bamboo cannon) has been adapted to the material taught in schools so that the delivery of material does not deviate from the competency standards and basic competencies. In the comic, the stories are based on everyday situations so that students are familiar with the events (Sari et al., 2019).

Comics can significantly improve critical thinking due to the unique and engaging nature of this medium, which combines visual and textual elements. Comics inherently encourage active engagement and interpretation, as readers must decode the relationship between images and text, and understand the sequencing of panels to grasp the story. This process stimulates cognitive functions related to critical thinking, such as

analysis, synthesis, and evaluation. Furthermore, comics often present information in a more accessible and relatable format, making complex concepts easier to understand and analyze.

Several aspects of comics contribute to the enhancement of critical thinking skills. Firstly, the visual element of comics aids in better comprehension and retention of information. Visuals can simplify abstract ideas, making them more tangible and easier to interpret. This aligns with dual coding theory, which posits that information processed through visual and verbal channels is more likely to be retained and understood. Secondly, the narrative structure of comics requires readers to follow a storyline, predict outcomes, and understand character motivations and actions, all of which are critical thinking activities. This narrative engagement fosters inferential thinking and encourages readers to draw conclusions based on the information presented.

Additionally, the interactive nature of comics can prompt readers to question and reflect on the material. For instance, dialogue in speech bubbles often presents different

viewpoints or conflicts that require resolution, prompting readers to evaluate and weigh these perspectives critically. Integrating local wisdom, such as the Long Bambung in comics, adds a layer of cultural relevance and authenticity that can further engage students. By seeing their cultural heritage reflected in the learning material, students may feel a stronger connection to the content, motivating them to think more deeply and critically about the subject matter.

Moreover, the creative aspect of comics allows for the presentation of hypothetical scenarios and problem-solving tasks that challenge students to apply their knowledge and think critically. This can be particularly effective in fostering higher-order thinking skills, as students are not merely consuming information but are also interpreting, questioning, and creating new understandings. The combination of visual appeal, narrative engagement, and interactive content makes comics a powerful tool for enhancing critical thinking skills, providing an immersive and stimulating learning experience that encourages active cognitive participation and deeper understanding (Nur'Azizah et al., 2021; Sujana & Wayan, 2020; Yulianti & Gunawan, 2019).

The comic based on local wisdom is based on indicators of critical thinking, namely giving simple explanations, building basic skills, concluding, making clarifications/further explanations, and setting strategies and tactics (Nurkhasanah et al., 2019). Therefore, applying visual representations using comics based on local wisdom can improve students' critical thinking skills. Thus, learning objectives can be achieved properly.

Students need to develop critical thinking skills to solve problems in real life and the world of work later. It should be emphasized that thinking skills are very suitable for students to develop (Fiery & Syukri, 2018). Student responses to learning using the local wisdom-based comic of Long Bambung were measured using a five-scale questionnaire. The questionnaire consisted of

11 questions, rated on a scale of 1-5, that students must answer after implementing learning.

The series of stories in the developed comic are easy to understand and read based on the student response results of 84.67%. Students' interest in learning to use comics based on the local wisdom of bamboo cannons was also researched by (Aeni & Yusupa, 2018). They found that students were interested in using comics based on local wisdom of bamboo cannon in learning science on other themes. Based on (Lestari & Projosantoso, 2016), the local wisdom-based comic is very suitable for use by students.

The representation using the local wisdom-based comic of bamboo cannon can be implemented. Almost all respondents felt an increase in critical thinking skills, increased knowledge about thermodynamics, and the discovery of new concepts about thermodynamics, evidenced by the increased percentage of 80.00%. Based on a high student response of 90.00%, the product can be applied in schools.

The application of Long Bambung's local wisdom-based comic has problems related to costs and difficulties. Several respondents stated that there were obstacles in the form of costs to access the comic by 58.67% and difficulty accessing the comic by 48.67%. As a solution, the learning can be done online, and the product can be sent via Google Classroom, so it does not cost a lot.

The product's online use did not encounter many difficulties. The difficulties were only related to the file format, which was not accessible to all students' cell phones. So, the teacher remained the most important component in teaching and learning activities, while the product only acted as alternative teaching materials.

The two most prominent aspects of teaching and learning activities are teaching methods and teaching materials. Based on students' responses regarding the application of representation using the product, the students can use the product for learning and are interested in using it. Despite the

obstacles and difficulties, this local wisdom-based Long Buntung comic can improve student learning outcomes.

CONCLUSION AND SUGGESTION

The local wisdom-based Long Buntung comic involves three key development stages: defining, designing, and developing. Various characteristics, such as panels, speech bubbles, characters, fonts, font sizes, and coloring, must be considered, all of which reflect the unique elements of the Long Buntung. Visual representation through these locally inspired comics has been shown to positively influence critical thinking skills, evidenced by the higher N-gain values observed in the experimental class compared to the control class.

Future research could explore several aspects, like the long-term retention of critical thinking skills developed through the use of local wisdom-based comics. Additionally, examining the applicability and effectiveness of this approach across different cultural contexts and subjects could provide valuable insights into the versatility of comics as an educational tool. Furthermore, integrating digital technology with local wisdom-based comics might offer innovative ways to engage students and foster critical thinking more interactively. This line of research could significantly contribute to developing culturally responsive teaching methods that enhance critical thinking skills in diverse learning environments.

AUTHOR CONTRIBUTION

SYE was responsible for the research design, execution, data collection, statistical analysis, and initial manuscript drafting. DNS assisted in the development of visual tools and data gathering. AW provided guidance in manuscript writing, critically supervised the article's content, and offered suggestions on the ideas presented. PHW played a key role in study design, data analysis interpretation, and contributed to reviewing and revising the manuscript for

substantial intellectual content. EAP facilitated access to research sites and aided in the interpretation of results.

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