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Urban Heat Island Context in Physics E-LKPD to Enhance Students' Critical Thinking and Communication Skills

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Abstract. This study aimed to develop a socio-scientific issues (SSI)-based electronic student worksheet (E-LKPD), integrated with the Urban Heat Island (UHI) phenomenon, to improve students' critical thinking and communication skills in learning temperature and heat. The study employed a research and development (R&D) approach, using the ADDIE model. The E-LKPD was implemented through the Liveworksheets platform and evaluated at SMA Negeri 11, Semarang. Data were collected through validation sheets, practicality questionnaires, pretest–posttest assessments, and documentation. Product feasibility was analysed using Aiken's V, while effectiveness was evaluated using independent sample t-tests, N-gain analysis, and effect size calculations. The E-LKPD achieved a validity score of 0.91 and a practicality score of 82.41%, indicating that it was valid and practical for classroom use. The effectiveness test revealed significant differences between the experimental and control groups in critical thinking skills (p = 0.01) and communication skills (p = 0.001). The experimental group also achieved higher N-gain scores in critical thinking (0.56) and communication (0.59) than the control group. Effect size analysis showed a medium effect on critical thinking (Cohen's d = 0.668) and a large effect on communication skills (Cohen's d = 0.874). These findings indicate that the SSI-based E-LKPD integrated with the UHI context is valid, practical, and effective in improving students' critical thinking and communication skills in physics learning.

Keywords: Communication Skills, Critical Thinking, E-LKPD, Socio-Scientific Issues, Urban Heat Island,

INTRODUCTION

Education in the 21st century requires students not only to master knowledge, but also to develop skills relevant to global challenges and technological advancement (Subro & Fawaid, 2025). Patrick Griffin & Esther Care ed (2015) categorized 21st-century competencies into ways of thinking, ways of learning, and ways of learning with others, which include critical thinking, communication, collaboration, and creativity. Among these competencies, critical thinking and communication are considered essential because they enable students to analyze information, solve problems, and express ideas effectively in both oral and written forms (Qodarsih, Sunarso, & Utanto, 2023). In physics learning, these competencies are particularly important because physics not only emphasizes conceptual understanding but also requires students to interpret phenomena, construct scientific arguments, and communicate scientific ideas logically.

However, the development of these competencies among Indonesian students is still relatively low. The results of the Programme for International Student Assessment PISA (2022) reported by OECD (2023) showed that only around 34% of Indonesian students achieved minimum proficiency in scientific literacy, far below the OECD average of 76%. One factor contributing to this issue is the dominance of teacher-centered learning practices, where students tend to become passive recipients of information (Simbolon et al., 2025). Such learning conditions limit students' opportunities to actively discuss, analyze problems, and develop higher-order thinking skills (Wilsa et al., 2017). This problem is also evident in physics learning, where instruction is often focused on mathematical problem solving rather than conceptual understanding connected to real-life situations. As a result, students experience difficulties in understanding concepts related to temperature and heat and in relating them to everyday phenomena.

Physics learning should ideally involve contextual investigations and analysis of real-world phenomena (Rende & Tulandi, 2022). One relevant phenomenon is the *Urban Heat Island* (UHI), which also occurs in Semarang City. Research showed that urban temperatures in Semarang can reach 37.3°C due to the dominance of heat-absorbing materials and the reduction of green areas (Ananta et al., 2025). The UHI phenomenon provides a meaningful context for students to understand concepts of temperature, heat transfer, heat capacity, and thermal equilibrium. In addition, UHI is closely related to environmental and social issues such as climate change, energy consumption, and urban environmental quality. Therefore, the phenomenon is highly relevant to the *Socio-Scientific Issues* (SSI) approach, which encourages students to analyze scientific issues critically and make decisions based on scientific evidence (Zeidler & Nichols, 2009).

The SSI approach is considered effective in improving students' critical thinking and communication skills because it engages students in discussions of contextual and controversial scientific issues (Freani, 2024). Through SSI-based learning, students are encouraged to evaluate information, construct arguments, and communicate ideas scientifically. To support the implementation of SSI-based learning, appropriate learning media are needed. One potential medium is the electronic student worksheet (E-LKPD), which can facilitate interactive and flexible learning through digital platforms accessible via smartphones or computers (Subakti et al., 2021; Supriatna et al., 2022). E-LKPD also supports student-centered learning activities and encourages students to actively participate in problem-solving and discussion processes (Sukorini & Paramastuti Purnomo, 2019).

The results of a study by Wisdayana et al. (2025) show that SSI-based instructional materials can significantly improve students' science literacy and critical thinking skills, as evidenced by the higher average n-Gain score for critical thinking (0.71, high category) achieved by the experimental group compared to the control group. The integration of socio-scientific issues into science learning not only deepens students' understanding of scientific concepts but also encourages them to analyze, evaluate, and draw conclusions critically. These findings are consistent with previous studies reporting that E-LKPDs designed within environmental learning contexts effectively foster critical thinking and communication skills. Hidayah & Kuntjoro (2022) found that science literacy-based E-LKPDs on environmental change possess high validity, practicality, and effectiveness, while Siombone et al. (2022) demonstrated that context-based physics learning using environmental issues, such as geothermal areas, can enhance students' science literacy and scientific communication skills. In addition, Susilawati & Sekartaji (2019) reported that students' knowledge of the Urban Heat Island (UHI) phenomenon remains relatively low, highlighting the need to introduce this issue into the learning process.

Recent studies indicate an expansion in the scope of Urban Heat Island research beyond the field of temperature mapping to encompass analyses of climate change impacts, urban energy consumption, vegetation dynamics, and sustainable urban planning. These developments demonstrate the increasing importance of UHI not only as an environmental issue, but also as a meaningful context for science education. Meanwhile, a recent systematic review by Mambu et al.

(2025) indicates that UHI research in Indonesia has mainly focused on remote sensing, land surface temperature, vegetation indices, and urban morphology. This trend is reflected in the study conducted by Fajary et al. (2024), which methodically examined urban growth, surface Urban Heat Island intensity, and urban thermal conditions on Java Island. The study highlighted the impact of urban expansion, anthropogenic heat, and reduced vegetation on UHI intensity. Despite the substantial advancement these studies have brought to the understanding of UHI from the perspectives of environmental and urban planning, they have rarely explored the Urban Heat Island phenomenon as a contextual learning resource in physics education. Furthermore, there is a paucity of studies that have developed Socio-Scientific Issues (SSI)-based E-LKPDs using the Urban Heat Island context to simultaneously enhance students' critical thinking and communication skills. The present study aims to address this gap by developing an SSI-based E-LKPD integrated with the Urban Heat Island phenomenon to support meaningful and contextual physics learning.[AA1]

Based on these considerations, this study aimed to develop an SSI-based E-LKPD integrated with the Urban Heat Island phenomenon on temperature and heat material and to examine its feasibility, practicality, and effectiveness in improving students' critical thinking and communication skills. The findings of this study are expected to contribute to the development of innovative physics learning media that support 21st-century skills and increase students' awareness of environmental issues in everyday life.

METHOD

The present study employed a Research and Development (R&D) method using the ADDIE development model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages as illustrated in Figure 1. The selection of the ADDIE model was predicated on its systematic and iterative procedures in developing instructional products that are valid, practical, and effective for classroom implementation. The research was conducted at SMA Negeri 11 Semarang during the 2025/2026 academic year. The participants comprised three Grade XI science classes, which were selected through purposive sampling. Specifically, the study comprised two experimental classes (n = 51) and one control class (n = 32), resulting in a total of 83 students. The sample size was deemed sufficient for a quasi-experimental study employing intact classroom groups to evaluate the effectiveness of the developed SSI-based E-LKPD. [AA1] The experimental classes were conducted using the developed electronic student worksheet (E-LKPD) based on Socio-Scientific Issues (SSI) integrated with the Urban Heat Island phenomenon, while the control class received conventional learning without the SSI-based E-LKPD.

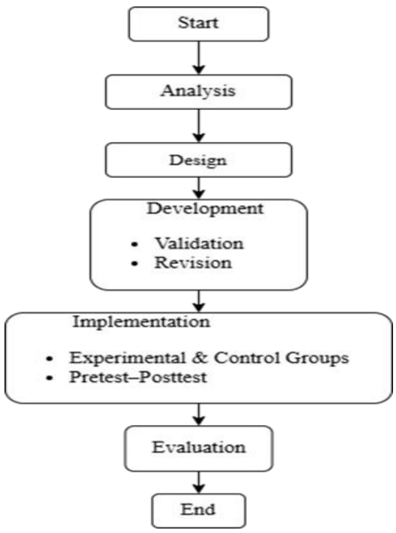

Figure 1. Research methodology based on the ADDIE development model.

The developmental process was initiated with an analytical phase that entailed conducting interviews with physics instructors and students. This phase was undertaken to ascertain learning difficulties, the requirements of students, and the constraints imposed by existing teaching materials. The design stage concentrated on preparing the structure and learning activities of the E-LKPD by integrating SSI contexts related to urban environmental issues into temperature and heat materials. The product was subsequently developed using the Liveworksheets platform to create interactive digital worksheets containing contextual problems, discussion activities, argumentation tasks, and scientific communication exercises. During the development stage, the product underwent validation by material and media experts. This validation process aimed to evaluate various aspects of the product, including content accuracy, presentation, language, visual design, and the integration of critical thinking and communication indicators.

The implementation stage employed a non-equivalent control group design, incorporating pretest and posttest procedures. To assess the efficacy of the learning process, students in both groups completed pre- and post-test evaluations that focused on critical thinking and communication skills. Supporting data were also collected through validation sheets, student response questionnaires, documentation, and essay tests developed based on critical thinking and scientific communication indicators. The effectiveness of the product was analyzed using independent sample t-test, N-gain analysis, and Cohen's d effect size analysis. The independent sample t-test was used to determine whether there were significant differences between the experimental and control groups, while Cohen's d was calculated to measure the magnitude of the treatment effect. Product validity was measured using Aiken's V, and instrument reliability was analyzed using Cronbach's Alpha through IBM SPSS Statistics 26. [AA1] The evaluation stage was conducted in a comprehensive manner to ascertain the feasibility, practicality, and effectiveness of the developed SSI-based E-LKPD in supporting physics learning on temperature and heat materials.

RESULT AND DISCUSSION

This section presents the results and discussion of the study, which covers the development and feasibility of the SSI-based E-LKPD on the Urban Heat Island phenomenon, its key characteristics, and its effectiveness in improving students' critical thinking and scientific communication skills. Furthermore, an analysis of students' responses and levels of engagement in the learning process is conducted. This is followed by an integrated discussion that compares the findings with relevant theoretical frameworks and previous studies, as well as the implications for physics learning.

1. Development and Feasibility of SSI-Based E-LKPD on Urban Heat Island

The development of the Socio-Scientific Issues (SSI)-based E-LKPD on the Urban Heat Island phenomenon was carried out using the ADDIE model, which consists of analysis, design, development, implementation, and evaluation stages. The developed product was designed to support learning on temperature and heat concepts by integrating real environmental issues into physics learning activities. The integration of Urban Heat Island (UHI) phenomena is a pedagogical strategy that aims to provide contextual learning experiences, thereby encouraging students to connect scientific concepts with real-life environmental problems.

The SSI-based E-LKPD was developed using the Liveworksheets platform, which was designed to integrate the UHI phenomenon into temperature and heat learning. The design is characterized by an emphasis on interactive learning features, including multimedia integration, guided inquiry questions, and contextual problem-solving tasks. These features are designed to facilitate a more nuanced understanding of abstract physics concepts by offering a contextual framework that links these concepts to real-world environmental phenomena, particularly the observed increase in urban temperatures, as illustrated in Figure 2.

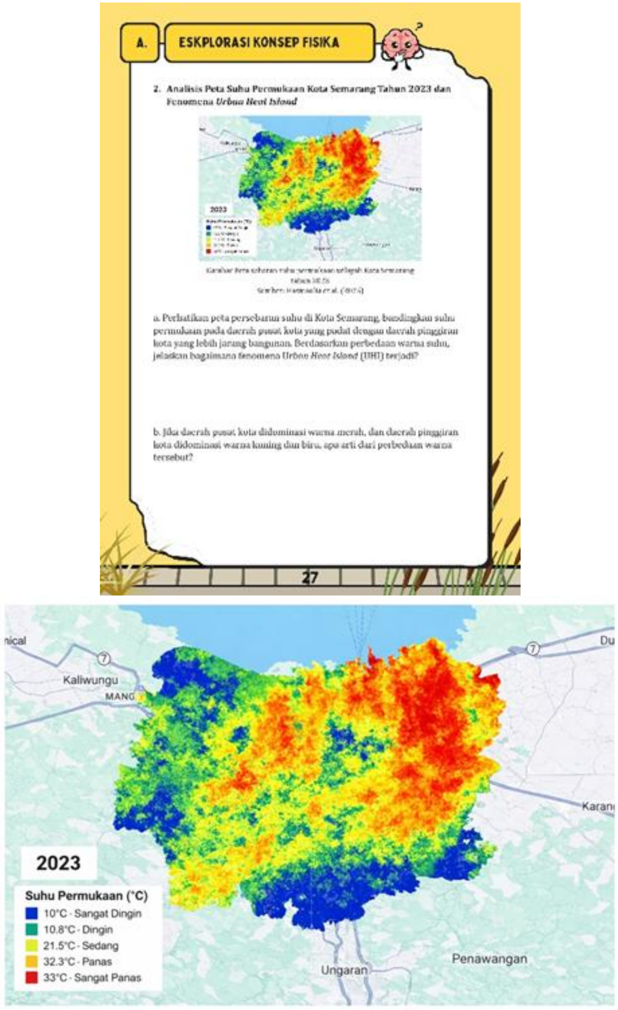

Figure 2. SSI-Based E-LKPD Design on Urban Heat Island Context.
(Source: Adapted from Hasmaulia et al., 2025)

Figure 2 illustrates the concept exploration section (Eksplorasi Konsep Fisika) of the SSI-Based E-LKPD, which was developed in Indonesian and presents the Urban Heat Island (UHI) phenomenon as a socio-scientific learning context. The E-LKPD incorporates a land surface temperature (LST) map of Semarang City, derived from remote sensing data. This map visually illustrates the distribution of temperature across urban and peri-urban areas through a heat gradient color scale. The use of warmer colors indicates higher surface temperatures, which are concentrated in the city center, while cooler colors represent lower temperatures in suburban and vegetated areas.

The figure helps students to understand how these temperature variations relate to fundamental physics concepts. Urban surfaces, such as asphalt and concrete, absorb more solar radiation due to their low albedo and high heat capacity. This results in higher surface temperatures than in vegetated areas. This thermal energy is then transferred to the surrounding environment through conduction, convection and radiation, creating the uneven thermal energy distribution that characterises the Urban Heat Island phenomenon. Thus, the figure provides a contextual representation of heat absorption, heat transfer, thermal equilibrium and thermal energy distribution, as influenced by land use and surface materials.

Students are guided to compare temperature differences between urban and rural areas, identify the factors contributing to the UHI phenomenon, and evaluate its environmental impacts. Through contextual questions embedded in the E-LKPD, students interpret scientific evidence, construct arguments, and communicate their findings. Therefore, Figure 2 serves not only as a visualization of the UHI phenomenon but also as a learning medium that connects real-world environmental issues with the physics concepts of temperature and heat while fostering students' critical thinking and scientific communication skills.

The feasibility of the developed E-LKPD was determined through expert validation and practicality testing. The validation process involved physics education lecturers and physics teachers who assessed the material, media, and language aspects of the product. The validation instruments were developed based on relevant learning media evaluation standards, covering several assessment aspects presented in Table 1.

Table 1. Expert Validation Aspects of SSI-Based E-LKPD

Aspect	Sub-Aspect	Indicator
Material	Content	Conceptual accuracy, curriculum alignment, and scientific correctness
	Critical Thinking Development	Integration of SSI, inquiry tasks, and higher-order thinking activities
	Communication Development	Argumentation tasks, written communication activities, and scientific discourse
Media	Display	Layout design, visual organization, and aesthetic presentation
	Readability	Font legibility, text clarity, and ease of navigation
	Illustration	Quality, relevance, and accuracy of visual illustrations
	Interactivity	Digital interactive features supporting active student engagement

The validation aspects presented in Table 1 were established to ensure that the SSI-based E-LKPD fulfilled both pedagogical and technical quality standards. For example, the Content aspect evaluated the accuracy of the temperature and heat concepts as well as their alignment with the senior high school physics curriculum. The Critical Thinking Development aspect examined whether the E-LKPD provided inquiry-based and socio-scientific tasks, such as analyzing the Urban Heat Island phenomenon using land surface temperature maps and evidence-based reasoning. Meanwhile, the Communication Development aspect assessed students' opportunities to construct written arguments and communicate scientific explanations based on the presented data.[AA1]

The expert validation results, reported using Aiken's V coefficient, are presented in Table 2. All aspects of the SSI-based E-LKPD fall within the "Valid" category.

Table 2. Expert Validation Results of SSI-Based E-LKPD

Aspect	Sub-Aspect	Aiken's V	Category
Material	Content	0.93	Valid
	Critical Thinking Development	0.90	Valid
	Communication Development	0.91	Valid
	Average	**0.91**	**Valid**
Media	Display	0.86	Valid
	Readability	0.80	Valid
	Illustration	1.00	Valid
	Interactivity	1.00	Valid
	Average	**0.91**	**Valid**

As shown in Table 2, all aspects of the validation process achieved Aiken's V values ranging from 0.80 to 1.00. This indicates that the expert validators considered the SSI-based E-LKPD to be valid. The E-LKPD obtained an average Aiken's V value of 0.91 for material and media validation, demonstrating the satisfactory quality of its content and instructional design. In the material aspect, the Content component received the highest score, indicating strong conceptual accuracy, alignment with curriculum objectives and appropriate integration of socio-scientific issues. For instance, the E-LKPD requires students to analyse the urban heat island phenomenon using a land surface temperature map, interpret the causes of temperature variation and justify their conclusions using heat transfer and thermal energy concepts. Additionally, the Communication Development aspect was represented by written argumentation activities that encouraged students to explain scientific phenomena based on evidence. While all media aspects were categorised as valid, the 'Readability' aspect received the lowest score (Aiken's V = 0.80), suggesting that improvements to the layout and interface design could enhance the user experience further. Overall, these findings suggest that the developed E-LKPD satisfies the content validity requirements, as well as the pedagogical and technological standards necessary for effective physics learning. This is consistent with Aiken (1998) concept of content validity, whereby an instructional product is considered feasible if its components are relevant and representative of the intended learning objectives.[AA1]

The practicality of the product was further validated through a series of trials conducted on students during the implementation stage, with the results documented in Table 3.

Table 3. The practicality of the results is contingent upon the responses of the students.

No	Aspect	Percentage (%)	Category
1	Comfort and Interest	78%	Good
2	SSI Relevance	87%	Very Good
3	Learning Practicality	81%	Good
4	Ease of Use	82%	Good

As presented in Table 3, the results of the student responses indicate an average score of 82.41%, categorised as 'Good', demonstrating that the developed SSI-based E-LKPD was practical for classroom implementation. The highest score was obtained in the SSI Relevance aspect (87.27%), which was categorised as Very Good, indicating that students perceived the Urban Heat Island context as highly meaningful and closely related to real-life environmental issues. The 'Ease of Use' (82.14%) and 'Learning Practicality' (81.96%) aspects were both categorised as 'Good', demonstrating that the E-LKPD could be used effectively during the learning process. In contrast, the 'Comfort and Interest' aspect received the lowest score (78.27%), though it remained in the 'Good' category, suggesting room for improvement in terms of learning comfort and student engagement. The remaining percentages across all aspects represent a small proportion of students who gave less positive responses. Based on student feedback, these responses were primarily related to advertisements displayed on the Liveworksheets platform, which occasionally distracted students during learning activities. However, these technical limitations originated from the online platform itself rather than the design or instructional content of the SSI-based E-LKPD. Overall, the results suggest that the E-LKPD was well received by students and could be useful in supporting physics learning.[AA2]

The favorable student responses were influenced by several characteristics of the developed E-LKPD. Initially, the implementation of the Liveworksheets platform facilitated students' access to learning materials with greater flexibility through digital devices.

Secondly, the incorporation of interactive features, including drag-and-drop activities, videos, illustrations, and guided questions, has been demonstrated to enhance student engagement. Thirdly, the integration of SSI-based discussions and case analyses encouraged students to actively participate in the interpretation of environmental problems and the construction of scientific explanations. The distinguishing characteristics of the developed E-LKPD are as follows: it focuses on problem-solving activities in addition to concept exercises, which is a departure from conventional worksheets that generally emphasize only the former.

Despite the validation results indicating the product's categorization as valid and practical, several revisions were implemented in response to feedback from validators. These revisions encompassed improvements in scientific notation consistency, refinement of conceptual explanations, and adjustments to visual layouts. These revisions ensured that the final product became more systematic, communicative, and suitable for classroom implementation. The validity and student response results collectively substantiate that the developed SSI-based E-LKPD is both theoretically and pedagogically congruent for implementation in physics learning, consistent with SSI learning theory. The latter emphasizes that science learning becomes more efficacious when connected to real-world issues requiring reasoning, evaluation, and decision-making (Zeidler & Nichols, 2009).

2. Characteristics of SSI-Based E-LKPD

The developed E-LKPD exhibits four key characteristics that distinguish it from conventional worksheets:

a. Integration of Socio-Scientific Issues (SSI) through the Urban Heat Island phenomenon, positioning physics concepts within authentic environmental problems. This enables students to construct knowledge through real-life contextualization rather than isolated conceptual learning.
b. Inquiry-based framework that guides students through systematic learning stages, including problem identification, data analysis, interpretation, and conclusion drawing. This structure promotes active knowledge construction and scientific reasoning.
c. Higher-order thinking tasks through open-ended questions that require analysis, evaluation, and decision-making based on scientific evidence, designed to stimulate cognitive engagement beyond memorization.
d. Digital delivery through the Liveworksheets platform, enabling interactive digital learning with multimedia integration, guided responses, and interactive tasks that enhance accessibility and learner engagement.

Collectively, these characteristics position the E-LKPD as a digital learning environment that supports inquiry, argumentation, and contextual scientific thinking.

3. Effectiveness of SSI-Based E-LKPD on Critical Thinking Skills

The effectiveness of the SSI-based E-LKPD in enhancing students' critical thinking skills was evaluated through multiple complementary approaches, including pretest–posttest analysis, independent sample t-test, N-gain analysis, and indicator-level critical thinking assessment. Overall, the findings indicate that the use of SSI-based E-LKPD on the topic of Urban Heat Island (UHI) produced a more substantial improvement in the experimental class compared to the control class, not only in terms of learning outcomes but also in the quality of students' thinking processes.

Based on the mean score analysis, students in the experimental class demonstrated a greater improvement in critical thinking skills than those in the control class. In the experimental class, the mean score increased from 39.17 (pretest) to 56.20 (posttest), with a gain of 17.47 points. In contrast, the control class increased from 37.06 to 50.81, with a gain of 13.75 points. The post-intervention mean score of the experimental class (56.20) was higher than that of the control class (50.81), showing a difference of 5.38 points. These results indicate that the SSI-based E-LKPD contributed positively to improving students' critical thinking skills compared to conventional instruction. The statistical analysis further supports this finding.

The independent sample t-test showed a significance value of 0.01 ($p < 0.05$), indicating a statistically significant difference between the experimental and control groups. This result confirms that the observed improvement in the experimental class was not due to random variation but was influenced by the implementation of the SSI-based E-LKPD.

In addition, the effect size analysis using Cohen's d yielded a value of 0.668, which is categorized as a medium effect size according to Cohen's (1988) criteria. This indicates that the intervention had a meaningful educational impact on students' critical thinking skills beyond statistical significance alone.

The N-gain analysis also revealed that both groups were categorized as having moderate improvement; however, the experimental class consistently showed higher gains. The experimental class obtained an N-gain value of 0.56, while the control class obtained 0.41, with a difference of 0.15. Although both fall within the same qualitative category, Hake (2002) emphasizes that such classification represents only a rough categorization and does not reflect precise differences in learning improvement. Therefore, the higher N-gain in the experimental class indicates that SSI-based learning was more effective in promoting conceptual and cognitive development in critical thinking.

The findings of this study are consistent with previous research demonstrating the effectiveness of E-LKPD and socio-scientific issue (SSI)-based learning in improving students' critical thinking skills. The experimental class achieved an N-gain score of 0.56, which is comparable to previous E-LKPD studies reporting moderate improvements, such as 0.44 reported by Nabilah et al. (2022), 0.51 by Febryanti & Rusmini (2022), and 0.531 by Prihandono et al. (2023). Similarly Wedana et al. (2025) reported a moderate N-gain of 0.56 following the implementation of Android-assisted PBL-based E-LKPD. These similarities suggest that digital worksheets designed to engage students in active problem-solving can consistently support the development of critical thinking skills.

Furthermore, the significant difference identified through the independent sample t-test ($p = 0.01$) supports findings from previous SSI-based studies. Pratiwi et al. (2016) found that SSI-oriented instruction produced significantly higher critical thinking performance than conventional learning, while Rosyidah & Subekti (2023) reported significant improvements in students' critical thinking skills following SSI implementation. The present study extends these findings by integrating SSI into an E-LKPD focused on the Urban Heat Island phenomenon, allowing students to engage with authentic environmental problems through evidence-based analysis and decision-making.

In addition to the moderate N-gain value, the effect size of 0.668 indicates that the intervention had a meaningful practical impact on students' critical thinking skills. This result supports the conclusions of Chomsun et al. (2025), who reported that SSI-based E-LKPD significantly improved students' critical thinking and scientific literacy. The consistency between the present findings and previous studies suggests that combining SSI contexts with digital learning materials provides an effective learning environment for fostering higher-order thinking skills.

However, unlike several previous studies that focused on environmental pollution, reaction rates, or reproduction topics, this study applied SSI-based E-LKPD to the Urban Heat Island issue, demonstrating that the effectiveness of SSI learning can also be extended to temperature and heat concepts in physics education. As shown in Table 4, the indicator-level N-gain analysis provides a more detailed picture of students' critical thinking development.

Table 4. N-Gain Scores per Critical Thinking Indicator

Indicator	Experimental	Control
Basic Skills	0.46	0.30
Conclusion Drawing	0.55	0.31
Strategy and Tactics	0.57	0,38

Further analysis at the indicator level provides a more detailed explanation of students' critical thinking development. In the experimental class, the N-gain for basic skills was 0.46, for strategy and tactics 0.57, and for drawing conclusions 0.55. In comparison, the control class obtained 0.30, 0.38, and 0.31 respectively. These results demonstrate that all critical thinking indicators in the experimental class outperformed those in the control class, with the most pronounced improvement observed in the strategy and tactics indicator.

The highest improvement in the strategy and tactics indicator suggests that SSI-based learning activities effectively trained students in decision-making and problem-solving processes. Through analyzing Urban Heat Island cases, evaluating alternative solutions, and engaging in evidence-based discussions, students were encouraged to develop logical reasoning and justify scientific decisions. This finding is consistent with previous studies indicating that learning activities centered on the Urban Heat Island phenomenon can promote critical thinking, collaborative discussion, and evidence-based interpretation of environmental issues (Adaktylou, 2020). Furthermore, evaluating various mitigation strategies for Urban Heat Island effects encourages students to consider alternative perspectives and make informed decisions based on scientific evidence (Spyrou et al., 2023). These activities directly supported higher-order thinking processes that are essential in critical thinking development.

The basic skills indicator also showed improvement in the experimental class (0.46), although it remained lower compared to other indicators. This suggests that while students were able to identify, interpret, and analyze UHI-related data and contextual information, some students still required time to adapt to the analytical demands of SSI-based learning. Nevertheless, exposure to authentic environmental data such as heat distribution maps and real-world case studies contributed to strengthening their foundational critical thinking abilities.

Similarly, the conclusion drawing indicator reached an N-gain of 0.55 in the experimental class compared to 0.31 in the control class. This indicates that students developed better abilities in synthesizing information and forming logical conclusions based on evidence. According to (Ennis, 1996), drawing conclusions is a complex cognitive process that requires integrating multiple sources of information and constructing justified judgments. In this study, SSI-based activities such as group discussion, case analysis, and solution formulation helped students gradually develop this skill.

Overall, the results show that although both groups experienced improvement, the experimental class demonstrated more structured and targeted development across critical thinking indicators. The differences between the two groups suggest that SSI-based E-LKPD not only enhances learning outcomes but also shapes the way students process information, analyze problems, and construct scientific reasoning.

Classroom observations further support these quantitative findings. At the beginning of the learning process, students tended to rely heavily on teacher guidance when working with the E-LKPD. However, over time, students became more active in discussions, more confident in presenting arguments, and more capable of analyzing UHI-related data independently. These observations are consistent with the findings of (Rochman & Yuliani, 2021), who reported that inquiry-based E-LKPD facilitated students' argumentation skills and encouraged more active participation during learning activities. By the final meeting, many students were able to evaluate alternative solutions and support their arguments using scientific evidence.

In addition, the SSI-based learning environment created meaningful engagement by connecting physics concepts such as temperature and heat with real-world environmental issues. The Urban Heat Island phenomenon served as a relevant socio-scientific context that encouraged students to question causes, analyze impacts, evaluate solutions, and make evidence-based decisions. This contextualization played an important role in fostering the development of critical thinking skills throughout the learning process.

In conclusion, the findings from multiple analyses including mean score comparison, t-test results, N-gain analysis, effect size (Cohen's d = 0.668), and indicator-level evaluation consistently demonstrate that SSI-based E-LKPD is effective in improving students' critical thinking skills on the topic of temperature and heat.

4. The Effectiveness of the SSI-Based E-LKPD on Students' Scientific Communication Skills

The effectiveness of the SSI-based E-LKPD in improving students' scientific communication skills was evaluated through pretest–posttest analysis, an independent sample t-test, effect size, N-gain analysis, and indicator-level assessment. Overall, the findings demonstrate that students in the experimental class achieved greater improvement than those in the control class. The evaluation of scientific communication was conducted using three essay questions designed to assess two communication indicators: idea delivery and logical argument construction.

Based on the mean score analysis, the experimental class showed a greater improvement than the control class. The mean score increased from 14.82 on the pretest to 24.07 on the posttest, representing a gain of 9.25 points. In contrast, the control class improved from 13.06 to 20.87, with a gain of 7.81 points. The higher posttest score achieved by the experimental class indicates that the SSI-based E-LKPD contributed more effectively to the development of students' scientific communication skills than conventional instruction.

The statistical analysis further supports these findings. The independent sample t-test produced a significance value of 0.001 ($p < 0.05$), indicating a statistically significant difference between the experimental and control groups. Furthermore, the effect size analysis yielded a Cohen's d value of 0.874, which is categorized as a large effect according to Cohen (1988). This result suggests that the SSI-based E-LKPD had a substantial educational impact on students' scientific communication skills, indicating that the improvement was not only statistically significant but also practically meaningful.

The N-gain analysis revealed that both groups achieved moderate improvement. However, the experimental class obtained a higher N-gain value (0.59) than the control class (0.45), with a difference of 0.14. Although both groups fall within the same qualitative category, Hake (2002) argues that N-gain categories provide only a general classification and do not fully reflect the magnitude of learning improvement. Therefore, the higher N-gain value in the experimental class indicates that the SSI-based E-LKPD more effectively promoted the development of students' scientific communication skills. Further insight into students' communication development can be obtained through indicator level analysis, as presented in Table 5.

Table 5. N-Gain Scores per Communication Indicator

Indicator	Experimental	Control
Logical Argument Construction	0.50	0.31
Idea Delivery	0.62	0.43

Further analysis based on communication indicators revealed differences in students' learning progress. As shown in Table 5, the experimental class achieved an N-gain of 0.62 for idea delivery and 0.50 for logical argument construction, whereas the control class obtained 0.43 and 0.31, respectively. These findings indicate that both communication indicators improved more substantially in the experimental class, with the greatest improvement occurring in idea delivery.

The higher improvement in idea delivery suggests that SSI-based learning effectively encouraged students to express scientific ideas and opinions in written form. Throughout the learning process, students analyzed Urban Heat Island (UHI) cases, proposed possible solutions, and connected scientific concepts with authentic environmental issues. These activities provided meaningful opportunities for students to articulate their understanding, explain their reasoning, and communicate scientific ideas more confidently. This finding is consistent with Wahyudi et al. (2024), who describe scientific communication as the ability to convey scientific knowledge and analytical results clearly, systematically, and effectively in both written and oral forms.

In contrast, the improvement in logical argument construction was lower than that of idea delivery, despite remaining higher than the control class. This finding suggests that constructing scientific arguments requires more complex cognitive processes than simply expressing ideas. Students were required not only to state opinions but also to integrate scientific concepts, supporting evidence, and logical reasoning into coherent written explanations. As reported by Saprina et al. (2020), students often experience greater difficulty organizing claims, evidence, and explanations into systematic scientific arguments than expressing ideas alone.

Classroom observations supported these quantitative findings. During the first learning session, students tended to provide brief responses with limited explanations and often relied on teacher guidance when discussing Urban Heat Island phenomena. As the learning activities progressed, students became more active in expressing opinions, discussing alternative solutions, and explaining scientific concepts using evidence provided in the SSI-based E-LKPD. By the final meeting, students' written responses were noticeably longer, more organized, and better supported by scientific reasoning, although many still experienced difficulties constructing fully developed scientific arguments.

These findings suggest that scientific communication develops progressively through repeated opportunities to analyze authentic socio-scientific issues, communicate ideas, and justify decisions using scientific evidence. However, the moderate N-gain values indicate that communication skills, particularly logical argument construction, require sustained practice beyond the three instructional meetings conducted in this study. This interpretation is supported by Fadlina et al. (2025), who argue that scientific communication and argumentation are cumulative competencies that develop gradually through continuous learning experiences. Therefore, future implementations of the SSI-based E-LKPD should incorporate more explicit scaffolding, such as structured claim–evidence–reasoning (CER) frameworks and iterative feedback, to further strengthen students' ability to construct well-supported scientific arguments.

5. Students' Responses and Learning Engagement

Student response data, reported in Table 3, reveal a pattern worth examining beyond the aggregate average of 82.41%. The hierarchy of aspect scores SSI Relevance (87.27%) > Ease of Use (82.14%) > Learning Practicality (81.96%) > Comfort and Interest (78.27%) maps onto three distinct response dimensions: contextual-cognitive engagement (relevance), functional-operational engagement (ease of use and practicality), and affective engagement (comfort and interest). The fact that contextual-cognitive engagement substantially outpaced affective engagement suggests that students recognized the intellectual value of UHI based learning before they experienced it as intrinsically enjoyable.

The high SSI relevance score confirms that the Urban Heat Island phenomenon successfully created meaningful learning: students did not merely complete tasks but understood why the concepts mattered beyond the classroom. This perception of relevance is not incidental it is the mechanism through which SSI is theorized to improve cognitive outcomes (Zeidler & Nichols, 2009), and the present data provide evidence of that mechanism operating as intended. The relatively lower comfort and interest score (78.27%), by contrast, reflects the adaptation cost of transitioning from teacher-directed learning to a student-centered, argumentation-intensive environment. As observed in class, students initially waited for teacher guidance before engaging with E-LKPD tasks; their growing autonomy across meetings was gradual rather than immediate.

Compared with prior studies Dasmasela., (2021) reported 62% and Yuliani., (2023) reported 85% the present result of 82.41% situates the E-LKPD within the upper range of student-reported practicality in the existing literature. The added contribution of the present study is demonstrating that within this aggregate score, contextual relevance through SSI is the strongest driver of student acceptance, rather than technical usability alone. For future development, this finding recommends prioritizing affective design elements varied interactive activities, more dynamic visualizations, and structured opportunities for student-led exploration to raise comfort and interest scores without compromising the contextual depth that produced the high relevance rating.

6. Integrated Discussion: Theory, Novelty, and Comparison with Prior Research

Overall, the findings indicate that the SSI-based E-LKPD contributed to the simultaneous development of students' critical thinking and scientific communication skills. By engaging students with the Urban Heat Island (UHI) phenomenon as an authentic socio-scientific issue, the E-LKPD encouraged students to analyze evidence, evaluate alternative solutions, and communicate scientific ideas, thereby supporting multiple higher-order learning outcomes.

These findings are consistent with constructivist learning theory, which emphasises knowledge construction through active engagement with meaningful problems. In this study, the UHI phenomenon functioned not only as a contextual example but also as a learning framework, requiring students to apply temperature and heat concepts in real-world situations. This lends further support to the argument of (Zeidler & Nichols, 2009) that SSI-based learning promotes scientific reasoning and evidence-based decision-making through authentic contexts.

The results are also consistent with previous studies reporting the effectiveness of SSI-based and E-LKPD-assisted learning in improving students' critical thinking skills. Similar moderate N-gain values have been reported by Chomsun et al., (2025) and Putra et al. (2023). However, the present study extends previous research by demonstrating that SSI-based E-LKPD can simultaneously improve both critical thinking and scientific communication skills within the context of physics learning on temperature and heat.

The indicator level analysis revealed that students demonstrated greater improvement in strategy and tactics than in conclusion drawing and logical argument construction. This finding suggests that students found it easier to evaluate solutions and make decisions than to synthesise multiple sources of evidence into coherent conclusions. The present findings lend support to the view that higher-order thinking skills develop gradually and require sustained practice over time (Rahma, 2025).

The novelty of this study lies in the integration of SSI-based learning with the Urban Heat Island phenomenon through an interactive E-LKPD platform. Contrary to the preponderance of extant SSI studies that have hitherto concentrated on environmental pollution or chemistry, this particular study demonstrates the applicability of SSI-based digital learning materials to temperature and heat concepts in the domain of physics education. The affirmative responses from the student body further substantiate the notion that environmental issues, when contextualised, have the capacity to augment engagement and facilitate meaningful learning experiences.

However, the moderate N-gain scores indicate the necessity for extended implementation periods to achieve higher levels of improvement. It is therefore recommended that future studies examine the long-term impact of SSI-based E-LKPD across broader instructional units and different physics topics.

7. Implications for Physics Learning

For physics teachers, the results challenge the assumption that conceptual accuracy and contextual relevance compete for instructional space. The E-LKPD achieved high validity precisely because SSI integration deepened conceptual engagement rather than supplementing it. Curriculum designers working on temperature and heat units should therefore treat SSI contextualization not as optional enrichment but as a core instructional strategy capable of supporting disciplinary rigor and higher-order thinking simultaneously.

For the broader field, this study demonstrates that productive SSI integration into digital learning environments is feasible within existing school infrastructure and replicable by practitioners with standard digital literacy. The critical design principle that emerges is embedding rather than decorating: the SSI context must be woven into every learning activity, not appended as a framing device. This principle, more than any specific platform feature, may be the most transferable lesson for educators seeking to move beyond conventional worksheets without abandoning evidence-based instructional design.

CONCLUSION

This study developed a socio-scientific issues (SSI)-based electronic student worksheet (E-LKPD) using the Urban Heat Island (UHI) phenomenon as a contextual framework for learning temperature and heat concepts. The developed E-LKPD was found to be valid and practical, with an average validity score of 0.91 and a practicality score of 82.41%, indicating its suitability for classroom implementation. The integration of SSI activities encouraged students to analyze real-world problems, evaluate evidence, and connect scientific concepts with everyday situations.

The SSI-based E-LKPD was found to be an effective tool for enhancing students' critical thinking skills, as evidenced by a significant discrepancy between the experimental and control groups ($p = 0.01 < 0.05$), a moderate N-gain score (0.56), and a medium effect size (Cohen's $d = 0.668$). The most significant enhancement was identified in the strategy and tactics indicator. The E-LKPD was also found to be effective in enhancing students' scientific communication skills, as evidenced by a significant difference ($p = 0.001 < 0.05$), a moderate N-gain score (0.59), and a large effect size (Cohen's $d = 0.874$). The most significant enhancement was observed in the delivery of ideas, while the construction of logical arguments necessitates further refinement. Furthermore, students expressed satisfaction with the E-LKPD, indicating that the UHI context enhanced engagement and facilitated meaningful learning experiences.

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