JPF | Volume 13 | Number 2 | 2025 | 275 - 290

p - ISSN: 2302-8939
e - ISSN: 2527-4015

Jurnal Pendidikan Fisika

https://journal.unismuh.ac.id/index.php/jpf

DOI: 10.26618/jpf.v13i2.17948

Enhancing Conceptual Understanding of Heat and Thermodynamics through Innovation of Local Wisdom-Differentiated Physics Learning Media

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Received: January 21, 2021; Accepted: March 31, 2025; Published: April 30, 2025

Abstract *– Physics learning in secondary schools often encounters challenges, including limited contextualization, low student motivation, and difficulties in grasping abstract concepts such as heat and thermodynamics. Addressing these issues, this research developed innovative physics learning media utilizing the Lumio by SMART application integrated with differentiated instruction and local wisdom. This study aimed to enhance the quality of physics learning and foster cultural awareness among students. Employing Educational Design Research (EDR) with the 4D (Define, Design, Development, and Dissemination) model, the research involved 33 senior high school students and one physics teacher from West Sulawesi. Validation by experts showed that the learning media achieved high validity (90.13%). Practicality tests with students and teachers indicated very practical outcomes, scoring 84.17% and 92.49%, respectively. The media's effectiveness was assessed through student learning outcomes, revealing that 87.87% of students met the Minimum Mastery Criterion, with an average N-Gain of 0.65, categorized as medium improvement. This research introduced a novel integration of differentiated pedagogy, modern digital technology, and local cultural elements, significantly improving conceptual understanding and accommodating diverse learning styles. The findings emphasize that culturally contextualized, differentiated instructional approaches enhance physics education, fostering inclusive and meaningful learning experiences. The developed media contributes positively to educational practice by aligning technological innovation with cultural preservation in physics learning.*

Keywords: *conceptual understanding; differentiated learning; heat and thermodynamics; local wisdom; physics learning media*

I. INTRODUCTION

The contemporary educational landscape emphasizes the critical importance of enhancing conceptual understanding in science education, particularly in challenging subject areas such as physics. Among the various physics topics, heat and thermodynamics stand out as particularly abstract and complex concepts for students to master (Weber et al., 2024; O'Connell, 2019). These topics involve microscopic phenomena, such as energy transfer, thermal equilibrium, and

temperature changes, which students often find difficult to visualize or relate directly to their everyday experiences. Consequently, students usually resort to memorization rather than developing a deep conceptual understanding, which leads to persistent misconceptions and inadequate comprehension.

Traditional teaching methodologies, which often rely heavily on direct instruction through methods such as PowerPoint presentations and explanatory videos sourced from platforms such as YouTube, frequently fall short in effectively addressing these conceptual learning challenges. Such methods may not adequately support diverse student learning styles or effectively engage students from various cultural backgrounds, resulting in reduced motivation, limited participation, and a limited conceptual grasp (Westbroek et al., 2020; Hasanah et al., 2022). In response to these pedagogical shortcomings, educational researchers have increasingly recognized the necessity for instructional strategies that incorporate differentiated learning approaches tailored explicitly to accommodate students' diverse cognitive styles, interests, and cultural contexts (Aguhayon et al., 2023).

Indonesia's education system has recently embraced the Merdeka Curriculum, introduced in 2023 by the Ministry of Education, which underscores the importance of flexible, student-centered learning environments. This curriculum advocates for instructional strategies that empower teachers to adapt and differentiate their teaching methods, catering specifically to the varied learning preferences, cognitive abilities, and developmental stages of students (Fitra, 2022). Differentiated instruction, as supported by current educational theories and empirical research, has emerged as a highly effective pedagogical approach. It provides learners with opportunities to engage deeply and meaningfully with the subject matter, significantly improving their conceptual understanding (Westbroek et al., 2020; Aji et al., 2019). Such an instructional approach recognizes and responds to individual differences, including students' readiness levels, interests, and learning profiles, thereby fostering inclusive educational experiences that promote higher academic achievement and deeper conceptual comprehension.

Despite these acknowledged benefits, the practical implementation of differentiated instructional approaches remains limited in many Indonesian classrooms, primarily due to restricted access to suitable instructional media and teachers' reliance on familiar yet conventional teaching tools. Observations conducted across schools in West Sulawesi, particularly at SMA Negeri 1 Campalagian, indicate that instructional practices predominantly utilize PowerPoint presentations and freely accessible online videos, chosen primarily for their practicality and ease of use rather than their pedagogical effectiveness. Interviews conducted with physics teachers revealed a significant lack of instructional media options, creating substantial obstacles to the

effective implementation of differentiated instruction methodologies, especially for complex physics concepts such as thermodynamics.

Addressing these educational challenges requires the strategic integration of advanced instructional technologies and culturally contextualized learning resources. Educational technology, particularly interactive digital applications, offers significant potential to facilitate differentiated and personalized learning environments. Lumio by SMART, an innovative digital education platform, provides comprehensive support for digital collaboration, personalization, and interactivity in learning processes. Recent studies confirm the effectiveness of Lumio in promoting critical thinking, engagement, and enhanced conceptual understanding across various educational settings (Arzfi et al., 2025; Dewi et al., 2023; Suastra et al., 2021). To further enhance the contextual relevance and intrinsic motivation of students, it is beneficial to integrate elements of local wisdom into educational materials. Mandar culture, indigenous to West Sulawesi, Indonesia, provides educators with rich contextual resources that can be leveraged to make physics concepts more tangible, relatable, and culturally meaningful for students. Traditional Mandar practices, including blacksmithing, construction of traditional houses (boyang), and the use of traditional cookware, inherently demonstrate practical applications of thermodynamic principles (Umamah et al., 2024; Suarga et al., 2023; Ma'ruf et al., 2021). Integrating these culturally familiar examples into physics instruction not only strengthens students' conceptual understanding but also fosters greater appreciation and respect for their local cultural heritage (Sarumaha, 2018; Sawab et al., 2021; Al-Qoyyim et al., 2022).

This study aims to develop, validate, and evaluate differentiated physics learning media based on the Lumio by SMART platform, enriched with culturally relevant elements of local wisdom from Mandar. Through a systematic Educational Design Research approach (Akker et al., 2006), this research seeks to address current pedagogical challenges and enhance educational outcomes in physics learning. The study's overarching goal is to provide educators with an effective instructional model that can significantly improve students' conceptual understanding, engagement, and motivation in physics education. By achieving these aims, the research makes a meaningful contribution to contemporary educational practice and pedagogical theory, promoting culturally inclusive and differentiated instructional strategies that can meet the diverse needs of learners within the Indonesian educational context.

II. METHODS

This research employed the Educational Design Research (EDR) approach, providing a systematic framework for designing, developing, evaluating, and disseminating educational interventions aimed at enhancing instructional practice through iterative and rigorous methods

(Akker et al., 2006). Specifically, the study employed the Four-D (4D) model consisting of Define, Design, Development, and Dissemination phases to ensure comprehensive development and evaluation of the instructional media as illustrated in Figure 1 (Sugiyono, 2019).

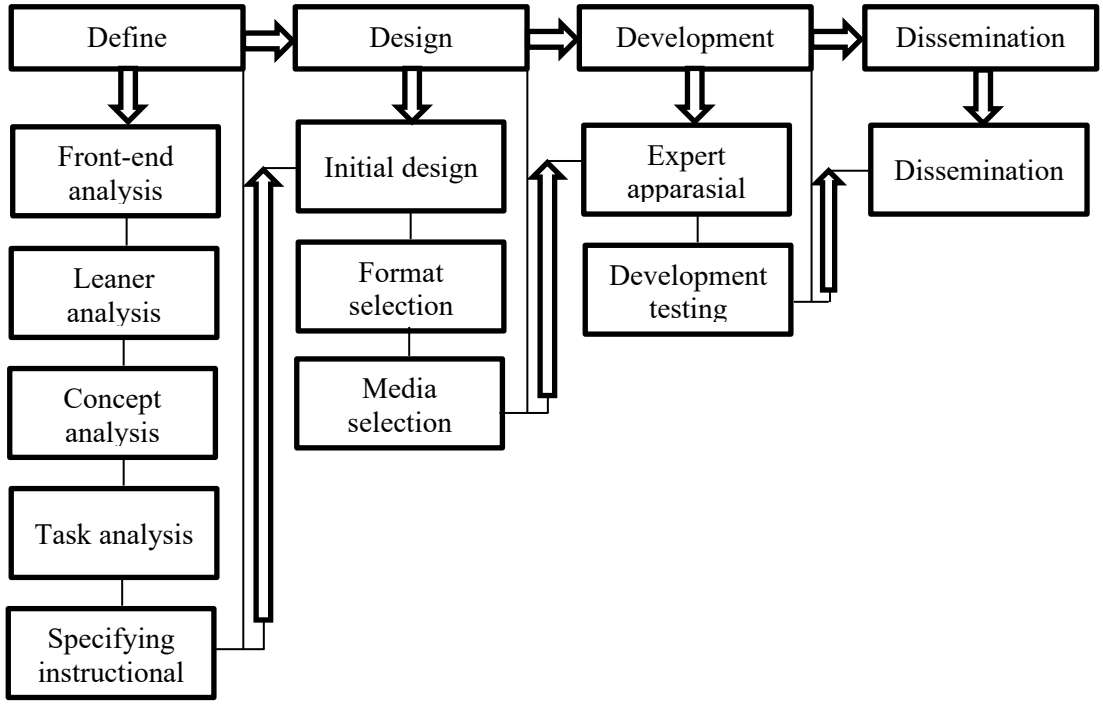

Figure 1. Development stage in the 4-D model

In the Define phase, an initial analysis was conducted to identify critical challenges in teaching physics, particularly regarding students' conceptual understanding of heat and thermodynamics. Preliminary analysis at SMA Negeri 1 Campalagian revealed significant misconceptions and limited engagement, primarily resulting from conventional teaching methods that primarily used PowerPoint presentations and online videos (O'Connell, 2019; Weber et al., 2024). Further analysis, conducted through interviews with students and teachers, underscored the necessity for differentiated instruction to accommodate diverse learning preferences (Aguhayon et al., 2023; Fitra, 2022). Concept and task analyses were also conducted to pinpoint essential physics concepts and competencies, culminating in clear learning objectives aligned with the Merdeka curriculum, emphasizing differentiated and meaningful learning experiences (Hasanah et al., 2022; Chaeruman, 2015).

In the Design phase, Lumio by SMART was chosen to develop the instructional media due to its capacity for personalized digital content creation suitable for diverse learning styles (Arzfi et al., 2025; Dewi et al., 2023). The Lumio application supports differentiated learning by offering customizable interactive activities and digital collaboration features, which are essential for effectively engaging students with varying learning preferences. The instructional media also

incorporated Mandar local wisdom, including traditional crafts, blacksmithing, and culturally relevant practices such as traditional housing, thereby enhancing students' intrinsic motivation through contextual relevance (Ryan & Deci, 2000). Furthermore, the instructional design adhered to constructivist principles, promoting active knowledge construction by encouraging students to connect new information with their prior knowledge and culturally familiar experiences, fostering meaningful and sustainable learning outcomes.

In the Development phase, comprehensive validation involved expert reviews by senior lecturers specializing in physics education. The validation assessed the instructional media's appearance, instructional design, and usability according to validity criteria established by Amir et al. (2024), as illustrated in Table 1. Validation categories ranged from invalid (<43.75%) to very valid (81.26% - 100%), ensuring the media's alignment with educational standards. The validation process was iterative, incorporating feedback and suggestions to enhance the instructional media's pedagogical robustness, visual appeal, and functionality.

Table 1. Learning media validity criteria (Amir et al., 2024)

No	Category	Percentage (%)
1	Very valid	81.26% - 100%
2	Valid	61.51% - 81.25%
3	Moderately valid	43.76% - 62.50%
4	Invalid	25% - 43.75%

Practicality assessments were conducted according to the criteria established by Sugiyono (2019), as presented in Table 2, which categorizes practicality from very impractical (0% - 20%) to very practical (81% - 100%). These assessments involved structured questionnaires that gathered detailed feedback on the media's usability, attractiveness, functionality, reliability, and motivational enhancement when used in actual classroom settings. By systematically gathering responses from students and teachers, practical assessments ensured the developed media could effectively support diverse learning environments and teaching practices. The insights gained from these assessments guided further refinements and adjustments to the instructional media, ensuring practical usability and optimal integration into classroom instruction.

Table 2. Practicality categories (Sugiyono, 2019)

No	Category	Percentage (%)
1	Very practical	81% - 100%
2	Practical	61% - 80%
3	Moderately practical	41% - 60%
4	Impractical	21% - 40%
5	Very impractical	0% - 20%

The effectiveness evaluation employed a one-group pretest-posttest design, utilizing validated instruments to measure improvements in student conceptual understanding. Effectiveness criteria required at least 80% of students to achieve the Minimum Mastery Criterion (MMC). The normalized gain (N-Gain) analysis, following the categorization by Sapitri et al. (2016), assessed learning outcome improvements as low (<0.30), medium (0.30–0.70), or high (>0.70), as depicted in Table 3. This analysis validated the effectiveness of instructional media, confirming significant enhancements in students' understanding resulting from differentiated, culturally integrated instructional media.

Table 3. N-Gain criteria (Sapitri et al., 2016)

No	Value Interval	Category
1	$g \geq 0.70$	High
2	$0.30 < g < 0.70$	Medium
3	$g \leq 0.30$	Low

The Dissemination phase involved sharing the finalized instructional media with a wider educational community, supported by targeted training sessions for educators. These sessions aimed to optimize the effective use of the media and enhance sustained student engagement. Additionally, continuous feedback mechanisms were established to enable ongoing refinements and adaptations, ensuring that the instructional media remained effective, relevant, and inclusive in supporting physics education.

III. RESULTS AND DISCUSSION

The integration of Mandar local wisdom into physics learning materials significantly contributed to contextualized, meaningful, and engaging learning experiences. Specific aspects of Mandar local wisdom were embedded into instructional materials, including traditional craft activities such as the manufacturing processes of the traditional clay wok (*kuwali*), traditional stilt houses (*boyang*), and blacksmithing techniques, as shown in Table 4.

Table 4. Main materials and sub-materials related to the Mandar local wisdom

Materia	Sub-material	Mandar local wisdom
Heat	Definition of heat	Pandama kowi' (traditional machete crafting), heating palm sap (*manyang*), boyang (traditional stilt house) roof, *kuwali* (wok), and Panjepangan (cooking pot)
	Heat transfer	
First Law of Thermodynamics	Definition of the first law of thermodynamics	Drawing water from a well, boiling water in an open container, boiling water using a kettle (*cere'*), and wrapping food in leaves

	The first law of thermodynamics process	
Second Law of Thermodynamics	Definition of the second Law of thermodynamics Entropy	Cross ventilation in the Mandar wooden *boyang*

These culturally relevant examples provided concrete contexts for understanding abstract physics concepts, such as heat transfer and the laws of thermodynamics. Figure 2 visually illustrates key elements of this integrated instructional design, showcasing traditional Mandar visuals, structured learning instructions, clearly defined learning objectives, material covers, differentiated content delivery, and interactive evaluation sections. Incorporating these culturally embedded examples effectively fostered cognitive engagement, intrinsic motivation, and deeper conceptual comprehension among students.

Figure 2. The main elements of instructional design

The instructional design strategically incorporated traditional Mandar terminology and visual representations, thereby enhancing cultural relevance and students' engagement through recognizable and meaningful contexts. Students actively connected theoretical physics concepts with culturally familiar real-world scenarios, supporting meaningful knowledge construction consistent with constructivist learning principles. This approach also aligned well with cognitive load theory, ensuring that intrinsic cognitive load was managed effectively by presenting complex scientific concepts in culturally relevant contexts, thereby enhancing overall comprehension and retention.

1. Validation

The validation process for the learning media based on the Lumio by SMART application involved expert lecturers specializing in physics education and instructional design. The primary validation aspects assessed were media appearance, instructional design, and usability, in alignment with the educational standards and cognitive load principles. Table 5 illustrates the detailed validation results, indicating a high level of media validity. Specifically, the media appearance scored 89.58%, categorized as very valid. Instructional design received a score of 93.33%, affirming its pedagogical effectiveness and robust integration of differentiated instruction and local wisdom elements. Usability, which measures ease of navigation and practicality for teachers and students, scored 87.50%, also categorized as very valid. Overall, the developed instructional media achieved an average validation score of 90.13%, reflecting strong adherence to the validity criteria and confirming its suitability for effective classroom integration.

Table 5. Validation results of the media

No	Aspect	Percentage (%)	Description
1	Media appearance	89.58	Very valid
2	Design	93.33	Very valid
3	Ease of use	87.50	Very valid
Average		**90.13**	**Very valid**

2. Practicality

Practicality tests were conducted to evaluate the usability, attractiveness, functionality, reliability, and motivational effectiveness of the media from the perspective of both students and teachers. Initially, a limited practical test was conducted involving 10 students to gather preliminary feedback. Subsequently, extensive trials involving 33 students and physics teachers were conducted to obtain comprehensive practicality data. Results from the student trials presented in Table 6 indicate a consistently high practicality rating across several key aspects. The attractiveness of the media was scored at 81.69%, showing that students found the media visually appealing and engaging. Interest and motivation scored 83.71%, reflecting a significant

enhancement in students' willingness and enthusiasm for learning physics. Ease of use and functionality were rated highly at 86.36% and 83.90%, respectively, underscoring the media's intuitive design and reliable operational performance. Overall reliability of the media in classroom usage was evaluated at 85.22%. Aggregating these results, the average practicality score among students was 84.17%, categorizing the media as very practical.

Table 6. Results of student responses in limited trials

No	Aspect	Percentage (%)	Description
1	Attractiveness	80.40	Practical
2	Interest/Motivation	79.10	Practical
3	Usage	73.70	Practical
4	Functionality	73.10	Practical
5	Reliability	82.50	Very practical
Average		**77.76**	**Practical**

Teacher evaluations in Table 7 highlighted the practicality of the media from the educators' perspective. Teachers rated the media's attractiveness at 91.66%, emphasizing its visual and educational appeal in classroom environments. Interest and motivation among teachers in adopting and continually utilizing the media reached an impressive score of 95.83%. Teachers appreciated the ease of usage, scoring it at 93.75%, indicating that the media effectively reduced preparation and instructional complexities. The functionality also received a high score of 93.75%, highlighting the robust performance of media features during actual instructional sessions. Overall, Table 7 reflects highly positive teacher perceptions, demonstrating the media's strong appeal and functionality.

Table 7. Results of student responses in wide trials

No	Aspect	Percentage (%)	Description
1	Attractiveness	81.69	Very practical
2	Interest/Motivation	83.71	Very practical
3	Usage	86.36	Very practical
4	Functionality	83.90	Very practical
5	Reliability	85.22	Very practical
Average		**84.17**	**Very practical**

Further detailed evaluations by teachers in Table 8 provided insights specifically on the reliability of media. Reliability from the teachers' perspective was scored at 87.50%, reflecting minor opportunities for technical enhancements, though still maintaining significantly high standards. Teachers' feedback suggested that while the media operated effectively during most sessions, some technical refinements could further enhance the overall user experience and reduce occasional disruptions. Despite these minor points for improvement, the cumulative average

practicality score from teachers remained exceptionally high at 92.49%, underscoring the media's exceptional suitability for effective and sustained classroom instruction.

Table 8. Results of teacher responses in wide trials

No	Aspect	Percentage (%)	Description
1	Attractiveness	91.66	Very Practical
2	Interest/Motivation	95.83	Very Practical
3	Usage	93.75	Very Practical
4	Functionality	93.75	Very Practical
5	Reliability	87.50	Very Practical
	Average	**92.49**	**Very Practical**

3. Effectiveness

The effectiveness of Lumio by SMART-based learning media, integrated with differentiated instructional methods and local wisdom from Mandar, was evaluated using a one-group pretest-posttest research design. This evaluation aimed to measure the improvement in students' conceptual understanding and their achievement of defined learning outcomes in the heat and thermodynamics topic. The evaluation criterion established that the learning media would be considered adequate if at least 80% of students met or exceeded the Minimum Mastery Criterion (MMC). Figure 3 illustrates the post-implementation student performance, revealing that 87.87% of students achieved or surpassed the MMC threshold. This result strongly indicates the instructional media's capability to facilitate meaningful conceptual gains in students' physics understanding.

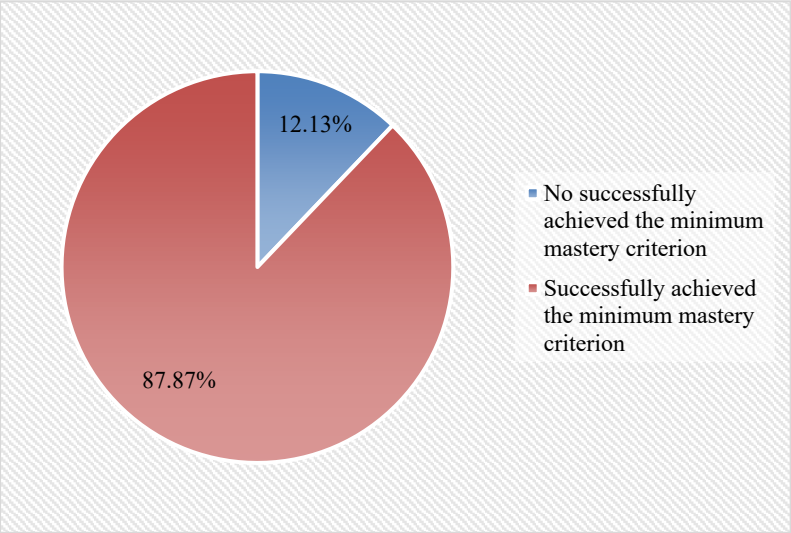

Figure 3. Student learning outcomes after using learning media

Further analysis of effectiveness was conducted using normalized gain (N-Gain) scores, categorizing improvements as high, medium, or low, as summarized in Table 9. This analysis revealed varied levels of conceptual improvement across different cognitive domains. The cognitive domain "Knowing" exhibited the highest N-Gain score of 0.79, classified as high improvement, reflecting significant gains in factual recall and basic conceptual comprehension. The "Understanding" domain recorded a moderate N-Gain score of 0.46, indicating a substantial but less pronounced improvement in students' abilities to grasp and interpret complex physics concepts. The overall average N-Gain was 0.65, classified as medium improvement, clearly demonstrating the substantial positive impact of the developed learning media on students' conceptual understanding and cognitive development.

Table 9. N-gain values

No	Indicator	N-gain	Description
1	Knowing	0.79	High
2	Understanding	0.46	Medium
3	Applying	0.72	High
4	Analyzing	0.65	Medium
	Average	**0.65**	**Medium**

This research demonstrates the educational value of integrating differentiated instructional methods, digital learning media, and culturally relevant local wisdom. The Lumio by SMART platform significantly enhanced differentiated learning by accommodating diverse student learning preferences, supporting previous findings on the efficacy of interactive digital platforms in improving instructional engagement (Arzfi et al., 2025; Dewi et al., 2023). Lumio's interactive and customizable features effectively addressed varied cognitive styles, aligning closely with cognitive load theory, which emphasizes instructional designs that efficiently manage intrinsic cognitive load (Sweller, 1988; Clark & Kimmons, 2023; Özdemir & Clark, 2007).

Expert validation confirmed the instructional media's pedagogical quality, particularly in instructional design, media appearance, and usability. High validation scores indicate successful integration of educational standards and cognitive principles into the instructional media. This rigorous validation aligns with prior research, emphasizing the critical role of comprehensive validation processes in ensuring the effectiveness of educational technology (Amir et al., 2024; Janah et al., 2023). Student practicality assessments underscored the instructional media's motivational and engagement benefits. High scores in attractiveness, interest, and usability highlight the platform's capability to enhance students' intrinsic motivation and classroom engagement, consistent with self-determination theory (Ryan & Deci, 2000). The ease of use and

functionality further validated the platform's practical application, reinforcing its suitability for diverse learning environments.

Teachers' evaluations similarly confirmed the practicality and utility of the instructional media. High ratings for attractiveness, ease of use, and functionality suggest effective integration into classroom teaching practices, consistent with research advocating practical, pedagogically robust instructional technologies (Maslakhah et al., 2024). Teachers noted minor reliability issues, recommending technical enhancements to facilitate smoother classroom integration, which reflects common challenges in technology-enhanced education that require continuous optimization (Dewi et al., 2023). Next, the effectiveness evaluations revealed significant improvements in students' conceptual understanding, evidenced by high achievement of the Minimum Mastery Criterion and notable N-Gain scores. Enhanced student performance in the "Knowing" and "Applying" domains indicates that the instructional media effectively bridged the gap between theoretical understanding and practical application. These results support prior studies that have asserted the efficacy of differentiated, contextually relevant instructional strategies in science education (Westbroek et al., 2020; Hasanah et al., 2022).

Integrating Mandar's local wisdom significantly contributed to contextualizing abstract physics concepts, facilitating deeper student comprehension. Traditional practices such as blacksmithing and traditional housing provided relatable, culturally meaningful examples, enhancing students' cognitive engagement and intrinsic motivation (Sarumaha, 2018; Sawab et al., 2021). The inclusion of local terminology and visuals effectively reduced cognitive load by presenting complex concepts in familiar contexts, aligning with cognitive load theory's principles (Sweller, 1988). Positive student responses validated this culturally embedded approach, reinforcing constructivist learning theories that emphasize experiential and contextually meaningful learning (Piaget, 1976; Posner et al., 1982; Saputra et al., 2024).

Teachers reported increased classroom participation and richer instructional discussions facilitated by culturally relevant content. The integration of local wisdom provided familiar and relatable contexts that encouraged students to actively engage in the learning process, resulting in more dynamic and interactive classroom environments. This enhanced interaction aligns closely with research highlighting culturally responsive pedagogy's potential to foster deeper student engagement, improve classroom dynamics, and enhance inclusivity by validating students' cultural backgrounds and experiences (Hasanah et al., 2022; Westbroek et al., 2020). Additionally, teachers noted that the culturally contextualized media facilitated deeper conceptual dialogues, enabling students to critically connect physics concepts to their real-life cultural experiences, thus promoting higher-order thinking skills. Teachers' feedbacks also underscored the instructional media's scalability, indicating that similar culturally responsive instructional

approaches could be effectively implemented across diverse educational contexts beyond the current study's scope, further emphasizing its adaptability and broad potential impact.

The research findings contribute meaningfully to physics education by demonstrating the effectiveness of integrating differentiated instruction, digital technology, and culturally relevant content. The success of the instructional media suggests significant potential for addressing contemporary educational challenges, particularly in diverse cultural contexts. Future studies could further enhance instructional effectiveness by integrating advanced technologies, such as virtual and augmented reality, potentially providing richer and more immersive learning experiences and further advancing pedagogical innovation in science education.

IV. CONCLUSION AND SUGGESTION

This research demonstrates that the integration of physics learning media based on the Lumio by SMART application, differentiated instructional strategies, and Mandar local wisdom significantly improves students' conceptual understanding of heat and thermodynamics. Expert validation results indicate a very high validity level of 90.13%, while practicality tests with students and teachers show very practical results, scoring 84.17% and 92.49%, respectively. The media's effectiveness is confirmed through student learning outcomes, with 87.87% of students achieving the Minimum Mastery Criterion and an average N-Gain score of 0.65, indicating moderate improvement. These findings underscore the importance of integrating modern technology and local cultural contexts to create meaningful and inclusive learning experiences.

However, this study has several limitations, including its focus on heat and thermodynamics topics only and the relatively small sample size. Future research should consider expanding the scope of learning materials and involving larger and more diverse samples to strengthen the generalizability of findings. Additionally, subsequent research could integrate additional features such as Virtual Reality (VR) and Augmented Reality (AR) simulations to enhance students' conceptual understanding further. The main contribution of this study lies in providing an innovative, culturally relevant, and pedagogically effective model of physics learning media, serving as an important reference for future developments in physics education.

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