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Designing a Digital Polya-Based E-Problem Sheet Integrated with Bengkulu Local Wisdom for Wave Mechanics Learning

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Abstract

Purpose of Study: This study aimed to design and validate a digital Polya-based e-problem sheet incorporating Bengkulu local wisdom to enhance understanding of wave mechanics and foster critical thinking among undergraduate physics students.

Methodology: The research employed a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, Disseminate), limited to the Develop stage. Sixty students from the Physics Education Program, University of Bengkulu, were purposively sampled based on prior academic performance. Nine experts (three each for content, media, and language) conducted validation. Expert feedback was analyzed using Aiken's V, while student practicality was assessed through descriptive percentage analysis, supplemented with qualitative observations and interviews.

Main Findings: The e-problem sheet achieved high validity in content (V = 0.948), media (V = 0.961), and language (V = 0.961) aspects. Student practicality scored an average of 91%, with the highest ratings for content appeal and clarity of Polya's steps. Readability and support for independent learning were identified as areas for enhancement. Integration of local wisdom improved contextual relevance and engagement, and the structured Polya stages effectively guided problem-solving and critical thinking.

Novelty/Originality of This Study: The study introduces an innovative instructional tool that combines culturally contextual learning with structured problem solving in a digital format. By bridging abstract physics concepts with local environmental and cultural contexts, the e-problem sheet provides a validated, practical model for enhancing conceptual understanding and critical thinking, with potential for adaptation across other science subjects and educational settings.

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INTRODUCTION

The rapid advancement of digital technology in the Industrial Revolution 4.0 era has transformed higher education into a technology-oriented learning ecosystem emphasizing higher-order thinking skills, creativity, collaboration, communication, and problem-solving abilities (Hwang et al., 2021). In science and physics education, critical thinking is considered one of the most essential competencies because students are required not only to understand formulas procedurally but also to analyze scientific phenomena logically, evaluate evidence critically, and formulate reasoned conclusions in solving real-world problems (Suprapto et al., 2024). Critical thinking skills are closely related to scientific literacy and conceptual understanding, especially in physics learning where many concepts are abstract, mathematical, and difficult to visualize directly (Docktor & Mestre, 2014; Kanyesigye et al., 2022).

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From a constructivist perspective, learning occurs when students actively build knowledge through interaction with problems and contexts rather than receiving information passively. This aligns with Piagetian constructivism and emphasizes the role of cognitive conflict in conceptual change. In addition, Vygotsky's social constructivism highlights the importance of scaffolding in supporting learners' development within the zone of proximal development. These perspectives support the use of structured problem-solving models in physics learning.

Wave mechanics is one of the physics topics frequently perceived by students as difficult because it involves abstract concepts such as oscillation, interference, resonance, wave propagation, damping, and energy transfer represented through mathematical equations and symbolic models (Nurohmah et al., 2025; Putra et al., 2020). Several studies have reported that students tend to memorize formulas without deeply understanding the physical meaning behind wave phenomena (Azfi et al., 2025). Consequently, students often experience difficulties in solving non-routine problems that require conceptual interpretation and analytical reasoning. This condition indicates that conventional instructional approaches emphasizing algorithmic calculations are still dominant in physics classrooms and are insufficient to facilitate students' critical thinking development (Muftidafila & Rosyida, 2025).

The integration of educational technology into physics learning has become an important strategy for overcoming these problems. Digital learning media such as e-modules, e-worksheets, simulations, and e-problem sheets provide interactive learning environments that support independent learning, increase student engagement, and facilitate conceptual understanding (Hwang et al., 2021; Y. Sung et al., 2016). Digital learning environments also enable the integration of multimedia visualization, contextual scenarios, and scaffolding processes that help students understand abstract scientific concepts more effectively (Sanca et al., 2026). Previous studies have revealed that digital problem based learning environments positively influence students' engagement, reasoning ability, and critical thinking because they encourage active knowledge construction through systematic problem solving activities (Kek & Huijser, 2011; Yusmita et al., 2026).

In structured learning design, Polya's problem-solving framework provides systematic cognitive scaffolding through four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. This structured reasoning process aligns with higher order thinking development because it trains students to organize thinking, evaluate strategies, and reflect on solutions. When combined with Facione's critical thinking framework, problem solving activities can explicitly train interpretation, analysis, inference, evaluation, explanation, and self-regulation as integrated cognitive skills.

Among various digital learning platforms, Wizer.me has emerged as an interactive educational technology platform that enables educators to design digital worksheets integrated with multimedia features, automatic feedback, online accessibility, and interactive problem solving activities. Wizer.me supports student-centered learning environments by allowing the integration of videos, images, hyperlinks, and structured learning tasks within a single digital interface. In physics learning, the use of interactive digital worksheets helps students visualize abstract concepts and engage actively in scientific reasoning processes (Kasmawati et al., 2025). Therefore, Wizer.me was selected in this study as the platform for developing a Polya-based e-problem sheet integrated with Bengkulu local wisdom.

One instructional approach that is widely recognized for improving students' systematic reasoning ability is Polya's problem-solving model. Polya proposed four important stages in problem solving activities, namely understanding the problem, devising a plan, carrying out the plan, and looking back. These stages function as cognitive scaffolding that guides students through systematic reasoning processes when solving complex scientific problems (Widiana et al., 2018). Previous studies revealed that Polya-based learning significantly improves students' analytical thinking, conceptual understanding, and self regulation because students are encouraged to evaluate and reflect critically on their reasoning procedures (Musengimana et al., 2025). Furthermore, integrating Polya's stages with Facione's critical thinking framework enables students to engage in interpretation, analysis, inference, evaluation, explanation, and self regulation simultaneously during learning activities.

Besides digital learning and problem solving strategies, contextual learning through local wisdom integration has recently gained considerable attention in science education research. Local wisdom-based learning enables students to connect scientific concepts with their cultural experiences and environmental contexts, making learning more meaningful and authentic (Lubis & Baiduri, 2025; Rasidi et al., 2025). Ethnophysics approaches integrating local culture into physics learning have been proven effective in improving conceptual understanding, learning motivation, and scientific literacy because students can directly observe physical phenomena in their surrounding environment (Batlolona et al., 2022; Kasim et al., 2025). Moreover, contextual ethnoscience learning encourages students to recognize that scientific principles are embedded within traditional technologies and local cultural practices (Festiyed et al., 2024; Sudarmin et al., 2019).

In science education, culturally responsive teaching emphasizes that learning becomes more effective when instructional content is connected to students' cultural identity and lived experiences. This approach strengthens engagement and conceptual understanding because students are able to link abstract scientific principles with familiar phenomena in their environment.

Bengkulu Province possesses various forms of local wisdoms and environmental phenomena highly relevant to wave mechanics concepts. Geographically, Bengkulu lies within the Mentawai Pagai Megathrust zone, making it highly vulnerable to earthquakes and seismic wave activity. This geological condition provides authentic examples of wave propagation, vibration, damping, and energy transfer. Furthermore, the traditional Bubungan Lima house utilizes a stone foundation system locally known as "umpak," which functions as a natural vibration isolator capable of reducing seismic wave impacts. In cultural contexts, Dol music instruments represent local acoustic phenomena involving membrane resonance and sound wave propagation. Coastal wave dynamics at Pantai Panjang also provide real examples of mechanical wave behavior, including reflection, diffraction, and wave attenuation. These local contexts have strong potential to transform abstract wave concepts into meaningful and observable learning experiences.

However, despite the richness of Bengkulu local wisdom, its integration into digital physics learning remains limited. Based on preliminary observations, interviews, and needs analysis conducted during the even semester of the 2025/2026 academic year involving students of the Physics Education Study Program, University of Bengkulu, several important problems were identified. Most students stated that wave mechanics was one of the most difficult topics because the concepts were abstract and mathematically intensive. Approximately 81% of students experienced difficulties in interpreting wave phenomena conceptually, while 76% reported low confidence in solving non routine wave problems requiring analytical reasoning. In addition, 84% of students expressed the need for interactive digital learning media integrated with contextual local phenomena to help them understand wave concepts more meaningfully. Interviews also revealed that current instructional materials mainly emphasize formula memorization and routine exercises without connecting physics concepts to students' real environments.

Several previous studies have attempted to address similar issues through digital learning innovation and local wisdom integration. Pradana et al. (2020) developed local wisdom-based physics e-modules that successfully improved students' learning motivation. Similar studies (Fitriah et al., 2025; Matsun et al., 2019; Widayanti et al., 2022) also emphasized motivational and cognitive outcomes, yet they did not specifically integrate critical thinking indicators and structured problem-solving activities. Studies on Polya based learning have predominantly focused on mathematics education (Rani et al., 2025; Wahab A, Dasari, et al., 2024; Wahab A, Kusuma, et al., 2024), while its application in higher education physics contexts, particularly wave mechanics, remains underexplored. Meanwhile, studies on digital worksheets generally emphasized conceptual understanding (Adhelacahya et al., 2023), while ethnophysics based modules focused on critical thinking (Eveline, 2025). Recent attempts to integrate ethnoscience into electronic worksheets (Utami & Emiliannur, 2025) still fall short of simultaneously embedding ethnophysics and critical thinking frameworks. Other ethnoscience studies focused mainly on cultural preservation aspects rather than systematic scientific reasoning development (Hikmah et al., 2025; Jihannita et al., 2024;

Sudirman et al., 2025). Therefore, a significant research gap still exists regarding the development of a digital e-problem sheet integrating Polya's problem-solving model, Facione's critical thinking framework, Bengkulu local wisdom, and interactive digital technology within wave mechanics learning in higher education.

The novelty of this study lies in the integration of four important components: interactive digital learning technology through Wizer.me, Polya's problem solving stages, Facione's critical thinking indicators, and Bengkulu local wisdom within an e-problem sheet specifically designed for wave mechanics learning. Unlike previous studies that focused separately on digital media, local wisdom integration, or problem solving strategies, this study combines contextual ethnophysics scenarios with systematic cognitive scaffolding to facilitate critical thinking development comprehensively. Therefore, this study aims to: (1) develop a Polya-based e-problem sheet integrated with Bengkulu local wisdom on wave mechanics material; (2) evaluate the validity of the developed product through expert judgment involving media, content, and language experts; (3) assess the practicality of the product through student responses and usability evaluation; and (4) analyze its potential in facilitating students' critical thinking skills in physics learning.

METHOD

This study employed a Research and Development (R&D) design using the 4D development model consisting of Define, Design, Develop, and Disseminate stages. The study was limited to the Develop stage because its main focus was to produce, validate, revise, and assess the practicality of a digital Polya-based e-problem sheet integrated with Bengkulu local wisdom for wave mechanics learning. The use of a development oriented design was appropriate because the study aimed to develop an educational product and evaluate its quality through expert judgment and user response rather than to test the causal effectiveness of an intervention (McKenney & Reeves, 2025).

The developed product was designed as an interactive e-problem sheet using the Wizer.me platform. Its learning structure combined Polya's four problem solving stages understanding the problem, devising a plan, carrying out the plan, and looking back with Facione's critical thinking indicators, namely interpretation, analysis, inference, evaluation, explanation, and self regulation (Liu & Pásztor, 2022; Nguyen et al., 2023). Local wisdom contexts from Bengkulu, including Dol music, Bubungan Lima traditional houses, and coastal wave phenomena, were embedded as contextual triggers to connect abstract wave mechanics concepts with students' real cultural and environmental experiences. This contextual integration is consistent with culturally responsive science education, which emphasizes the use of learners' cultural and social contexts to support meaningful science learning (Smith et al., 2022).

The participants of this study consisted of undergraduate students of the Physics Education Program at the University of Bengkulu during the even semester of the 2025/2026 academic year, with a total of 196 active students. Of these, 144 had completed the Wave Mechanics course and were considered eligible for participation. From this group, 60 students were purposively selected to join the practicality trial, representing heterogeneous academic achievement levels.

The classification of students into high, medium, and low competence groups was conducted based on their standardized Wave Mechanics examination scores. The score distribution was converted into percentage values and categorized using academic achievement thresholds commonly applied in educational evaluation studies. Students with scores ≥80 were classified as high competence, scores between 60–79 as medium competence, and scores <60 as low competence. This stratification ensured that the practicality evaluation captured diverse cognitive performance levels and reduced bias toward high achieving students.

The sample was stratified into three competence groups based on their previous examination scores: 20 students with high competence, 20 with medium competence, and 20 with low competence. Purposive sampling was employed to ensure proportional representation of students' prior academic achievement, thereby enhancing the comprehensiveness of the practicality evaluation (Campbell et al., 2020). Complementing the student participants, the validation process involved nine expert validators purposively selected according to their professional expertise. These included three content experts, who evaluated scientific accuracy, alignment with learning outcomes, integration of Polya's problem solving steps, and incorporation of critical thinking indicators; three media experts, who assessed interface layout, multimedia integration, and usability; and three language experts, who examined clarity, grammar, and coherence of the instructional materials (Wulanningtyas et al., 2026). The involvement of both heterogeneous student respondents and multidisciplinary expert validators ensured that the developed E-Problem Sheet was comprehensively reviewed in terms of content, media, and language dimensions.

Population and Methods of Sampling, Instrumentation

The population of this study was undergraduate physics education students who had studied wave mechanics. The sampling method used was purposive sampling based on the criterion that participants had completed the Wave Mechanics course.

The instrumentation consisted of expert validation sheets and a student practicality questionnaire. The expert validation sheets covered three aspects: content, media, and language. The content validation indicators included alignment with learning outcomes, scientific accuracy of wave concepts, relevance of local wisdom contexts, Polya systematization, and critical thinking stimulation. The scientific accuracy of wave mechanics content was supported by previous physics education studies showing that mechanical wave propagation, conceptual integration, and wave-related misconceptions require careful instructional design (Goodhew et al., 2019; Xie et al., 2021; Kanyesigye et al., 2022).

The media validation indicators included layout, visual quality, digital navigation, multimedia integration, and usability. These indicators were used because digital and multimedia-based learning environments can support learning when their visual and interactive elements are designed clearly and aligned with learning purposes (Y. T. Sung et al., 2016; Noetel et al., 2021). The language validation indicators included communicativeness, technical term accuracy, grammar, instruction clarity, and coherence.

The practicality questionnaire measured students' responses to ease of use, time efficiency, content appeal, clarity of Polya's steps, readability of text and visuals, and support for independent learning. The instrument was developed using a five-point Likert scale. Content validity was assessed through expert judgment using Aiken's V, while reliability analysis using Cronbach's alpha may be reported only if the reliability coefficient is calculated from the complete response data (Almanasreh et al., 2019; Taber, 2018; Wulanningtyas et al., 2026).
The instruments used in this study consisted of expert validation sheets, a student practicality questionnaire, observation notes, and interview guidelines. The validation sheets were used to assess the feasibility of the product from content, media, and language perspectives. The practicality questionnaire was used to collect student responses after using the e-problem sheet. Observation notes and interview guidelines were used to obtain qualitative feedback regarding usability, readability, attractiveness, and potential product revisions.

The development procedure consisted of three main stages. In the Define stage, the researchers conducted observation, interviews, and needs analysis to identify students' difficulties in learning wave mechanics. This stage was necessary because previous research has shown that mechanical wave concepts are often difficult for students due to their abstract, representational, and conceptual nature (Goodhew et al., 2019; Xie et al., 2021; Kanyesigye et al., 2022).

In the Design stage, the researchers prepared the product blueprint by mapping wave mechanics concepts, local wisdom contexts, Polya's problem solving stages, and Facione's critical thinking indicators. The e-problem sheet (Figure 1) was structured into learning objectives, contextual problems, Polya based problem solving activities, critical thinking reflection, interactive tasks, summary, conclusion, and self reflection.

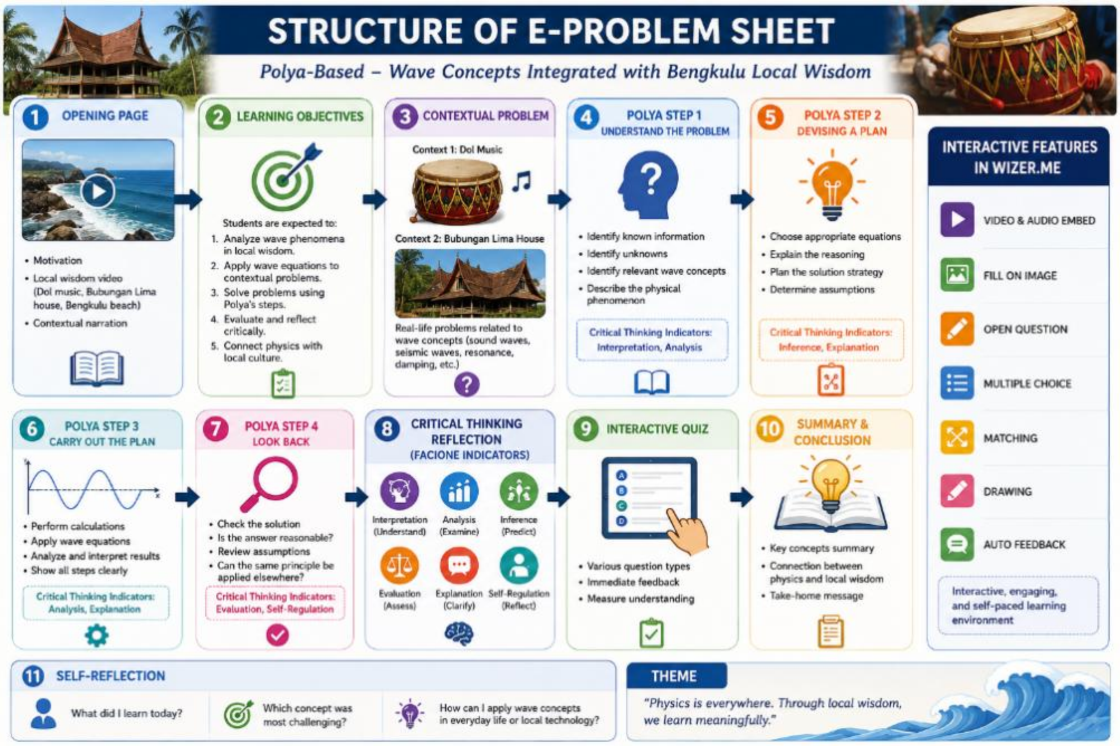
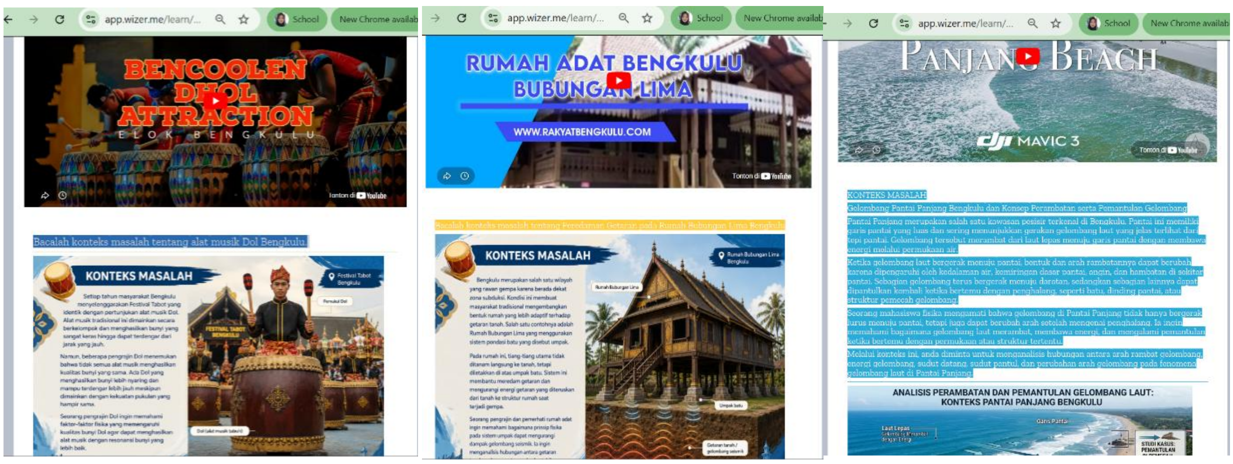


Figure 1. Design Structure of E-Problem Sheet

The integration of Bengkulu local wisdom into learning materials was operationalized through contextual problem scenarios embedded in the e-problem sheet (Figure 2). Each wave mechanics problem was constructed using real-life cultural and environmental contexts. The concept of wave resonance was represented through *Dol music instruments*, where students analyze sound vibration patterns (Figure 2a.) The concept of vibration damping was linked to the *Bubungan Lima traditional house foundation system (umpak)*, which reduces seismic wave impact (Figure 2b). The concept of wave propagation and reflection was represented through *coastal wave phenomena at Pantai Panjang* (Figure 2c).



(a) (b) (c)

Figure 2. Contextual Problem Scenarios Embedded in the E-Problem Sheet

This scenario-based integration aligns with contextual learning theory, which emphasizes that knowledge becomes meaningful when it is connected to authentic situations experienced by learners.

In the Develop stage, the initial prototype was produced and submitted to expert validation. The validation process involved content, media, and language experts. After validation, the product was revised based on expert comments and suggestions. The revised product was then tested in a practicality trial involving 60 students. Student responses, observation notes, and interview feedback were used to identify the usability, readability, attractiveness, time efficiency, and learning support provided by the e-problem sheet. The study was conducted during the even semester of the 2025/2026 academic year.

Analysis Plan

Expert validation data were analyzed using Aiken's V index. Aiken's V was used to determine the degree of agreement among validators regarding the relevance and quality of each item or indicator (Almanasreh et al., 2019; Wulanningtyas et al., 2026). The formula used was:

$$V = \frac{\sum(r - l_0)}{n(c-1)}$$

where r is the score given by the validator, l_0 is the lowest score in the rating scale, $n$is the number of validators, and $c$is the number of rating categories. The interpretation of Aiken's V values in this study followed a predefined validity criterion. Items with V ≥ 0.80 were categorized as valid and acceptable, while items with V < 0.80 were considered to require revision before use. This threshold is widely used in instrument development studies to ensure content validity based on expert agreement levels. The Aiken's V value ranges from 0 to 1, with higher values indicating stronger content validity. The validation results were interpreted based on these criteria and used to guide product revision.

The practicality questionnaire data were analyzed using descriptive percentage analysis:

$$\text{Practicality (\%)} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100$$

The percentage results were interpreted based on practicality criteria: scores above 85% were categorized as very practical, scores between 70% and 85% as practical, and scores below 70% as less practical. The practicality questionnaire was further tested for internal consistency reliability using Cronbach's Alpha. This analysis was conducted to ensure that all items consistently measure the same construct, namely usability, readability, and learning support. A Cronbach's Alpha value of ≥ 0.70 was used as the threshold for acceptable reliability in educational research instruments.
Qualitative data obtained from observation notes and interviews were analyzed using an interactive model consisting of data reduction, data display, and conclusion drawing. This process followed Miles and Huberman's framework to ensure systematic qualitative interpretation. In addition, qualitative reporting was guided by principles of clarity, contextualization, and transparency to ensure rigor in educational research (Levitt et al., 2018). The qualitative findings were used to complement quantitative results and identify necessary product revisions related to usability, readability, and instructional clarity.

The study was intentionally limited to the Develop stage of the 4D model. This decision was made because the primary objective of this research was to produce a validated and practical learning product, not to measure its effectiveness in improving student learning outcomes.

In development research, stopping at the Develop stage is acceptable when the focus is on product validation and feasibility testing before large-scale implementation. Further stages such as Disseminate require broader field testing, implementation scaling, and longitudinal evaluation, which are beyond the scope of this study.

Therefore, the limitation of scope ensures methodological alignment and prevents overclaiming of instructional effectiveness.

This manuscript is best framed as educational design research or R&D based product development. STROBE, CARE, CONSORT, and PRISMA are not the primary reporting frameworks for this study because the manuscript is not an observational epidemiological study, case report, clinical trial, or systematic review. Qualitative feedback from observations and interviews may be reported using qualitative reporting principles such as transparency of context, sampling, data collection, and analytic interpretation (Levitt et al., 2018).

RESULTS AND DISCUSSION

Results

This section presents the empirical findings obtained from expert validation and student practicality testing of the digital Polya-based e-problem sheet integrated with Bengkulu local wisdom for wave mechanics learning. The findings are organized into six tables. Table 1 describes the research participants and expert validators. Table 2 presents the instrument blueprint used for validation and practicality assessment. Tables 3, 4, and 5 present the validation results for content, media, and language aspects using Aiken's V. Table 6 presents the practicality results obtained from 60 students who had completed the Wave Mechanics course. The results are interpreted based on validity and practicality criteria commonly used in development research, where higher Aiken's V values indicate stronger expert agreement regarding item relevance and quality (Almanasreh et al., 2019; Wulanningtyas et al., 2026).

Table 1. Description of Participants and Expert Validators

Component	Description
Research site	Physics Education Study Program, University of Bengkulu
Academic period	Even semester of the 2025/2026 academic year
Total active students	196 students
Eligible population	144 students who had completed the Wave Mechanics course
Practicality trial sample	60 students
Sampling technique	Purposive sampling based on prior Wave Mechanics examination scores
Student ability representation	20 high achieving students, 20 medium-achieving students, and 20 low-achieving students
Expert validators	9 experts
Content validators	3 experts
Media validators	3 experts
Language validators	3 experts

Table 1 shows that the practicality trial involved 60 students selected from 144 eligible students who had completed the Wave Mechanics course. The sample was intentionally distributed across three levels of prior academic achievement: high, medium, and low competence, with 20 students in each group. This sampling strategy was used to ensure that the practicality assessment did not merely reflect the perceptions of high-performing students, but also captured the experience of students with different levels of prior conceptual mastery. Purposive sampling is appropriate when participants are selected based on specific characteristics relevant to the research purpose, particularly when their experience enables them to provide meaningful information about the phenomenon being studied (Campbell et al., 2020).

The table also shows that product validation involved nine experts: three content validators, three media validators, and three language validators. This distribution strengthens the evaluation process because each major quality dimension of the e-problem sheet was assessed by specialists in the relevant domain. Content validators focused on scientific accuracy and instructional alignment, media validators assessed digital design and usability, while language validators examined clarity, coherence, and technical precision. Such multidimensional validation is important in educational product development because the quality of a learning product depends not only on its content accuracy but also on its presentation, accessibility, and instructional clarity (Almanasreh et al., 2019; Boateng et al., 2018).

Table 2. Instrument Blueprint and Data Analysis Technique

Instrument	Respondent / Validator	Aspect	Indicator	Scale	Data Analysis
Content validation sheet	3 content validators	Content validity	Alignment with learning outcomes Scientific accuracy of wave concepts Local wisdom relevance in Bengkulu context Polya systematization Critical thinking stimulation based on Facione's indicators	Likert 1–5	Aiken's V
Media validation sheet	3 media validators	Media validity	Layout aesthetics Visual illustration quality Digital navigation Typography Media utility for visualization	Likert 1–5	
Language validation sheet	3 language validators	Language validity	Communicativeness Technical term precision Grammatical correctness Instruction clarity of Polya steps Coherence between sentences	Likert 1–5	
Practicality questionnaire	60 students	Practicality	Ease of use Time efficiency Content Appeal Related to Bengkulu Local Wisdom Clarity of Polya's steps Readability of text and visuals Independent learning support	Likert 1–5	Descriptive percentage

Table 2 presents the blueprint of the instruments used in this study. The validation instruments were divided into three major domains: content, media, and language. Each domain was assessed using a five-point Likert scale and analyzed using Aiken's V. This approach was used because expert judgment is commonly employed to examine content validity, particularly in the development of educational products, learning instruments, and assessment tools (Almanasreh et al., 2019; Wulanningtyas et al., 2026). The practicality questionnaire was administered to students and analyzed using descriptive percentage analysis to determine how practical the product was from the user's perspective.

The instrument blueprint also shows that the study did not only evaluate whether the product was scientifically correct, but also whether it was usable, readable, visually supportive, and suitable for independent learning. This is important because the success of digital learning media depends on the alignment between content, pedagogy, interface design, and user experience. Studies on instrument development emphasize that validity evidence should be built through clear constructs, relevant indicators, and systematic expert review (Boateng et al., 2018). Therefore, the instrument structure used in this study supports a comprehensive evaluation of the developed e-problem sheet.

Table 3. Results of Content Aspect Validation

No.	Content Indicator	Average Aiken's V	Category	Interpretation
1	Alignment with Learning Outcomes (CPMK)	0.97	Valid	The e-problem sheet was highly aligned with the intended learning outcomes.
2	Scientific Accuracy of Wave Concepts	0.93	Valid	The wave mechanics concepts were considered scientifically accurate by content experts.
3	Local Wisdom Relevance (Bengkulu Context)	0.93	Valid	The Bengkulu local wisdom contexts were considered relevant to wave mechanics learning.
4	Polya Systematization	0.96	Valid	The problem-solving sequence followed Polya's stages in a systematic manner.
5	Critical Thinking Stimulation	0.94	Valid	The learning tasks were considered capable of stimulating critical thinking indicators.
	Average Content Aspect Score	**0.95**	**Valid**	The content aspect met the validity criterion.

Table 3 shows that all content indicators obtained Aiken's V values above 0.93, with an average score of 0.95. The highest score was obtained by alignment with learning outcomes (V = 0.97), indicating that the validators strongly agreed that the e-problem sheet was consistent with the expected course learning outcomes. This finding is important because alignment between learning objectives, learning activities, and assessment tasks is a central requirement in educational product development. Without such alignment, even an attractive digital product may fail to support the intended learning process.

The scientific accuracy indicator obtained V = 0.93. Although valid, this score was lower than the alignment indicator, suggesting that wave mechanics content still requires careful conceptual treatment. This is reasonable because mechanical waves are known to involve abstract and representationally complex concepts, including wave propagation, energy transfer, vibration, superposition, and medium-related properties. Previous studies have shown that students often develop fragmented or incomplete understanding of wave propagation, which makes conceptual accuracy especially important in instructional design (Goodhew et al., 2019; Xie et al., 2021;Kanyesigye et al., 2022).

The local wisdom relevance indicator obtained V = 0.93, the lowest score within the content domain, although it remained valid. This suggests that Bengkulu local contexts such as Dol music, Bubungan Lima traditional houses, and coastal wave phenomena were considered relevant but still require explicit conceptual bridging to wave mechanics concepts. In culturally responsive science education, cultural context should not merely function as decoration; it should help learners connect scientific concepts to meaningful lived experiences (Smith et al., 2022). Therefore, the product should clearly explain how each local context represents specific wave concepts, such as resonance, vibration, damping, sound propagation, or mechanical wave behavior.

Table 4. Results of Media Aspect Validation

No.	Media Indicator	Average Aiken's V	Category	Interpretation
1	Layout Aesthetics	1.00	Valid	The layout design was considered highly appropriate and visually organized.
2	Visual Illustration Quality	0.94	Valid	The visual illustrations were considered supportive for understanding the material.
3	Digital Navigation	0.94	Valid	The digital navigation was considered clear and usable.
4	Typography	0.97	Valid	The font size, spacing, and text arrangement were considered readable.
5	Media Utility for Visualization	0.94	Valid	The media supported visualization of abstract wave mechanics concepts.
	Average Media Aspect Score	**0.96**	**Valid**	The media aspect met the validity criterion.

Table 4 presents the validation results for the media aspect. The average Aiken's V score for this aspect was 0.96, indicating that the digital design of the e-problem sheet was considered valid by media experts. The layout aesthetics indicator obtained the highest possible value (V = 1.00), showing complete expert agreement that the visual organization of the product was appropriate. This result indicates that the product's layout, spacing, and visual structure were considered suitable for supporting students' interaction with the learning material.

The visual illustration quality, digital navigation, and media utility for visualization indicators each obtained V = 0.94. These results suggest that the e-problem sheet was considered visually and functionally adequate, but still had room for refinement. In digital learning environments, visual materials can support conceptual understanding when they are directly related to the learning objectives and when students are guided to interpret them correctly. Research on multimedia learning and technology supported instruction shows that digital media can improve learning performance and engagement, but its effectiveness depends on design quality, navigation simplicity, and alignment with learning tasks (Noetel et al., 2021; Y. Sung et al., 2016). Therefore, the media components in this product should continue to emphasize clarity, simplicity, and instructional relevance rather than excessive visual decoration.

The high score for typography (V = 0.97) indicates that font size, spacing, and text arrangement were considered readable by experts. This finding is important because wave mechanics learning often involves verbal explanations, equations, diagrams, and contextual problems. Poor typography may increase cognitive load and reduce students' ability to process information. Thus, the high media validation results show that the product is visually feasible, but refinement of visual guidance, captions, and navigation prompts would further strengthen its usability.

Table 5 shows that the language aspect obtained an average Aiken's V score of 0.96, indicating that the language used in the e-problem sheet was valid. The highest score was obtained by instruction clarity of Polya steps (V = 1.00), suggesting that the instructions guiding students through understanding the problem, devising a plan, carrying out the plan, and looking back were very clear. This result is important because problem solving frameworks require explicit instructional language. If students do not understand what they are expected to do at each stage, the framework may become procedural rather than reflective.

Communicativeness, technical term precision, and grammatical correctness each obtained V = 0.94. These results indicate that the language was understandable and technically appropriate. However, the scores also suggest that further refinement may still be useful, especially for students with lower prior understanding of wave mechanics. Studies on mechanical wave learning show that students may struggle not only because the concepts are abstract, but also because terminology such as propagation, medium, frequency, resonance, and damping requires conceptual precision (Goodhew et al., 2019; Xie et al., 2021). Therefore, adding a glossary or short conceptual notes could improve accessibility, especially for medium and low-achieving students.

Table 5. Results of Language Aspect Validation

No.	Language Indicator	Average Aiken's V	Category	Interpretation
1	Communicativeness	0.94	Valid	The language was considered communicative and understandable.
2	Technical Term Precision	0.94	Valid	The use of technical physics terms was considered appropriate.
3	Grammatical Correctness	0.94	Valid	The sentence structure and grammar were considered acceptable.
4	Instruction Clarity of Polya Steps	1.00	Valid	The instructions for each Polya stage were considered very clear.
5	Coherence between Sentences	0.97	Valid	The flow of ideas between sentences was considered coherent.
	Average Language Aspect Score	**0.96**	**Valid**	The language aspect met the validity criterion.

The coherence indicator obtained V = 0.97, indicating that validators viewed the sequence of sentences, instructions, and problem solving prompts as logically connected. Coherent language is essential in digital worksheets because students often work independently and rely heavily on written instructions. This result supports the feasibility of using the product as an independent or semi-independent learning tool. The reliability test of the practicality instrument showed a Cronbach's Alpha value of 0.98 ($\geq$ 0,70). This indicates that the questionnaire has high internal consistency and is suitable for measuring student perceptions.

Table 6. Results of Student Practicality Trial

No.	Practicality Indicator	Average Percentage	Category	Interpretation
1	Ease of Use	95%	High Practicality	Students found the e-problem sheet easy to access and operate.
2	Time Efficiency	85%	High Practicality	The product was considered efficient enough for learning activities.
3	Content Appeal Related to Bengkulu Local Wisdom	100%	High Practicality	The local wisdom context was perceived as highly attractive.
4	Clarity of Polya's Steps	100%	High Practicality	Students found the problem solving stages very clear.
5	Readability of Text and Visuals	80%	High Practicality	Text and visuals were readable, although this was the lowest practicality indicator.
6	Independent Learning Support	83%	High Practicality	The product supported independent learning, but still has room for improvement.
	Average Practicality Score	**91%**	**High Practicality**	Overall, the e-problem sheet was highly practical for student use.

Table 6 presents the practicality results from 60 students. The overall practicality score was 91%, indicating that the digital Polya-based e-problem sheet was highly practical for student use. The highest scores were obtained by content appeal related to Bengkulu local wisdom and clarity of Polya's steps, both reaching 100%. This suggests that students found the local wisdom integration attractive and the problem solving stages easy to follow. The result supports the idea that contextual and culturally meaningful science learning can increase learner engagement when students recognize the relevance of the learning context (Smith et al., 2022).

Ease of use also obtained a very high score of 95%, indicating that students were generally able to operate the digital e-problem sheet without major difficulty. This result is consistent with studies showing that digital learning tools are more likely to be accepted when they are easy to access, easy to navigate, and compatible with students' learning routines (Y. T. Sung et al., 2016). Time efficiency obtained 85%, which remains in the high practicality category but is lower than ease of use and content appeal. This suggests that although students found the product usable, some activities may have required more time than expected.

Readability obtained the lowest score at 80%, followed by independent learning support at 83%. These two findings are especially important for product revision. Although both indicators still fall within the high practicality category, they indicate that students may still need clearer text organization, stronger visual text integration, and more learning support when using the e-problem sheet independently. Research on digital and multimedia learning warns that digital materials do not automatically improve learning; they must be designed with clear explanations, guided prompts, and appropriate cognitive support (Liu & Pásztor, 2022; Noetel et al., 2021).

Discussion

The findings indicate that the digital Polya-based e-problem sheet integrated with Bengkulu local wisdom is valid and highly practical for wave mechanics learning. However, deeper analysis is required to explain the variation in validation and practicality scores, particularly for Local Wisdom Relevance and Readability indicators, which obtained comparatively lower values. The developed e-problem sheet that is presented in Figure 3.

Instead of interpreting validation results only as numerical agreement among experts, this study positions the findings within Cognitive Load Theory and multimedia learning principles. Cognitive Load Theory explains that learning effectiveness is influenced by the balance between intrinsic, extraneous, and germane cognitive load during instructional processing. When instructional materials contain multiple representations such as text, visuals, cultural context, and problem solving steps, poorly structured integration may increase extraneous cognitive load and reduce conceptual clarity.

The Local Wisdom Relevance indicator received the lowest validity score among content components. Although experts agreed that Bengkulu cultural elements (Dol music, Bubungan Lima house, and coastal wave phenomena) are relevant, the score suggests insufficient explicit mapping between cultural context and physics concepts.

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Figure 3. The developed E-Problem Sheet

From a cognitive perspective, this issue reflects partial integration between contextual information and scientific abstraction. According to Cognitive Load Theory, contextual elements that are not explicitly linked to core concepts can create a split-attention effect, where learners divide attention between cultural narrative and scientific meaning without forming coherent schemas.

Similarly, Multimedia Learning Theory states that meaningful learning occurs when learners actively integrate words and visuals into a coherent mental model. In this study, some local wisdom elements functioned more as contextual "background stories" rather than integrated conceptual scaffolds. For example, Dol music and coastal waves were presented as examples, but not consistently connected to specific wave mechanics principles such as resonance, frequency, or wave attenuation.

Based on qualitative feedback from experts and student interviews, the following revisions were made:

1. Added explicit concept mapping between each local wisdom element and specific wave mechanics concepts.
2. Included guiding questions such as "What type of wave phenomenon is represented in Dol music?"
3. Inserted concept labels directly beside cultural illustrations.
4. Added short explanatory notes to reduce ambiguity in cultural scientific interpretation.

These revisions were designed to strengthen germane cognitive load by helping students build meaningful conceptual connections rather than treating cultural context as decorative content.

Readability received the lowest score in the student practicality test, indicating that some students experienced difficulty in processing text and visual information in the e-problem sheet. From the perspective of multimedia learning, readability issues are closely related to cognitive overload caused by poor information design. According to Mayer's Cognitive Theory of Multimedia Learning, learning is optimized when extraneous processing is minimized and essential processing is supported through clear segmentation and signaling principles.

The readability issue in this study can be explained by three cognitive factors:

1. High information density in some problem pages
2. Insufficient visual hierarchy between instructions and content
3. Limited segmentation of long instructional text

These conditions increase extraneous cognitive load, making it harder for students, especially low-achieving groups, to process and organize information efficiently.

The product revision was conducted based on three sources of feedback: expert validator comments, student observation notes, and interview data. One of the validators emphasized the need to improve the clarity of instructions, visual organization, and the explicit connection between local wisdom contexts and wave mechanics concepts. In addition, student observations and interviews indicated that several parts of the e-problem sheet still needed improvement in terms of readability, navigation, and independent learning support. Therefore, several concrete revisions were implemented to reduce cognitive load, clarify the problemsolving flow, and help students engage with each Polya stage more systematically. The details of the product revisions are presented in Table 7.

Table 7. Concrete Product Revisions

No.	Revision Aspect	Concrete Design Revisions	Purpose of Revision
1	Text simplification	Long paragraphs were broken into shorter instructional chunks. Key instructions were rewritten using a step by step format.	To make the instructions easier to read, understand, and follow.
2	Visual restructuring	Headings, icons, and numbering were added to improve navigation. Spacing	To help students identify each learning section clearly and

No.	Revision Aspect	Concrete Design Revisions	Purpose of Revision
		between Polya stages was improved to support sequential thinking.	follow the problem solving flow systematically.
3	Signaling enhancement	Important formulas and instructions were highlighted using visual cues. Arrows and labels were added to guide students' attention flow.	To direct students' focus to essential information and reduce confusion during learning.
4	Segmentation of learning tasks	Each Polya stage was separated into distinct interactive sections. Students can now complete tasks step by step without cognitive overload.	To reduce excessive information processing and support gradual problem-solving activities.
5	Readability support tools	A glossary of key physics terms, such as wave, resonance, damping, and interference, was added. Hint buttons were also provided for difficult questions in the digital worksheet.	To support students' understanding of technical terms and help them complete challenging tasks independently.

These revisions directly addressed student difficulties and reduced extraneous cognitive load while increasing usability and comprehension.

Overall, the lower scores in Local Wisdom Relevance and Readability do not indicate failure of the product, but rather highlight critical design constraints in integrating contextual learning and multimedia-based instruction. When interpreted through Cognitive Load Theory and Multimedia Learning principles, these limitations point to the need for stronger alignment between cultural context, scientific explanation, and instructional design structure.

The revision process demonstrates that improving educational digital tools is not only about content validity, but also about optimizing cognitive processing conditions so that learners can construct meaningful scientific understanding.

Implications

The findings imply that the developed e-problem sheet can be used as a practical digital learning tool for wave mechanics instruction. The integration of Polya's problem solving stages provides a structured pathway for students to analyze problems, plan solutions, implement strategies, and reflect on their answers. The integration of Bengkulu local wisdom also provides contextual relevance that may increase student engagement and help students connect abstract wave concepts with real-world phenomena.

From a pedagogical perspective, the product is suitable for guided independent learning, blended learning, or classroom-based problem solving activities. However, instructors should still provide initial orientation, especially for students with lower prior achievement or limited digital learning experience. This is important because digital learning materials are most effective when accompanied by clear scaffolding and feedback.

Research Contribution

This study contributes to physics education research by developing and validating a digital e-problem sheet that integrates three important components: Polya based problem solving, critical-thinking-oriented tasks, and Bengkulu local wisdom. The study also provides a systematic example of product evaluation through expert validation and student practicality testing. Methodologically, the study demonstrates how content, media, language, and practicality indicators can be combined to evaluate an educational product at the development stage.

Limitations

This study was limited to product validity and practicality evaluation. It did not measure the effectiveness of the product in improving students' critical thinking skills, conceptual understanding, or academic achievement. The practicality trial was also limited to 60 students from one study program, although the sample represented high, medium, and low competence groups. Therefore, the findings should not be generalized beyond similar contexts without further testing.

Suggestions

Future research should examine the effectiveness of the e-problem sheet using a pretest-posttest control group design or quasi-experimental design. Further studies may also compare student performance across different competence levels to determine whether the product supports high, medium, and low-achieving students equally. In addition, future product revisions should focus on improving readability, adding conceptual feedback, strengthening independent learning support, and making the connection between Bengkulu local wisdom and wave mechanics concepts more explicit.

CONCLUSION

The study successfully developed a digital Polya-based e-problem sheet integrated with Bengkulu local wisdom for wave mechanics learning, demonstrating strong validity across content, media, and language aspects and high practicality among students of varying competence levels. Unlike experimental studies that measure learning outcomes through pretest-posttest comparisons, this research is positioned within Research and Development (R&D) methodology, which emphasizes product quality in terms of validity and practicality rather than learning effectiveness. Therefore, the interpretation of results must remain consistent with the methodological scope of the study.

The product aligns with instructional needs by providing structured problem-solving guidance, contextual learning integration, and scaffolding based on Polya’s stages and critical thinking indicators. However, instead of claiming direct improvement in student achievement, the findings indicate that the developed e-problem sheet has the potential to support critical thinking processes by guiding students through structured reasoning, contextual interpretation, and reflective problem solving.

Specifically, the integration of digital learning design, Polya-based scaffolding, and Bengkulu local wisdom suggests that the learning tool can potentially stimulate students’ critical thinking engagement, particularly in interpretation, analysis, and evaluation processes, when applied in structured learning environments.

Readability and independent learning support require minor refinement to optimize user experience and reduce cognitive load. Nevertheless, the product is feasible for classroom implementation and guided independent learning.

Overall, this study confirms that culturally contextual and problem-solving oriented digital learning tools can support meaningful learning design in physics education. The product should be further tested in future research using experimental or quasi-experimental designs to examine its actual impact on critical thinking development and conceptual understanding.

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AUTHOR CONTRIBUTION STATEMENT

DHP, AR, FAY, and SNM contributed to the conceptualization, methodology, and design of the research. DHP and FAY conducted the data collection and validation processes, while AR and SNM performed data analysis and interpretation, AW assisted the data collection process. All authors contributed to manuscript writing, revision, and approval of the final version.

AI DISCLOSURE STATEMENT

All conceptual development, data analysis, interpretation of findings, and final scientific decisions were conducted solely by the authors. The authors used ChatGPT and Grammarly during the preparation of this manuscript for graphic visuals, language refinement, structural editing, and academic writing enhancement. After using these tools, the authors carefully reviewed, revised, and validated the manuscript and take full responsibility for the accuracy, originality, and integrity of the final publication.

CONFLICTS OF INTEREST

The authors declare that there are no financial, institutional, personal, or other potential conflicts of interest that could have influenced the conduct of this study, the analysis and interpretation of the data, the preparation of the manuscript, or the decision to publish the results.

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