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The Development of Adaptive E-Scaffolding to Support the Academic Diversity of High School Students on Mechanical Waves Material

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Abstract

Waves are an abstract concept frequently challenging for students to grasp, as it is believed that only talented students can master it. Moreover, upon entering the classroom, each student possesses a unique understanding. Differentiated learning is suggested as a solution to manage the diversity of students in the classroom. This study aims to develop adaptive e-scaffolding for the Moodle LMS. This study design was the research and development using Analyze, Design, Develop, Implement, and Evaluate (ADDIE) model. Variable levels of scaffolding are incorporated into adaptive e-scaffolding by student abilities. The validation conducted by three experts in physics education and educational technology yielded a score of 3.78 and deemed adaptive e-scaffolding valid. The implementation outcomes show that the adaptive e-scaffolding achieves an average readability percentage of 79.2%, and the highest score was obtained in the feedback category. In summary, implementing adaptive learning technologies, such as e-scaffolding, can enhance students' engagement with learning materials and assist teachers in addressing classroom diversity. Teachers, e-learning developers, and other professionals in the field of education must give due consideration to how technology enables adaptive learning strategies.

Keywords: adaptive; differentiated instruction; e-scaffolding; mechanical wave

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INTRODUCTION

The utilization of the wave concept is progressively becoming more evident to individuals in contemporary society, from tangible occurrences like rope or slinky to intangible ones like radio or ultrasound (USG). Nevertheless, 58% of students consider the notion of waves complex, abstract, and unsuitable for all but the talented (Erinosho, 2013). Furthermore, students' comprehension of concepts is also influenced by their ability to multi-represent wave theory. As an illustration, a study conducted by Rangkuti dan Karam, (2022) found that to ascertain the speed of wave propagation, students compare the graph to the motion of a roller coaster. Furthermore, it is common for students to become entangled in a misunderstanding of the mathematical correlation that exists among propagation speed, wavelength, and frequency

(Goodhew et al., 2019; Kanyesigye et al., 2022; Rangkuti & Karam, 2022; Xie et al., 2021). Students, therefore, bring a variety of resources to the classroom. This creates a challenge for teachers to accommodate the diverse needs of all students in the classroom, and differentiated learning (DL) is one practical solution. Fundamentally, DL is an instructional approach that facilitates effective learning by catering to the diverse needs of students (Kristiani et al., 2021; Suprayogi et al., 2017).

The number of studies devoted to DM increases annually (Am et al., 2023; Sun & Xiao, 2021). Likewise, Differentiated Learning has emerged as a pivotal subject in Indonesia, universally integrated into the Merdeka Curriculum (Santoso et al., 2022). The theme of DM has been widely studied on how to improve teacher professionalism, but limited research has been conducted on its effects on students (Gheyssens et al., 2022). Scholarly attention has been drawn to academic self-concept, social inclusion, and student well-being in recent years (Pozas et al., 2021) and reading fluency (Peters et al., 2021).

Teachers encounter a multitude of challenges and impediments when attempting to implement DL. According to research findings presented by Suprayogi et al. (2017), teachers in Indonesia continue to be subordinate to the central authority, lack independence, and some teachers do not engage in any form of self-development. Since the distribution of the Merdeka Curriculum, teachers have actively engaged in numerous workshops incorporating DL as one subject matter (Astiti et al., 2023; Mastuti et al., 2022; Sutaga, 2022). However, their comprehension of DL remains incomplete (Usman et al., 2022). Diverse methods have been utilized to streamline the implementation of differentiated learning, which has been deemed difficult (Gheyssens et al., 2022). For instance, DL involves the initial learning of complex tasks (Westbroek et al., 2020). Research by Santoso et al. (2022a) demonstrates that physics teachers encounter challenges with regard to assessment accuracy and fairness, which consequently contributes to an increase in teachers' workloads. Therefore, it is critical to develop technology that assists teachers in catering to the diverse needs of their students.

The discourse surrounding the advancement of educational technologies capable of supporting students' learning in the context of academic diversity remains limited. Am et al. (2023) dan Santoso et al. (2022a), citing the findings of bibliometric studies, suggest online learning and the application of technology in DM as a central theme. According to the findings of an additional literature review conducted by Safarati & Zuhra (2023), assessing the influence of DL on student learning outcomes is its primary focus. This demonstrates that research on the role of technology in DL is lacking.

The researcher's objective is to develop adaptive e-scaffolding on the Moodle LMS using Mechanical Wave Material, as described in the preceding section. Additionally, the researchers seek an expert's assessment regarding the learning media's eligibility and readability.

METHOD

This study is Research and Development (R&D). On the subject of mechanical waves, the researchers developed adaptive e-scaffolding on the LMS Moodle utilizing the ADDIE (Analyse, Design, Develop, Implement, and Evaluate) model. This design includes some stages: analysis, design, development, implementation, and evaluation (Branch, 2009). The flowchart stages are illustrated in Figure 1.

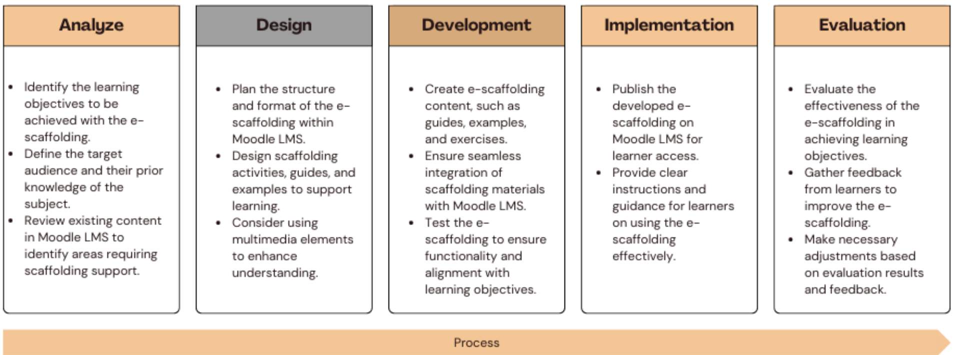

Figure 1 ADDIE model design for research

During the Analyze phase, a comprehensive review of the literature was undertaken concerning learning media that have been designed with students' academic diversity in mind. Furthermore, interviews and observations were conducted regarding implementing differentiated instruction in schools. The findings of the analysis were subsequently implemented as a basis for developing e-scaffolding (as in the design stage). The blueprint design was subsequently refined via an LMS Moodle course incorporating the adaptive mode functionality of Quiz (Develop). In addition, the outcomes of the adaptive e-scaffolding development were evaluated with a restricted sample size of five students, who subsequently offered their feedback and input.

Physics education and learning technology experts validated the adaptive e-scaffolding after revisions prompted by feedback obtained during the limited trial phase. For data validation, the closed-ended questions employing a Likert scale of 1-4 and open-ended questions were utilized. E-scaffolding underwent enhancements in response to recommendations from experts prior to its extensive adoption. During the Implementation Phase, E-scaffolding was implemented in one of 35 (N=35) randomly selected classes at an Indonesian public high school. Students were provided with a username and password during the implementation phase to access and utilize e-scaffolding for learning. After employing the technology, students responded openly to a questionnaire regarding their experience with adaptive e-scaffolding.

The data analysis was conducted by calculating the mean score for each indicator as follows.

$$\bar{x} = \frac{\sum x}{n} \qquad \dots (1)$$

Description:

$\bar{x}$ = average score for eligibility

Σx = sum of eligibility scores

n = quantity of participants

The analysis results indicate the adaptive e-scaffolding product's mean eligibility score. Then, the product eligibility criteria can be determined based on Table 1.

Table 1 The validation criteria for every indicator

Average score	Validation criteria
3.2 – 4.0	Valid (without revision)
2.2 – 3.1	Valid (minor revision)
1.2 – 2.1	Less Valid (mayor revision)
0.0 – 1.1	Invalid (full revision)

In addition, the technique employed for assessing the media's readability involves using a percentage calculation technique. The percentage of readability is ascertained using the equation provided below.

$$x = \frac{\sum x}{\sum x_m} \times 100\% \qquad \dots (2)$$

Description:

x = Score for readability

Σx = Total score for readability
Σx_m = Maximum total score for readability

Table 2 Criteria for the results of student readability tests

Percentage	Readability criteria
76 – 100	Very readable
51 – 75	Readable
26 – 50	Less readable
0 – 25	Not readable

RESULTS AND DISCUSSION

A requirements analysis was undertaken during the preliminary phase, drawing upon a review of relevant literature and observations/interviews. The literature review on technology integration in DL has identified several key findings, including the significance attributed to android-based learning media (Purwanto & Gita, 2023) and multimedia tools (Estaiteyeh & DeCoito, 2023; Nurlaili et al., 2023). In conclusion, technologically advanced learning can create inclusive environments for all students (Alshareef et al., 2022; Johler & Krumsvik, 2022). However, not all of these technologies provide students with optimal guidance. The researchers found several explanations in the literature. For example, Johler & Krumsvik (2022) mentioned that relying too much on technological sophistication can divert the Teacher's primary pedagogical and didactic role. The incorrect focus results in an imbalance between inclusive learning and individualized learning.

The researchers also discovered other views on how DL should be conducted. For example, research by Nurlaili et al. (2023) revealed that school facilities such as projectors, speakers, and microphones are mandatory needs to service students based on learning styles. However, the discussion about learning styles is still much debated (Nancekivell et al., 2021). Part of the research community regards learning styles as a myth based on empirical evidence from several years back. Thus, in developing this media, the researchers did not consider learning styles as one of the references for designing adaptive e-scaffolding.

The results of a bibliometric study by Am et al. (2023) also highlighted the transition in the theme of DL from scaffolds and customization services to adaptive systems. This result prompted the researchers to use the terms scaffolds and adaptive. Actually, the term scaffolding pertains to the tutorial process by an adult or expert to someone younger or a beginner (Belland et al., 2017; Kim et al., 2020; Wood et al., 1976). However, since 2015, the term scaffold has been used to guide students with different academic diversity (Am et al., 2023). Recommendations by Johler & Krumsvik (2022) to improve the quality of inclusive learning include a lot of guidance on the technology utilized.

The results of interviews with three physics teachers (Initials M, N, and O) in three public high schools in East Java concluded that wave material still tends to be taught textually, with application descriptions, example problems, and simple demonstrations. All three teachers claimed to have attended differentiated learning workshops and implemented them in their respective schools. However, Teacher N said it is difficult to implement differentiated designs to adjust to the complex variations in student diversity. Teacher M confessed that the difference in initial knowledge is a challenge for teachers in adjusting learning activities. Students with high prior knowledge were often considered peer tutors by Teacher O. However, Teacher O could not corroborate how students with prior knowledge learn. These interview results confirm previous research Alshareef et al. (2022); Johler & Krumsvik (2022); and Santoso et al., (2022a) that teachers tend to experience workload, do not have much preparation time, lack support, and feel inaccurate in making DL decisions. Teachers also do not have sufficient competence to develop engaging learning technologies (such as research by Estaiteyeh & DeCoito, (2023)). Thus, based on the field observations and literature evaluation results, the researchers used it as a reference in the next stage.

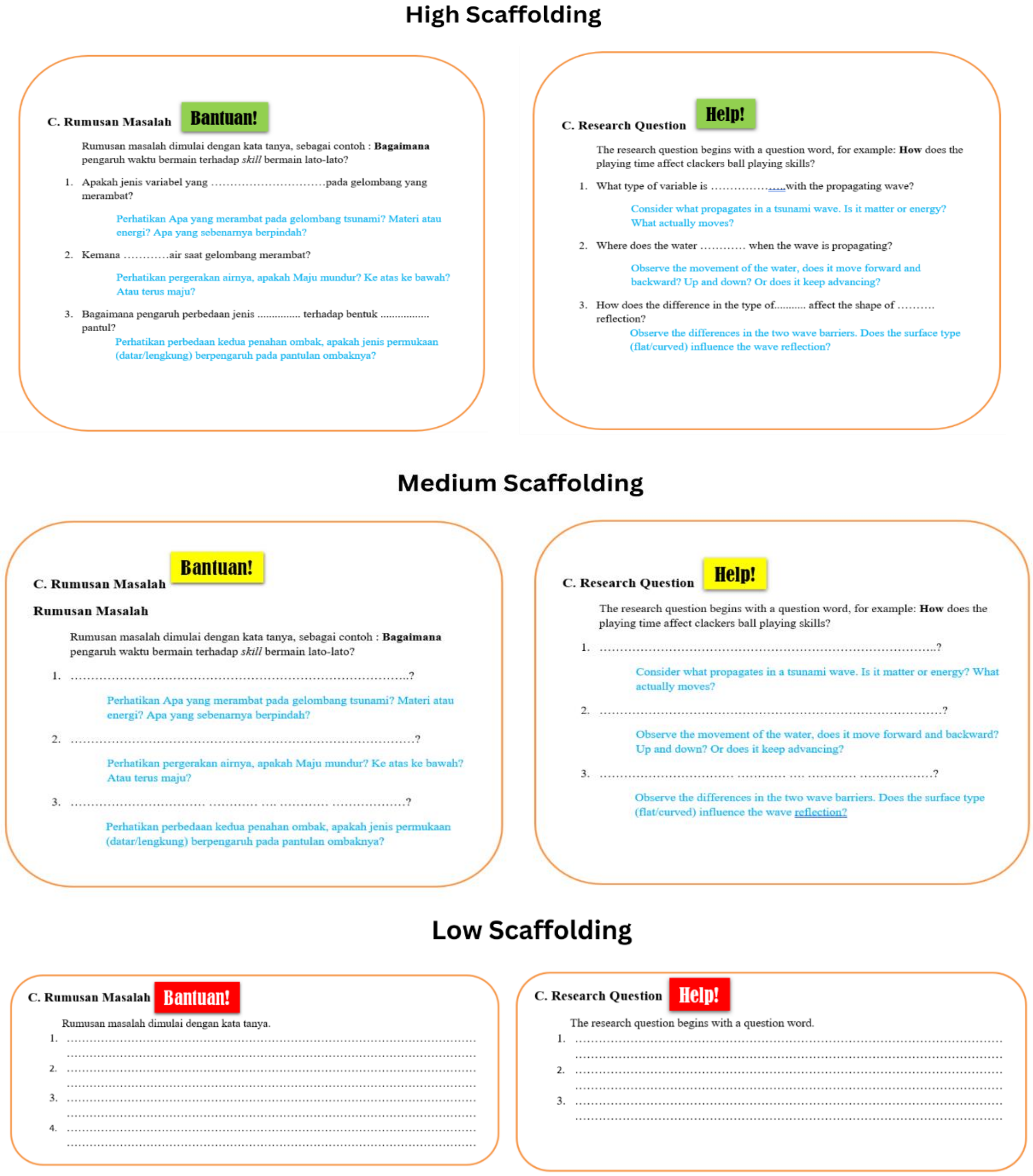

Figure 2 Scaffolding level design

At the Design stage, the researchers designed an inquiry-based learning framework on Mechanical Waves using several categories of guides. The researchers highlighted the results of a meta-analysis by Lazonder & Harmsen (2016), which mentioned that a combination of various types of guides offers more effective results than a single type of guide.

Students are guided by worksheets that offer high, medium, and low levels of scaffolding during learning (See Figure 2). The worksheet utilized depends on the results of the initial knowledge test for the first worksheet and the previous performance worksheet scores for the second to sixth worksheets. As illustrated in Figure 2, the low scaffolding worksheet (red help button) directs students to perform a task with a prompt sentence (e.g. using a query sentence when formulating the problem) (Zacharia et al., 2015). Worksheets with medium-level scaffolding (yellow assistance button) offer heuristic guidance to emphasize what should be considered in formulating the problem, formulating hypotheses, analyzing data, and making conclusions (Zacharia et al., 2015). In the worksheet with a high level of scaffolding (green assistance button), additional guidance is provided, like the second worksheet. However, the problem formulation is provided incompletely, so students need to fill in the dots according to instructions such as research by Kuang et al. (2020)

Adaptive e-scaffolding was designed on six subchapters of wave material, as shown in Figure 3. The color of the arrow denotes the level of scaffolding used by students. As described in Figure 2, students were directed to use the assistance according to their prior knowledge. The researchers chose to move up or down one level on each scaffolding in each meeting.

At the design stage, several revisions were made based on the physics expert's assessment of the worksheet developed before being integrated into Moodle. For example, the scaffolding to create a problem formulation about wave characteristics from "Look at the wave barrier, how do you think the waves will reflect?" to "Look at the difference between the two wave barriers, does the type of surface (flat/curved) affect the reflection of the waves?". The change in redaction stimulates students to formulate a problem by comparing the shapes of various wave barriers and how they affect the reflected waves.

Figure 3 Wave sub-material

The design results indicate that the media was developed on a course on Moodle LMS. Moodle LMS is a suitable choice because its features are quite complete, so it tends to have a positive impact due to several factors such as performance expectations, social influence, habitual facility conditions, and satisfaction (Ikhsan et al., 2023). The course display and e-scaffolding level categories are shown in Figures 4 and 5, respectively.

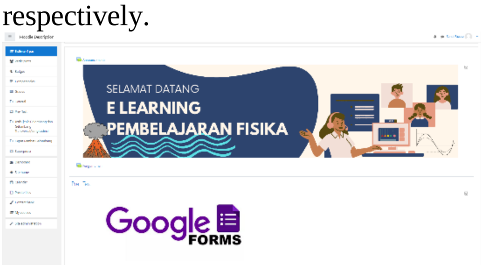

Figure 4 Course display

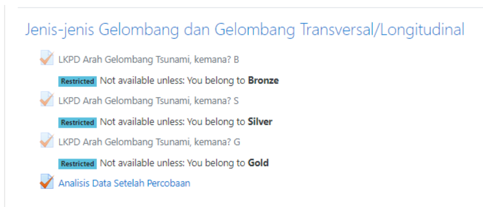

Figure 5 Adaptive e-scaffolding access display

Students have been divided based on their test results or performance during learning in Figure 5. This development is like the one done by Aitdaoud et al. (2023), who used Moodle to group students based on learning methods. Then, the developed version of the media was validated by one educational technology expert and two physics education experts. The validation results are shown in Table 3.

Table 3 Content validation results

Category	Score
Appropriateness of physics concepts and principles in the media	3.67
Conformity with learning objectives in the curriculum	3.67
Appropriateness to students' cognitive aptitude	4.00

Table 3 summarizes the content validation findings encompassing three components: correctness of ideas, curriculum suitability, and students' cognitive level related to media use, with an average of 3.78. Table 4 illustrates the results of concept validation using two indicators of language and design.

Table 4 Construct validation results

Category	Score
Language	
The suitability of the sentences used in the worksheet and E-scaffolding with sound and correct language rules	3.67
Use straightforward sentences that are easy to understand and do not contain double meanings	3.67
Design	
The color of the help button makes it simpler to remember the desired scaffolding level	3.67
Images and text as instructions provided are inserted proportionally	4
The worksheets and E-Scaffolding design make it simple for media users	3.67
Media design is fascinating to use	3.67

In addition, the researchers claim several categories that demonstrate the validity of the media that have been developed. Table 5 summarizes the expert perspectives on this claim.

Table 5 Claim validation results

Category	Score
The help button is easy to locate and access	4
The e-scaffolding available is appropriate for the student's capabilities	3.67
The use of media in education has the potential to increase student engagement	3.67
Media can assist students in improving their ability to conduct scientific inquiry	3.67
Media can help students enhance their understanding of mechanical waves	3.33

The most interesting part of the validation process was when the validators openly disclosed their responses, as the researchers believe this contributed more to the development of the idea than just quantitative findings. Table 6 summarizes the answers from the experts and practitioners.

Table 6 Summary results of open suggestions from experts

No	Open Suggestion
1	Add student hint captions on Gold, Bronze, and Silver levels
2	The Help button should not be available if students are continually using it
3	Provide a special marker if the assistance button is accessed too much
4	Online worksheets need to be provided in PDF form
5	Add step-by-step instructions to any online worksheets that lack detail.

The evaluation results at the development stage are considered to enhance the course that has been developed, for example, by adding information on the division of students based on prior knowledge into three distinct groups of students. It is emphasized that the division of groups and the differences in online worksheets accessed by each student are by their initial knowledge. If, in the learning process, students perceive that they are not in accordance with the level of worksheet accessed, then students can adjust by choosing down / up the level of the group type.

After revision, the media was implemented on 35 grade XI students to be evaluated based on the readability test results. The average percentage value of adaptive e-scaffolding readability is 79.2%.

Table 7 Readability trial results

Category	Percentage
Language	79.4
Display	81.7
Accessibility	74.9
Material	77.1
Feedback	82.9

The implementation results to determine the readability of e-scaffolding media yielded the test results as in Table 7. From these results, the accessibility category obtained the smallest score among others. A possible explanation for this result is the first experience of students using the Moodle LMS, which makes them unfamiliar with it (Al-Hunaiyyan et al., 2020; Ožvoldová et al., 2012). Secondly, students complained about internet access because accessing the assistance button took quite a while. Meanwhile, the feedback category obtained the highest score. In accordance with the results of the review by Gamage et al. (2022), Moodle LMS is very suitable for adaptive learning so that it can serve according to students' abilities. The e-scaffolding developed in it provides students with satisfaction, performance enhancement, and engagement in learning.

The results of this study have two implications. First, teachers can use adaptive technology to reduce their workload in adjusting learning to each student. Teachers can prepare learning materials accompanied by scaffolding on E-learning through adaptive mode (Quiz). Second, students' experience during the pandemic cannot ensure that students are familiar with e-learning. Thus, teachers need to introduce features and procedures for students to use by adding captions, etc. Finally, future research can integrate Artificial Intelligence with scaffolding to implement a more refined adaptive system based on student big data.

CONCLUSION

This article explains the significance of differentiated learning in overcoming students' difficulties in understanding the concept of mechanical waves. The development of adaptive e-scaffolding on LMS Moodle for the material has been carried out. The results of validation by physics education and educational technology experts showed this media's eligibility in concept, language, and design. Implementation on students resulted in an excellent readability level (79.2%), with the feedback category receiving the highest score. This article provides a comprehensive view of the development of adaptive learning technology in confronting student diversity challenges in the classroom. This adaptive e-scaffolding can provide solutions for teachers in serving students with various abilities.

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