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DESIGN OF AN INTERACTIVE E-MODULE BASED ON COGNITIVE CONFLICT AND DEEP LEARNING APPROACH FOR REMEDIATING STUDENTS' MISCONCEPTIONS ON LIGHT WAVE CONCEPTS

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ABSTRACT

Conceptual understanding is a critical 21st-century competency that enables students to solve increasingly complex problems; however, physics instruction particularly regarding light waves is highly prone to misconceptions due to the subject's abstract nature. A preliminary study at MAN 3 in Padang City showed that only 18.1% of students were classified as having a good grasp of the concepts, while 12.6% did not understand the concepts and 69.4% held misconceptions. Interviews with teachers and students revealed that instruction remains teacher-centered and that no specially designed digital learning materials are currently available, while an analysis of textbooks identified conceptual errors that could potentially lead to new misconceptions. This study aims to describe the characteristics of and develop a valid and practical interactive e-module based on cognitive conflict and the deep learning approach for the topic of light waves. The e-module was designed to remediate students' misconceptions. This development study utilized Plomp's model, limited to the one-to-one practicality testing phase with three students of high, moderate, and low ability levels. The e-module integrates four cognitive conflict strategies activation of preconceptions and misconceptions, presentation of cognitive conflicts, discovery of concepts and equations, and reflection combined with the principles of mindful, meaningful, and joyful learning. Expert validation results indicate that the e-module is highly valid, with an average Aiken's V index of 0.92, and the one-to-one test results show that the e-module is highly practical, with an average score of 88.3% based on student perceptions. These results demonstrate the validity and practicality of the e-module, but not its effectiveness in remediating misconceptions. An effectiveness test has not yet been conducted; therefore, this e-module currently only has the potential to support the remediation of misconceptions and requires further testing in subsequent research.

Keywords :E-Module, Cognitive Conflict, Deep Learning Approach, Misconception Remediation, Light Waves.

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I. INTRODUCTION

Twenty-first-century education demands that students not only master information but also be able to think critically and understand concepts in depth so that they can be used to solve more complex problems. It is this demand that underlies the introduction of the Merdeka Curriculum, which defines the success of learning not by how much information students can memorize, but by the depth of their conceptual understanding [1]. Conceptual understanding is the ability to know, comprehend, and restate a concept in one's own words, including relating it to other concepts and applying it to new problems [2], and even the slightest error in interpreting it can lead to misunderstandings in subsequent stages [3]. One field of study that demands a deep conceptual understanding is physics, given its role as a foundational science that underpins the development of science and technology [4].

Physics concepts are hierarchical, and many physics terms sound similar to everyday language but have different meanings This characteristic makes physics learning prone to misunderstandings. If initial misunderstandings are not corrected immediately, they will carry over and affect understanding of subsequent material [5]. Such misunderstandings are known as misconceptions that is, the use of concepts that do not align with those scientifically agreed upon by experts [6], which can stem from the students themselves, teacher errors, textbook errors, contextual errors, or teaching method errors (Suparno (2013)) in [7]. There are still few teachers who pay attention to and address their students' misconceptions [8], even though misconceptions held by teachers have the potential to be passed on to students [9].

The topic of light waves was chosen for this study because many of its concepts are abstract and difficult to observe directly. Reflection and refraction involve changes in the direction of wave propagation at the interface between two media, while interference and diffraction depend on wave superposition and phase differences that are invisible to the naked eye. Students cannot see how light waves behave when they are reflected, refracted, or meet and interfere with one another. This situation can easily lead students to form their own incorrect understandings. Therefore, teaching this topic requires interactive visualizations such as animations, videos, and simulations—that allow students to change variables and observe the results directly. Similar needs have also been reported in the topics of dynamic electricity [10] and reflex motion [11]. Concepts conveyed solely verbally are difficult for students to visualize, making visual teaching materials such as e-modules necessary. Research [12] shows that direct observation through laboratory experiments can correct misconceptions. Students who heated ice observed that the temperature remained at 0°C during melting, thereby correcting the assumption that temperature always rises when heat is applied. Such direct observation is difficult to conduct for light interference and diffraction due to limitations in optical equipment at schools, as found in preliminary research. Therefore, virtual simulations are needed as a substitute for direct observation, allowing students to vary the conditions and observe these phenomena independently.

Three previous studies on students' conceptual understanding of light waves showed a consistent pattern: the percentage of students who did not understand the concepts and held misconceptions was always higher than the percentage who did understand the concepts. The study [13] reported that only 13.2% of students understood the concepts. The study [14] reported the highest rate of misconceptions (48%) regarding interference and diffraction, while the study [15] reported the highest rate of conceptual misunderstanding (40%) regarding the formation of rainbow colors. These findings indicate that misconceptions regarding light waves recur across different contexts, making it necessary to address these misconceptions in this subject matter. However, all three studies stopped at identifying the level of understanding and did not provide instructional materials to address these misconceptions. This is the basis for the need for further development in this study.

To determine whether this pattern also occurs in the context of this study, a preliminary study was conducted at MAN 3 Kota Padang through three stages. First, interviews with two physics teachers and three 12th-grade students in Phase F revealed that instruction is still dominated by the lecture method, resulting in passive student learning. Misconceptions arise quite frequently, particularly the belief that light always travels in a straight line and errors in understanding refraction; however, these have so far been identified only through verbal questioning without structured instruments. The physics laboratory is also inadequate, with only one incomplete set of optical lab equipment available. Students reported difficulty understanding abstract material and consistently preferred smartphone-based learning materials over printed ones. Second, an analysis of the 11th-grade high school/MA physics textbook in use, employing the content suitability instrument [16], revealed that content suitability remains problematic. One such issue is found in the explanation of thin-film light interference, which incorrectly refers to a concave (diverging) lens, whereas the lens that should focus two coherent light beams to cause interference is a convex (converging) lens. This error risks creating new misconceptions among students who read the material independently. Third, a four-tier multiple-choice diagnostic test assessing conceptual understanding among 31 Grade 12 Science Class 2 students revealed that only 18.1% understood the concept, 12.6% did not understand it, and 69.4% held misconceptions. These results align with the patterns observed in the three previous studies.

Based on this preliminary study, it was found that at MAN 3 Kota Padang, digital instructional materials have not yet been used in teaching the wave nature of light, no specific instructional model has been implemented to address misconceptions, and the textbooks used have the potential to create new misconceptions . These findings stem from the preliminary study at that school and are not intended as a generalization for other schools. Among these factors, instructional materials are considered the most critical because they play a direct role in shaping students' understanding of a concept, while also serving as a learning

resource, a communication tool, and a means of conveying information in education [17]. Engaging instructional materials can capture students' attention, stimulate critical thinking, and boost their motivation to learn [18]. Among various forms of instructional materials, e-modules were selected because they address two identified issues: limited access to printed books and students' preference for electronic instructional materials. E-modules can also present content in a structured and interactive manner through images, animations, videos, and simulations [10].

E-modules have been developed for other subjects as well. The study [11] developed a biology e-module on reflex movements based on a contextual approach for 11th-grade high school students using the ADDIE model. The e-module received very high ratings from media experts (84%), learning experts (84%), teachers (69%), as well as students in small-scale (80%) and large-scale (74%) pilot tests. These results indicate that the e-module is suitable for use as instructional material. However, the study was limited to assessing quality and feasibility, so the authors state that its effectiveness requires further testing. The contextual approach used was also not designed to address and correct established misconceptions, and the material falls outside the scope of physics. These results indicate that the e-module can be developed appropriately but does not yet address the need for remedial instruction regarding misconceptions in light wave material.

Providing instructional materials alone is not sufficient without a learning model specifically capable of correcting conceptual errors that have already taken root, rather than merely repeating the same material. A cognitive conflict-based learning model is considered suitable for this purpose[19]. This model exposes students to phenomena or data that contradict their preconceptions. This conflict creates a cognitive imbalance that prompts students to reconstruct their knowledge toward concepts consistent with scientific explanations. The process unfolds through four stages: (1) activation of preconceptions and misconceptions, (2) presentation of cognitive conflict, (3) discovery of concepts and equations, and (4) reflection [6]. This model has been proven effective in remediating misconceptions while simultaneously enhancing students' conceptual understanding [9]. Research [12] also notes that the cognitive conflict strategy is among those widely used in the remediation of misconceptions.

The application of cognitive conflict in instructional materials has also been reported. The study [20] developed an interactive e-module based on cognitive conflict to address misconceptions regarding the concept of force, with a focus on its design and validity. The study [21] integrates cognitive conflict into instructional materials for teaching light waves and examines its impact on students' conceptual understanding and learning motivation. However, neither of these studies has combined cognitive conflict with a deep learning approach, so they have not addressed how to ensure that the newly formed understanding remains meaningful and enduring. The study [20] was also conducted on the concept of force, not light waves. Based on the literature review conducted by the author, no study has been found that combines cognitive conflict and the deep learning approach in the form of an e-module to remediate misconceptions in light wave material.

Nevertheless, the cognitive conflict model places greater emphasis on the stages of identifying and confronting misconceptions. This model has not specifically addressed how to ensure that the new understanding formed is long-lasting and meaningful for students. The deep learning approach, which emphasizes meaningful, mindful, and joyful learning [22], is integrated with this model to address these shortcomings. The term "deep learning approach" in this paper refers to a pedagogical approach, not "deep learning" as a branch of artificial intelligence. Cognitive conflict corrects initial misconceptions, while the deep learning approach ensures that new understanding is not merely fleeting.

The roles of these three principles can be explained as follows. The mindful principle enables students to consciously observe and recognize changes in their understanding from preconceptions to scientific concepts ensuring that cognitive conflict does not simply pass by unnoticed. The meaningful principle connects the phenomena that trigger conflict to everyday experiences so that new concepts hold meaning for students. The "joyful" principle maintains student engagement throughout the process of conceptual confrontation and discovery. In this e-module, these principles are mapped to each syntax. The preconception activation quiz applies the "mindful" and "joyful" principles; the use of everyday phenomena in presenting cognitive conflicts applies the "meaningful" principle; the PhET simulation experiment during concept discovery applies the "mindful" and "meaningful" principles; and the review of " " hypotheses during reflection applies the "mindful" and "meaningful" principles. Thus, the deep learning approach complements every stage of cognitive conflict and is not merely an additional component.

[12] 's research integrated the deep learning approach with the Waves and Thermodynamics KIT in three 11th-grade high school classes, using a one-group pretest–posttest design and a three-tier diagnostic test. The results showed a statistically significant reduction in misconceptions regarding the concepts of temperature,

the first law, and the second law of thermodynamics. The average N-gain fell into the moderate category (0.64) in the experimental class and the high category (0.76 and 0.75) in the two replication classes. The study states that the use of a deep learning approach in misconception remediation is still a novel element. However, the treatment combined the deep learning approach with a KIT laboratory activity without a control group, so the contributions of each component cannot yet be separated. The treatment also did not use cognitive conflict as a learning syntax framework, was not in the form of an e-module, and was conducted on thermodynamics material.

[23] also conducted a systematic review of deep learning in the context of misconceptions, examining 10 articles. The review concluded that deep learning that integrates meaningful, enjoyable, and problem-based approaches is more effective at preventing and addressing misconceptions through conceptual understanding and active student engagement. This supports the selection of the deep learning approach as a complement to cognitive conflict in this study. The review also included a study on the use of artificial intelligence to identify misconceptions, which falls outside the scope of this study because deep learning is understood here as a pedagogical approach. Nevertheless, the authors state that studies combining various deep learning approaches in the context of physics misconceptions remain limited, and no studies were found that integrate this approach with cognitive conflict in the form of e-modules.

Based on this discussion, the research gap this study aims to address is the lack of an e-module specifically designed to remediate misconceptions in light wave material by integrating cognitive conflict and deep learning approaches. The novelty of this research lies in the integration of these two elements. Cognitive conflict confronts misconceptions, while the principles of mindful, meaningful, and joyful learning foster the formation of new understanding in a conscious, meaningful, and enjoyable manner. This integration is presented through an interactive e-module supported by PhET simulations that visualize the abstract concept of light waves. Therefore, this study aims to describe the characteristics of and develop a valid and practical interactive e-module based on cognitive conflict and the deep learning approach for the topic of light waves.

II. METHOD

This study is a development research project also known as design research which aims to design, develop, and validate a product as a solution to complex research problems [24]. The development model used is the Plomp & Nieveen (2013). The product developed is an e-module based on cognitive conflict and the deep learning approach for light wave material, designed to remediate students' misconceptions.

The research procedure followed the Plomp model, which consists of a preliminary research phase and a development/prototyping phase, with the study limited to a one-to-one practicality test. This limitation was imposed because the research objective was to produce a valid and practical e-module, which could be assessed through expert evaluation and an initial practicality test. Testing the effectiveness and ability of the e-module to remediate misconceptions requires a follow-up evaluation phase with a larger sample, which will therefore be the focus of future research. Consequently, small-group testing, field testing, effectiveness testing, and misconception remediation testing were not conducted in this study. The preliminary stage was carried out through a needs analysis, which included interviews with teachers and students; an analysis of the suitability of the textbooks used in schools based on the four elements of suitability according to [16] a concept comprehension test using a four-tier diagnostic instrument adapted from [21] and an analysis that categorized students' answers into "understands the concept," "does not understand the concept," or "holds a misconception" based on a combination of answer choices, the level of confidence in the answer, the choice of reasoning, and the level of confidence in the reasoning [25], as well as a review of three journals related to student misconceptions, with the aim of identifying the material that is the source of misconceptions, the types of misconceptions that occur, and the learning problems that cause them. The results of the needs analysis revealed a high prevalence of student misconceptions regarding wave and light due to teaching methods that remain teacher-centered and the lack of electronic instructional materials specifically designed to remediate misconceptions, which thus served as the basis for product design.

Table 1. Criteria for Classifying Conceptual Understanding on the Four-Tier Diagnostic Test

Criteria	Answer	Confidence Answer	Reason	Confidence Reason
Understand	True	High	True	High
Dont Understand	True	High	True	Low

	True	High	False	Low
	True	Low	True	High
	True	Low	True	Low
	True	Low	False	Low
	False	Low	True	Low
	False	Low	True	High
	False	Low	False	Low
Misconception	True	High	False	High
	True	Low	False	High
	False	High	True	High
	False	High	True	Low
	False	High	False	High
	False	High	False	Low
	False	Low	False	High

(Source: Ref[25])

The development phase aims to design a product in the form of an interactive e-module based on cognitive conflict and a deep learning approach, and then evaluate it through formative assessment based on Tessmer's diagram. The e-module was designed using Canva Pro and converted into an interactive flipbook using Heyzine Flipbooks to make it digitally accessible. The formative evaluation consisted of three steps: self-evaluation, which involved the researcher's independent assessment of the completeness and errors in the initial product; expert review, which involved a validity test conducted by three physics lecturers from the Faculty of Mathematics and Natural Sciences at Padang State University using a validation questionnaire, followed by product revisions based on the validators' suggestions; and one-to-one evaluation, which involved a practicality test with three students from MAN 3 Padang representing low, medium, and high ability levels, with revisions made if the product was categorized as impractical. The research data at this stage consisted of quantitative data on the self-evaluation scores, validity, and practicality of the e-module, while qualitative data were obtained from the results of the needs analysis conducted in the preliminary stage.

The self-evaluation scores were analyzed by the researcher to refine the e-module before submitting it to the validators, using a percentage-based technique formulated as follows.

$$\text{Score} = \frac{\text{Weighted Score}}{\text{Maximum Weight}} \times 100 \qquad (1)$$

Product validity was analyzed based on a questionnaire completed by three physics lecturers from the Faculty of Mathematics and Natural Sciences at Padang State University, who served as validators. The questionnaire was designed using a Likert scale, which is used to measure the attitudes, opinions, and perceptions of an individual or group, as presented in Table 2.

Table 2. Likert Scale for Validity

Likert Scale	Rating
1	Strongly disagree
2	Disagree
3	Undecided
4	Agree
5	Strongly Agree

(Source: Ref[26])

The validity test results were then analyzed using Aiken's V validity index, which is formulated as follows.

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

$$s = r - l_0 \quad (2)$$

Note :

V = Validity Index

$\sum s$ = A score determined by the sum of all validators' scores

n = Number of Validators

l_0 = The lowest validity score (in this case, = 1)

c = Highest validity score (in this case = 5)

r = Score assigned by the validator

Decision categories based on Aiken's V index are presented in Table 3.

Table 3. Decisions Based on Aiken's V Index

Interval	Category
$\leq 0{,}4$	Invalid
$0{,}4 \leq V \leq 0{,}8$	Valid
$0{,}8 \leq V \leq 1$	Highly Valid

(Source: Ref[27])

Product practicality was analyzed based on student responses to a questionnaire during the one-to-one evaluation stage, with assessment aspects including ease of use, appeal, efficiency, and benefits. The practicality questionnaire was also designed using a Likert scale, as presented in Table 4.

Table 4. Practicality Likert Scale

Likert Scale	Rating
1	Strongly disagree
2	Disagree
3	Undecided
4	Agree
5	Strongly Agree

(Source: Ref[26])

The practicality value is calculated using the following equation.

$$\text{Score} = \frac{\text{Weighted Score}}{\text{Maximum Weight}} \times 100 \quad (3)$$

The practicality categories of the e-modules based on the scores obtained are presented in Table 5.

Table 5. E-Module Practicality Categories

Score	Category
81–100%	Very Practical
61–80%	Practical
41–60%	Fairly Practical
21–40%	Not Very Practical
0–20%	Not Practical

(Source: Ref[28])

III. RESULTS AND DISCUSSION

RESULT

The following presents the results of the research during the preliminary research (Preliminary Research) and the development phase (Development/Prototyping Phase), which include needs and context analysis, a literature review, e-module prototype design, self-evaluation results, expert review results, and one-to-one practicality test results, accompanied by a discussion linking the preliminary findings to the development results.

Preliminary Research Phase

A concept comprehension test was administered to 31 students in Class XII IPA 2 at MAN 3 Padang using a four-level diagnostic instrument adapted from [21] , with the results presented in Table 6.

Table 6. Percentage of Students' Conceptual Understanding of Light Waves

Category	Average Percentage (%)
Conceptual Understanding	18.1
Does Not Understand the Concept	12.6
Misconceptions	69.4

Based on Table 6, the "misconception" category (69.4%) far exceeded the "conceptual understanding" category (18.1%). The two most common misconceptions are that students associate the blue color of the sky with light interference, when the actual mechanism is Rayleigh scattering, and that they assume the diffraction angle is determined by the screen distance, when in fact the diffraction angle is directly proportional to the wavelength according to the diffraction grating equation. The error patterns in these two concepts which appear visually similar but have different physical mechanisms indicate that the root of the problem is not merely forgetting a formula, but rather a conceptual understanding that was formed incorrectly from the start. This finding served as the basis for the design of the e-module. However, activities specifically targeting these two misconceptions have not yet been explicitly designed in this version of the e-module; therefore, adapting activities to address both will be the focus of future development.

In addition to the conceptual understanding test, an analysis was conducted on the 11th-grade physics textbook used in schools, using a suitability assessment tool based on the four elements of suitability as defined by the [16]. This analysis found that some sections explaining concepts in the light waves unit did not meet the criteria for content suitability. Furthermore, the presentation of material in this textbook is one-sided, leading directly to formulas without first introducing phenomena that trigger cognitive conflict. These findings do not indicate that students' misconceptions stem from the textbook, as this study did not trace the sources of each student's misconceptions. Nevertheless, given the textbook's role as one of the primary learning resources, these sections have the potential to be a factor influencing students' understanding if read without further guidance.

The learning conditions underlying these findings are reflected in the results of interviews with teachers, which indicate that instruction remains centered on one-way lecturing; as a result, students tend to be passive and are not yet accustomed to developing their own understanding through direct experience. Although the term "blended learning" has been mentioned, its implementation has not been well-directed, and there is no specific plan in place to identify or remediate misconceptions. The identification of misconceptions has so far relied solely on spontaneous oral questions without structured instruments, so teachers do not yet have a clear map of misconceptions to follow up on systematically. Efforts to elicit cognitive conflict and by relating the material to daily life have actually been made, but they are still limited to occasional examples and are not yet systematic.

The results of interviews with students reinforced the teachers' findings. Students found the material on light waves difficult to understand due to its abstract nature, and they felt that classroom explanations lacked detail; meanwhile, the use of smartphones for learning physics remains limited, so learning resources tend to consist only of teachers' explanations and printed textbooks. When asked about their preferences, all students consistently chose smartphone-based learning materials over printed materials because they can be accessed and reviewed at any time without having to wait for the teacher, and they cited simple explanations and engaging visuals as the most helpful factors for their understanding.

Development Stage

Design of an E-Module Based on Cognitive Conflict and the Deep Learning Approach

The design phase aimed to develop instructional materials in the form of interactive e-modules to address misconceptions and improve students' conceptual understanding of light waves. The e-modules were designed using Canva Pro to create the layout and learning content, then converted into interactive flipbooks using Heyzine Flipbooks to make them digitally accessible. The development of the e-modules followed the module structure outlined at Depdiknas (2008) [29], namely: title, learning instructions, competencies to be achieved, supporting information, tasks, steps, and assessment. These elements were then integrated with the four learning syntaxes based on cognitive conflict and the three principles of the deep learning approach.

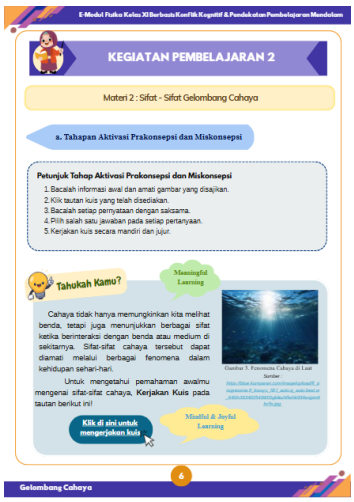


Fig. 1. E-Module in the Preconception and Misconception Activation Stage

The first syntax, the activation of preconceptions and misconceptions, aims to identify students' prior knowledge before learning begins so that teachers can take appropriate actions. At this stage, students are presented with statements related to the material's basic concepts through interactive quiz links, thereby applying the principles of mindful and joyful learning through activities that encourage students to observe and actively engage with full awareness from the very beginning of the learning process.

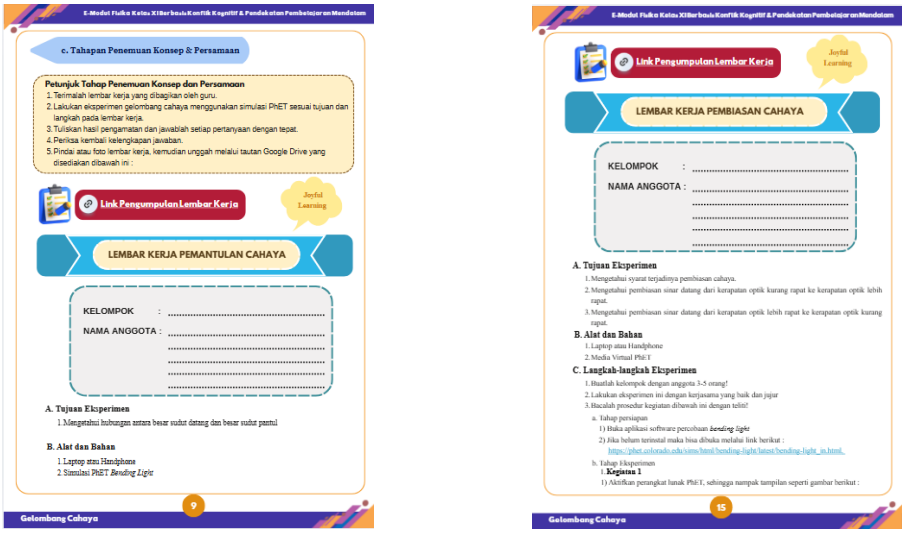


(a) (b)

Fig. 2. (a, b) E-Module in the Cognitive Conflict Presentation Stage

The second syntax, the presentation of cognitive conflict, confronts students with everyday phenomena that contradict their initial understanding, with the aim of eliciting conceptual conflict before students undergo a conceptual shift toward a concept consistent with scientific explanations. Students are asked to formulate a

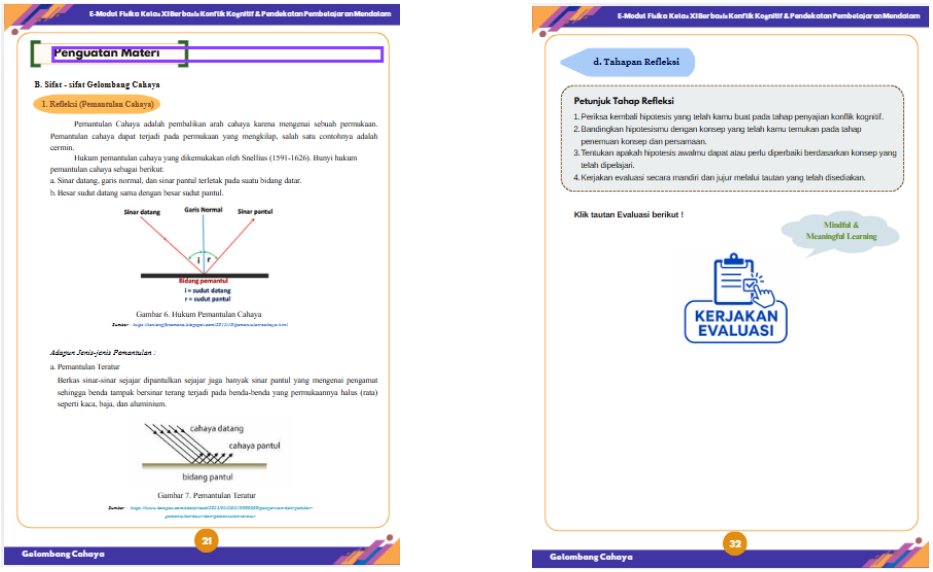
tentative hypothesis regarding the presented phenomenon; thus, this stage simultaneously applies the principle of meaningful learning because the phenomenon addressed stems from everyday events closely related to the students' experiences.



(a) (b)

Fig. 3. (a, (b) E-Module in the Concept and Equation Discovery Stage

The third syntax, the discovery of concepts and equations, aims to achieve conceptual understanding that is retained in students' memory. The discovery process is carried out through experimental activities using the PhET Simulation virtual laboratory, so that students build their own understanding through direct observation and analysis, while also applying the principles of mindful and meaningful learning.



(a) (b)

Fig. 4. (a, b) E-Module in the Reflection Stage

The fourth syntax, reflection, aims to ensure that teachers can assess the extent to which students' conceptual understanding has changed after going through the previous three stages. This stage is carried out by reviewing students' initial hypotheses and administering assessment questions using a four-level diagnostic instrument, so that teachers can identify whether students truly understand the concept, do not understand the concept, or still hold misconceptions, while also applying the principles of mindful and meaningful learning so that students become aware of meaningful changes in their understanding.

Self-Evaluation

Self-evaluation is conducted by the researcher to review the completeness and appropriateness of the designed e-module before the product is submitted to experts for validation. The assessment covers six evaluation aspects.

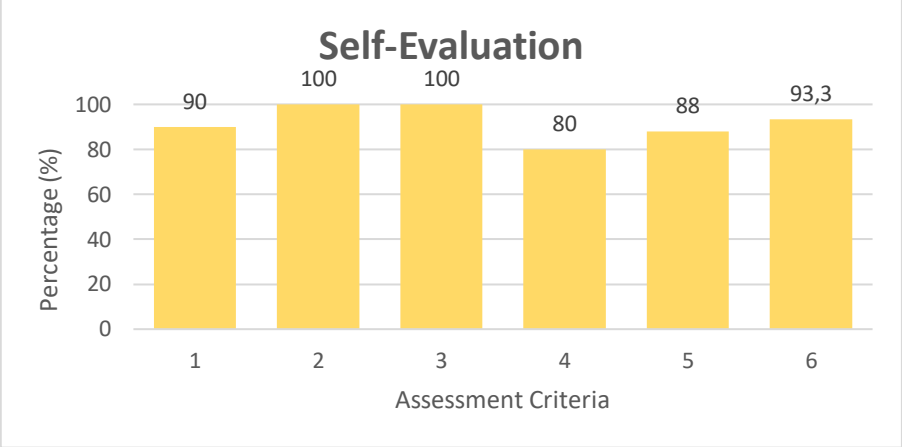


Fig. 5. Self-Evaluation Results

The evaluation aspects in self-evaluation consist of six aspects, namely: 1) the completeness of the e-module's components and supporting information; 2) the alignment of the e-module with the cognitive conflict-based learning framework specifically, the activation of preconceptions and misconceptions, the presentation of cognitive conflicts, the discovery of concepts and equations, and reflection; 3) the application of the three principles of the deep learning approach mindful, meaningful, and joyful learning; 4) the appropriateness of exercises and assessments, as well as the interactivity of questions; 5) language, layout, navigation, and tables; and 6) the clarity of illustrations, images, and references. The scores for these six aspects ranged from 80% to 100%, with an average of 91.9% in the "very good" category. The highest scores (100%) were observed in the aspects of alignment with cognitive conflict syntax and the application of deep learning principles, indicating that the core structure of the e-module is consistent with the underlying model and approach guiding its development. The lowest score was in the aspects of the alignment of exercises and assessments as well as the interactivity of the questions (80%), indicating that the format and quality of the questions still need improvement. The aspects of language, layout, navigation, and tables (88%), as well as the completeness of components and supporting information (90%), also require refinement in technical details. The aspects of illustrations, images, and references received a score of 93.3%, as the illustrations and images were deemed clear, while the references still need to be supplemented.

Although it falls into the "very good" category, this stage still identified several areas that need improvement before the e-module can be validated, namely in supporting information, exercises, assessments, references, language, layout, navigation, tables, and question interactivity, while the illustrations and images used were deemed clear. These findings indicate that the shortcomings identified during the self-evaluation stage are primarily technical in nature and involve refinements of details, rather than issues with the structure or pedagogical content; therefore, improvements can be made without altering the core design of the e-module before proceeding to the expert review stage.

Expert Rewiew

The e-module was validated by three physics lecturers from the Faculty of Mathematics and Natural Sciences at Padang State University using an assessment instrument consisting of six components. The validation data were analyzed using Aiken's V index. A summary of the validation results for all components is presented in Table 7.

Table 7. Summary of Expert Validation Results

No	Component	Indicator	Average Aiken's V	Category
1	Content Substance	Accuracy, scope of content, timeliness, readability	0.88	Highly Valid
2	Visual Communication Design	Navigation, typography, media, color, layout	0.94	Highly Valid

3	Instructional Design	Title, learning instructions, competencies achieved, supporting information, activity instructions or worksheets, evaluation or assessment, references	0.95	Highly Valid
4	Software Utilization	Interactivity, primary or supporting software	0.95	Highly Valid
5	Cognitive Conflict-Based Learning	Activation of preconceptions and misconceptions, presentation of cognitive conflict, discovery of concepts and similarities, reflection	0.88	Highly Valid
6	Deep Learning Approach	Mindful learning, meaningful learning, joyful learning	0.94	Highly Valid
		Overall Average	0.92	Highly Valid

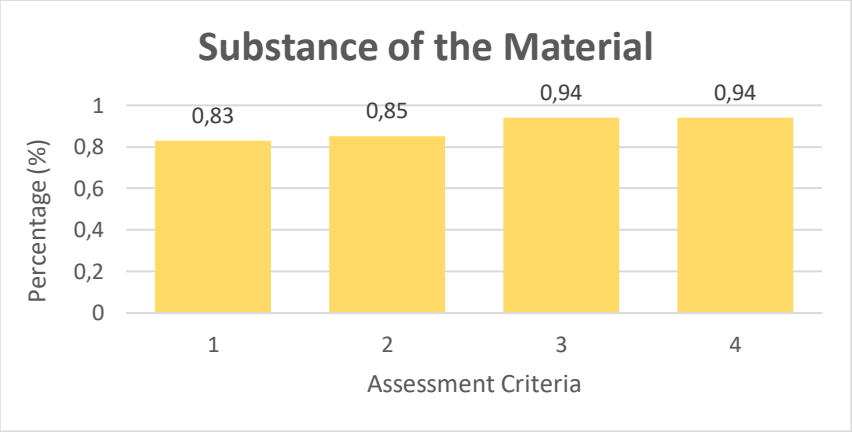


Fig. 6. Results of the Content Assessment

The first component, content substance, consists of four assessment indicators: 1) accuracy, 2) scope of content, 3) currency, and 4) readability. Indicator 1, accuracy, includes the following items: a) the content on light waves is presented in accordance with scientific principles of physics; b) the accuracy of the content can be scientifically verified; c) physics equations and symbols are correct and consistent; and d) the presentation of the content is organized logically, systematically, and rationally. Indicator 2, content coverage, includes the alignment of the content with the Learning Outcomes (CP), Learning Objectives (TP), and Indicators of Learning Objective Achievement (IKTP) of the Merdeka Curriculum; encouraging conceptual exploration; facilitating conceptual imagination; and ensuring the depth of content aligns with the cognitive abilities of high school (SMA/MA) students in Phase F. Indicator 3, timeliness, covers the relevance of the material to scientific developments, the presentation of examples based on current phenomena and technology, and the delivery of material using interactive applications. Indicator 4, readability, covers the alignment of language with Indonesian spelling rules, the use of standard language, and the clarity of sentences and instructions to avoid ambiguity.

The scores for the four indicators ranged from 0.83 to 0.94, with an average component score of 0.88 in the "highly valid" category. The lowest score was recorded for Indicator 1 (accuracy) at 0.83, followed by Indicator 2 (content coverage) at 0.85, while Indicator 3 (relevance) and Indicator 4 (readability) received the highest scores, at 0.94 each. These results indicate that the coverage of topics namely reflection, refraction, interference, and diffraction—has been systematically organized and verified for accuracy by subject matter experts, thereby reducing the risk of conceptual errors in the material, as found in the textbooks analyzed in the preliminary stage. However, expert validation cannot guarantee that students will not develop misconceptions during actual learning.

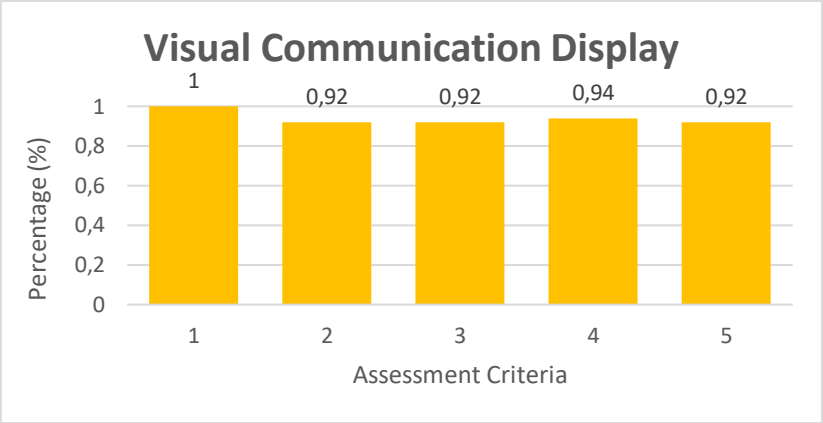


Fig. 7. Visual Communication Presentation Assessment Results

The second component, visual communication presentation, consists of five assessment indicators: 1) navigation, 2) typography, 3) media, 4) color, and 5) layout. Indicator 1, navigation, includes the criterion that navigation features function properly and facilitate the user experience. Indicator 2, typography, covers the clarity and readability of font types and sizes, as well as the proportional balance between headings, subheadings, and body text. Indicator 3, media, covers the relevance of images or videos to the content. Indicator 4, color, covers a harmonious and visually pleasing composition of background and text colors. Indicator 5, layout, covers the proportional arrangement of text, images, and video elements, as well as the consistency of visual elements throughout the activity. The scores for the five indicators ranged from 0.92 to 1.00, with an average component score of 0.94 in the "highly valid" category. The highest score of 1.00 was achieved by Indicator 1 (navigation), followed by Indicator 4 (color) at 0.94, while Indicator 2 (typography), Indicator 3 (media), and Indicator 5 (layout) each scored 0.92. These results indicate that the flipbook's navigation features function well and that the color composition and layout support readability, allowing students to navigate the e-module's content without technical or visual obstacles.

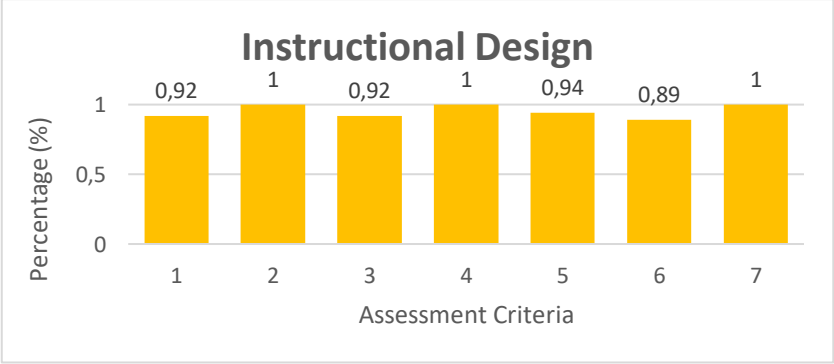


Fig. 8. Instructional Design Assessment Results

The third component, instructional design, consists of seven assessment indicators: 1) title, 2) learning instructions, 3) competencies to be achieved, 4) supporting information, 5) activity instructions or worksheets, 6) evaluation or assessment, and 7) references. Indicator 1, title, covers the relevance of the title to the material and an attractive cover that reflects the content. Indicator 2, learning instructions, covers the clarity of instructions for using the application and learning guidelines. Indicator 3, competencies achieved, covers the completeness of CP, TP, and IKTP as well as their alignment with the Merdeka Curriculum. Indicator 4, supporting information, covers the relevance of supporting information prior to learning activities. Indicator 5, activity instructions or worksheets, covers the facilitation of experiments or virtual simulations, the completeness of procedures and data tables on the worksheets, and the facilitation of drawing conclusions. Indicator 6, evaluation or assessment, covers items regarding the design of practice questions to address misconceptions, evaluation questions to identify changes in understanding, and the appropriateness of the difficulty level of the questions. Indicator 7, references, covers the clarity of the author's identity and a minimum of five references.

The scores for the seven indicators ranged from 0.89 to 1.00, with an average component score of 0.95 in the "highly valid" category. A perfect score (1.00) was achieved by Indicator 2 (learning instructions), Indicator 4 (supporting information), and Indicator 7 (references). The lowest score was found in Indicator 6 (evaluation or assessment) at 0.89, indicating that the exercise design, evaluation questions, and question difficulty levels

still need refinement to be more effective in remediating misconceptions and identifying changes in students' understanding.

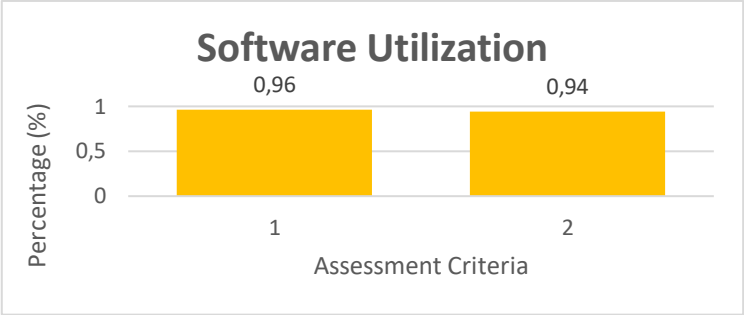


Fig. 9. Results of Software Utilization

The fourth component, software utilization, consists of two assessment indicators: 1) interactivity and 2) primary or supporting software. Indicator 1, interactivity, covers the presence of interactivity in exercises and assessments as well as the suitability of features to support learning and assessment. Indicator 2, primary or supporting software, covers the use of Heyzine Flipbooks as the primary tool; the functionality of navigation and links on Quizizz, Google Forms, Google Drive, and PhET; the use of Canva for attractive and easy-to-understand designs; and the clarity of sources for supporting images and videos. The scores for both indicators ranged from 0.94 to 0.96, with an average component score of 0.95 in the "highly valid" category. Indicator 1 (interactivity) received the highest score of 0.96, while Indicator 2 (primary or supporting software) received a score of 0.94. These results indicate that Canva, Heyzine, PhET, and Quizizz complement each other's functions ranging from visual design and the creation of interactive flipbooks to experiment simulations and assessment and are integrated without significant technical issues.

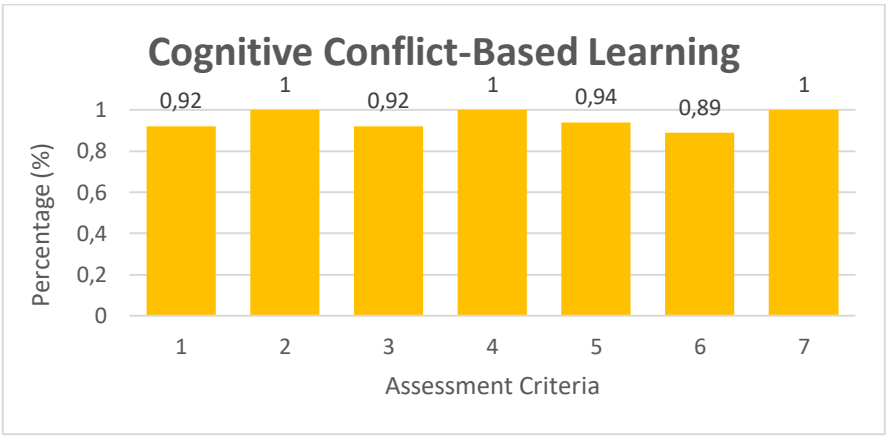


Fig. 10. Results of Cognitive Conflict-Based Learning Assessment

The fifth component, cognitive conflict-based learning, consists of four assessment indicators that represent its four syntactic elements, namely: 1) activation of preconceptions and misconceptions, 2) presentation of cognitive conflict, 3) discovery of concepts and equations, and 4) reflection. Indicator 1, activation of preconceptions and misconceptions, includes items that facilitate the disclosure of prior understanding and the identification of misconceptions through preconception questions. Indicator 2, the presentation of cognitive conflict, includes items that present phenomena that contradict students' initial understanding, encourage the formulation of hypotheses, and guide the discovery of concepts through experiments and exploration. Indicator 3, concept and equation discovery, includes items that facilitate linking observational results to physics concepts and equations and help refine initial understanding into correct scientific concepts. Indicator 4, reflection, includes items related to final assessment to measure conceptual understanding and the alignment of assessments with learning objectives. The values for the four indicators ranged from 0.83 to 0.92, with a component average of 0.88 in the "highly valid" category. The highest score was obtained by Indicator 4 (reflection) at 0.92, followed by Indicator 2 (presentation of cognitive conflicts) at 0.89 and Indicator 1 (activation of preconceptions and misconceptions) at 0.88, while the lowest score was for Indicator 3 (discovery of concepts and equations) at 0.83. These results indicate that all four syntactic elements are sequentially incorporated into each learning activity, meaning that the design of the misconception

remediation process developed from the preliminary stage has been successfully implemented in the final product.

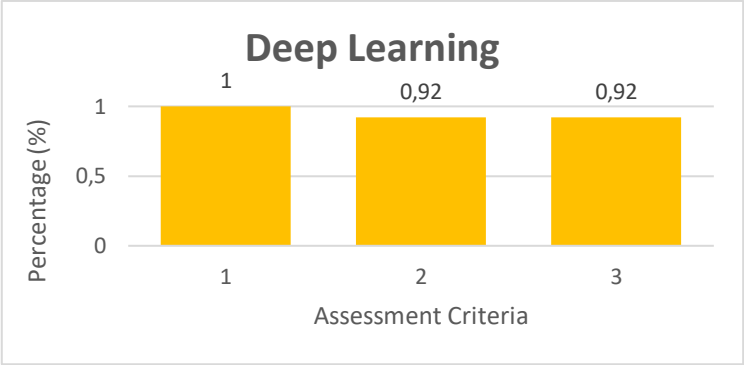


Fig. 11. Assessment Results of the Deep Learning Approach

The sixth component, the deep learning approach, consists of three assessment indicators: 1) mindful learning, 2) meaningful learning, and 3) joyful learning. Indicator 1, mindful learning, includes items that facilitate students' conscious engagement in understanding, processing, and reflecting on concepts. Indicator 2, meaningful learning, includes items that relate the concept of light waves to students' prior knowledge and experiences, as well as its application in real life. Indicator 3, joyful learning, includes items that create engaging and enjoyable learning experiences through activities that actively involve students. The values for the three indicators range from 0.92 to 1.00, with a component average of 0.94 in the "highly valid" category. The highest value was obtained by Indicator 1 (mindful learning) at 1.00, indicating that the e-module consistently encourages students to engage consciously in understanding the concepts being studied, rather than merely memorizing them. Indicator 2 (meaningful learning) and Indicator 3 (joyful learning) each scored 0.92, indicating that the connection between concepts and everyday experiences, as well as engaging and enjoyable learning experiences, were also very well met.

Practicality (One-to-One Evaluation)

A practicality test was conducted on three students from MAN 3 Kota Padang representing high, medium, and low ability levels, using a response questionnaire consisting of four components: ease of use, appeal, efficiency, and benefits. The three students completed the questionnaire independently, while the researcher remained present to ensure all items were filled out. Comments and suggestions from the students were also collected but have not been further analyzed in this article; they will be used as input for revisions should development proceed to the small-group phase or effectiveness testing. The evaluation results are presented as preliminary evidence of the e-module's usefulness, given the very limited number of respondents.

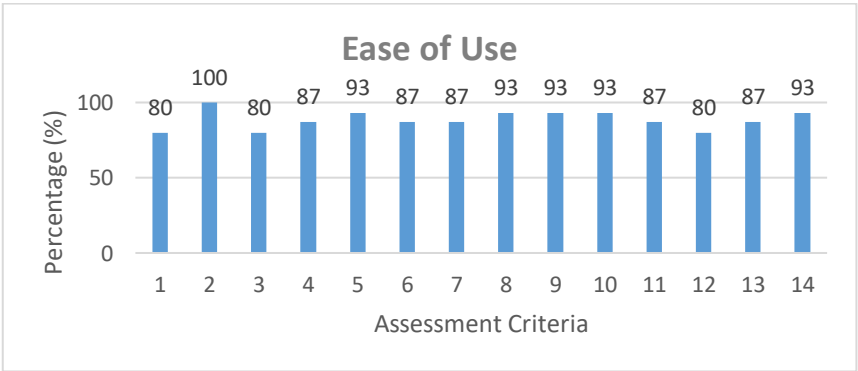


Fig. 12. Evaluation Results: Ease of Use

The first component, ease of use, consists of 14 statements, namely: 1) the e-module's usage instructions are easy to understand, 2) the sequence of material is easy to follow, 3) the material on light waves presented is easy to understand, 4) the steps for activating preconceptions and misconceptions are easy to carry out, 5) the steps for presenting cognitive conflicts are easy to implement, 6) the steps for discovering concepts and equations are easy to implement, 7) experimental activities using PhET simulations are easy to conduct, 8) the reflection steps are easy to implement, 9) the videos in the e-module are easy to play, 10) links within the e-

module are easily accessible when needed, 11) the activity stages facilitate active learning through the processes of observing, thinking, analyzing, and discovering concepts, 12) the stages in the e-module make it easy to connect new knowledge with prior knowledge, 13) questions and activities facilitate the expression and review of initial understanding, and 14) the sequence of activities is easy to follow to discover the meaning or main principles of the material. The scores for these fourteen items ranged from 80% to 100%, with an average component score of 88.6% in the "very practical" category. The highest score of 100% was achieved by item 2 (the sequence of material is easy to understand), followed by item 5 (stages of presenting cognitive conflicts), item 8 (stages of reflection), item 9 (videos in the e-module), item 10 (links in the e-module), and item 14 (activity flow), each of which received a score of 93%. Item 4 (activation of preconceptions and misconceptions), item 6 (discovery of concepts and equations), item 7 (PhET simulation experiments), item 11 (active learning), and item 13 (disclosure and re-examination of initial understanding) each received 87%. The lowest scores were found in three items: Item 1 (understanding of usage instructions), Item 3 (ease of understanding the material), and Item 12 (connection between new knowledge and prior knowledge), each of which scored 80%. This indicates that students still need time to adjust since this was their first time using a cognitive conflict-based e-module. These results show that the sequence of material, learning stages, and video and link features in the e-module were easy for students to follow and implement, while the user instructions and presentation of the material can be addressed during the revision stage.

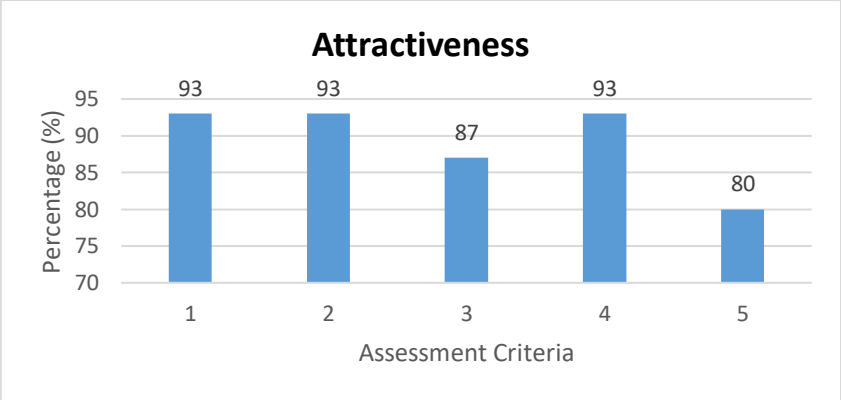


Fig. 13. Appeal Assessment Results

The second component, appeal, consists of five statements: 1) the e-module's cover is appealing, 2) the e-module's content is appealing, 3) the font used in the e-module is appealing, 4) the videos in the e-module are appealing, and 5) the e-module makes students interested in participating in the learning process. The scores for these five items ranged from 80% to 93%, with an average component score of 89.3% in the "very practical" category. The highest scores of 93% were achieved by item 1 (cover design), item 2 (content layout), and item 4 (videos in the e-module). Item 3 (font type) scored 87%, while the lowest score was recorded for item 5 (the e-module's ability to engage students in the learning process) at 80%. These high scores for the visual aspect align with the results of the visual communication validation during the expert review stage, which showed that improvements to the layout, colors, and typography based on the validators' suggestions successfully produced an e-module that is appealing to students. However, the relatively lower score for item 5 indicates that students' overall interest in participating in the learning process can still be improved, so this should be addressed during the revision stage.

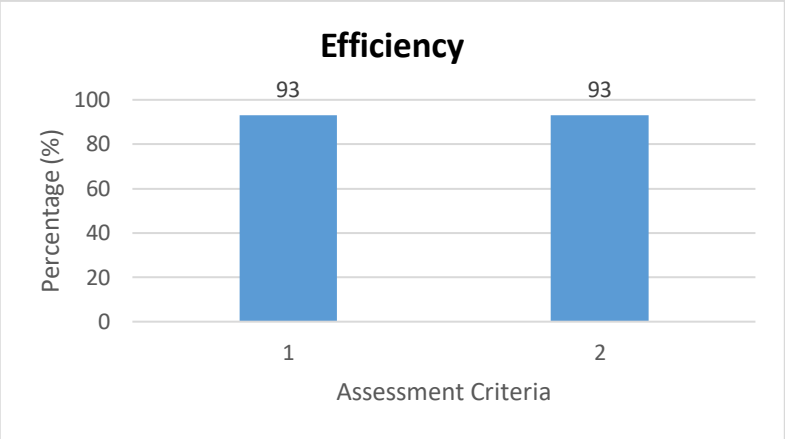


Fig. 14. Efficiency Assessment Results

The third component, efficiency, consists of two items: 1) the e-module streamlines learning time, and 2) the e-module reduces the costs of ownership and use. Both items received the same score 93% with a component average of 93.3% in the "very practical" category. This score indicates that students perceive the digital e-module format as more time and cost efficient than printed instructional materials, consistent with students' preference for smartphone-based instructional materials, which had been identified during the preliminary interview phase.

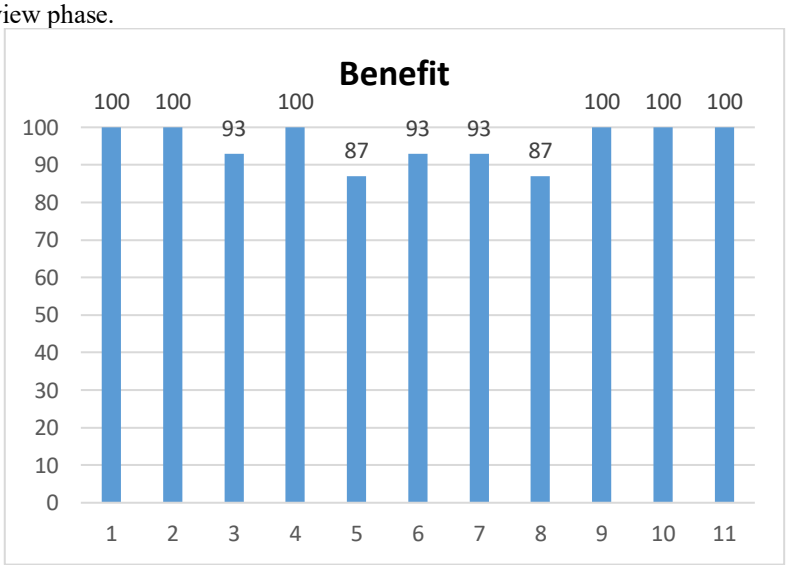


Fig. 15. Benefits Assessment Results

The fourth component, benefits, consists of 11 statements, namely: 1) the e-module facilitates independent learning about light waves; 2) the e-module helps achieve learning objectives; 3) the e-module helps students utilize various learning activities to understand concepts; 4) activities to identify preconceptions and misconceptions help students recognize their own misconceptions; 5) the presentation of phenomena that differ from initial understanding helps students recognize discrepancies in their understanding, 6) hypothesis-formulation activities help students propose conjectures based on their initial understanding, 7) exploration, experimentation, discussion, and analysis activities help build understanding in accordance with scientific concepts, 8) reflection activities help students reassess the understanding they have gained, 9) activities in the e-module help learners consciously engage in the learning process while observing phenomena and exploring concepts, 10) the e-module helps learners see the connection between concepts and everyday phenomena, and 11) activities in the e-module make the learning process enjoyable. The scores for these eleven items ranged from 87% to 100%, with an average component score of 95.8% in the "very practical" category. Six items received the highest score of 100%: item 1 (independent learning), item 2 (achievement of learning objectives), item 4 (activation of preconceptions and misconceptions), item 9 (conscious learning), item 10 (connection of concepts to everyday life), and item 11 (an enjoyable learning process). Item 3 (use of various learning activities), item 6 (presentation of hypotheses), and item 7 (exploration, experimentation, discussion, and analysis) each received 93%, while the lowest scores of 87% were obtained by item 5 (presentation of phenomena differing from initial understanding) and item 8 (reflection activities). The 100% score on the item

regarding the activation of preconceptions and misconceptions indicates that students were able to consciously recognize their own misconceptions after using the e-module, in line with the initial objective of developing the e-module to remediate the misconceptions identified in the preliminary stage. However, the lowest scores on the presentation of cognitive conflict and reflection indicate that these two stages can still be improved upon during the revision phase.

Discussion

During the validation process, the validators provided several suggestions regarding the interactive e-module based on cognitive conflict and the deep learning approach to the topic of light waves. These suggestions included: (1) revising the cover to better reflect the activities in the e-module, (2) avoiding misconceptions in the e-module's content and adding the concept of total internal reflection to the section on light diffraction, (3) revising the Learning Objectives (LO) and Learning Objective Achievement Indicators (LOAI) to align with the Learning Outcomes (LO) and the ABCD guidelines, (4) varying the joyful learning elements, such as games and icebreakers, and (5) adding the e-module's contribution to the SDGs in the introduction. Revisions made to the e-module based on the validators' suggestions included the cover page, foreword, formulation of LO and LAI, color schemes for indicators and learning materials, variations in joyful learning activities, and the addition of the concept of total internal reflection to reinforce the material.

The e-module is classified as highly valid in the content substance component (Aiken's V = 0.88) because the coverage of light wave material ranging from reflection, refraction, and interference to diffraction is presented in accordance with the principles of physics, has been verified for accuracy by subject matter experts, and is structured in accordance with the Competency Standards (CP), Learning Outcomes (TP), and Core Competencies (IKTP) of the Merdeka Curriculum Phase F, thereby reducing the risk of new misconceptions arising from content errors. This cognitive conflict-based e-module contains four components: activation of preconceptions and misconceptions, presentation of cognitive conflict, discovery of concepts and equations, and reflection (Mufit & Fauzan, 2019), which are integrated with the three principles of deep learning mindful, meaningful, and joyful learning.

The validity of the visual communication presentation falls into the "highly valid" category (0.94) because the navigation, typography, media usage, colors, and layout of the e-module developed using Canva Pro and converted to Heyzine Flipbooks are consistent and well-proportioned, making it easy for students to navigate the flipbook's content. Regarding the instructional design component (0.95), its validity is very good because the learning stages are arranged sequentially, starting from the emergence of students' prior understanding, the presentation of phenomena that trigger cognitive conflict, to the discovery of concepts through experiments all reinforced by PhET virtual simulations to visualize abstract phenomena such as light interference and diffraction. The software utilization component is also highly valid (0.95) because Canva, Heyzine Flipbooks, PhET, Quizizz, Google Forms, and Google Drive complement each other's functions from visual design and the creation of interactive flipbooks to experimental simulations and assessment resulting in seamless integration without significant technical issues.

The cognitive conflict-based learning component received a rating of "highly valid" (0.88) because the four components activation of preconceptions and misconceptions, presentation of cognitive conflict, discovery of concepts and similarities, and reflection are explicitly and sequentially included in each learning activity, thereby guiding students to recognize their misunderstandings before reconstructing them into correct scientific concepts (Pratama et al., 2021). The deep learning approach component received a rating of "highly valid" (0.94) because the e-module encourages students to engage consciously, connect concepts to real-world experiences (meaningful), and learn through enjoyable experiences (joyful), so that the resulting understanding is expected to be more meaningful and enduring. Overall, the interactive e-module based on cognitive conflict and the deep learning approach falls into the "highly valid" category with an average Aiken's V index of 0.92.

These validation results are also supported by the self-evaluation conducted by the researcher prior to the expert review stage, with an average score of 91.9% in the "very good" category, indicating that the e-module was prepared in accordance with the cognitive conflict syntax and deep learning principles before being evaluated by experts. These findings align with the results of previous research on the development of cognitive conflict-based instructional materials, which showed that instructional materials designed systematically using stages of cognitive conflict achieve a high level of validity because they encourage learners to actively reconstruct their understanding, rather than merely passively receiving information (Mufit & Fauzan, 2019).

The lowest scores in the validation specifically in evaluation or assessment (0.89) and the discovery of concepts and equations (0.83) require more critical discussion because both are directly related to the product's primary objectives. Practice and evaluation questions serve as tools to reveal changes in students' understanding and to remediate misconceptions, whereas the concept and equation discovery stage is where observations from simulations are linked to correct physics concepts and equations. Weaknesses in these two

sections mean that the very parts most critical for misconception remediation are precisely the ones that most need refinement. Weaknesses in the practice questions and assessments are also evident in the self-evaluation stage (80%), suggesting this is a consistent shortcoming of the product rather than an error specific to a single stage. Therefore, improving the quality of the questions, their difficulty level, and the correlation between simulation results and equations must be a priority in further development before the e-module's effectiveness is tested.

In addition to being valid, the developed e-module was also deemed highly practical according to the instrument's criteria based on a practicality test during the one-to-one evaluation stage involving three students with high, moderate, and low abilities, with an overall average of 91.5%. The ease-of-use component received the lowest score (88.6%) compared to appeal (89.3%), efficiency (93.3%), and benefits (95.8%). This is likely not due to poor quality of the e-module, but rather because the students were using a cognitive conflict-based e-module for the first time and therefore still needed to adjust to a learning flow that differs from conventional learning. On the other hand, the high scores for efficiency and benefits indicate that, in the perception of the three students, the e-module saved time and costs, and helped them learn about light waves and recognize their misconceptions.

Since only three students were involved, these results are interpreted as preliminary evidence of the e-module's usefulness, not strong evidence of its practicality for the target population. The "very practical" category is a classification based on the instrument criteria in Table 5, not broad evidence that the product is practical for students in general. The validity and practicality results also do not indicate the e-module's effectiveness in remediating misconceptions, as an effectiveness test has not yet been conducted.

IV. CONCLUSION

Preliminary research at MAN 3 Kota Padang showed that 69.4% of students held misconceptions regarding light waves, 12.6% did not understand the concept, and only 18.1% understood the concept. Instruction remains teacher-centered; electronic instructional materials to address misconceptions are not yet available; and an analysis of the textbook revealed sections explaining concepts that have the potential to cause new misconceptions. These findings highlight the need for instructional materials specifically designed to address misconceptions.

During the development phase, an interactive e-module was created that integrates four cognitive conflict syntaxes with the principles of mindful, meaningful, and joyful learning. The e-module was deemed highly valid based on evaluations by three experts (average Aiken's V of 0.92) and highly practical in initial testing based on a one-to-one trial with three students (average score of 88.3%). These results indicate only initial validity and practicality, not the e-module's effectiveness in addressing misconceptions, as effectiveness testing has not yet been conducted.

Thus, this e-module is ready for further testing in the small-group and field-test phases. Future research needs to examine whether the e-module significantly reduces misconceptions, using diagnostic instruments appropriate for an experimental or quasi-experimental design.

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