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Development and Validation of a Problem-Based Learning E-Module Integrating Sidoarjo Milkfish Local Wisdom for Enhancing Students' Critical Thinking Skills

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Abstract: This study aims to evaluate the validity and readability of a Problem-Based Learning e-module integrated with the local wisdom of Sidoarjo milkfish cultivation on the topic of ecosystems to enhance 10th-grade students'critical thinking. This study used the Fenrich's model of development which comprises analysing, planning, designing, developing, and implementing, each cycle of which goes through an evaluation and a revision. The validIty of PBL e-module was assessed by three evaluators, consisting of two expert lecturers and a biology teacher. Data analysis relied on both descriptive-quantitative and qualitative approaches. The results indicated that the validity for PBL e-module were 3.94 which is a very highly valid category, while the Fry readability graph placed the text of the PBL e-module at level 10, making it highly practical and suitable for 10th-grade students. The output revealed that PBL e-module integrating Sidoarjo milkfish local wisdom is valid and practical for learning. Incorporating local wisdom and contextual issues into biology can have the potential to enhance students' critical thinking skills.

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Introduction

Modern education of 21st century seeks to produce human resources with comprehensive capabilities to face life's challenges, such as students mastering critical thinking skills (Alali, 2024). Critical thinking skills are crucial within the educational sphere alongside everyday life because they help individuals face complex challenges, avoid thinking errors, and make better decisions (Sternberg & Hayes, 2025). Critical thinking means to have the ability of analyzing, evaluating, and interpreting information objectively to make logical and rational decisions or solve problems (Agustine & Nawawi, 2020). Facione (2015) identifies interpreting, analysing, inferencing, explanating, evaluating, and self-regulating as six indicators of critical thinking. Critical thinking skills are among the highest levels or stages in the thinking process and are part of reasoning, characterized by the ability to solve problems in unique and diverse ways (Pramasdyahsari *et al*, 2023).

Evaluation results from PISA and TIMSS declared that Indonesian students' critical thinking skills need improvement (Ridzkiyah & Effendi, 2021). The 2018 PISA results showed Indonesia ranked 72nd out of 78 countries with a score of 379, far below the average of 489 and TIMSS results showed that Indonesian students were only able to solve simple math problems, indicating their under level mathematical critical thinking skills. Research by Farida *et al*. (2021) stated that students were not yet accustomed to and trained in solving critical thinking test questions, which are an important element in the Pancasila student profile. The students only achieved an average percentage of 48.89% in critical thinking indicators such as defining terms and answering questions that require explanation. These

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outcomes highlight the necessity of innovative learning to foster Indonesian students' critical thinking capabilities.

Applying PBL modules proves to be a highly effective method for enhancing students' critical thinking capabilities (Pertiwi *et al*., 2024). The use of e-modules is becoming increasingly aligned with advancements within Industry 4.0 and Society 5.0. The problem-based learning (PBL) drives learners to actively participate in the educational process by addressing authentic, contextual (real-life) problems that require creative and critical solutions through case studies and assignments that require students to gather information, analyze data, and formulate solutions (Nicholus *et al*., 2023).

In the Society 5.0 era, education focuses not only on technological mastery but also on character development and values derived from local wisdom, fostering individuals who are academically intelligent, wise and ethical as well (Togo & Gandidzanwa, 2021). Thus, local wisdom is a key element in adaptive and relevant learning today, ensuring that technological advances do not sacrifice cultural heritage and human values (Sary & Asri, 2023). One example of local wisdom content that can be used in learning media that combines technology and local wisdom is an integrated learning e-module on the local wisdom of milkfish (*Chanos chanos*) in the Sidoarjo region into ecosystem material through issue the ecosystem of milkfish pond in Sidoarjo. Milkfish pond ecosystem in Sidoarjo sit at the center of several intersecting environmental pressure such as industrial effluent from the Surabaya–Sidoarjo manufacturing belt severely impairs water quality through erratic dissolved oxygen levels, high BOD, and toxic runoff; the ongoing mud eruption has diverted massive amounts of sediment and heavy metal-laden runoff into river estuaries that supply the ponds (Irawan *et al*., 2021). Hence, the PBL e-module integrating Sidoarjo milkfish local wisdom requires students to analyze real-time pollution transfer and bioaccumulation that can develop students' critical thinking skills better than conventional textbook ecosystem.

While previous studies by Fitria (2024) and Pitorini *et al*. (2024) have developed PBL-based digital learning materials to enhance cognitive capabilities, research specifically integrating Sidoarjo milkfish local wisdom into a PBL e-module for ecosystem topics remains lacking. To bridge this gap, this study aims to evaluate the validity and readability of PBL e-module embedded with Sidoarjo milkfish local wisdom, designed to enhance the critical thinking skills of 10th-grade high school students.

Research Method

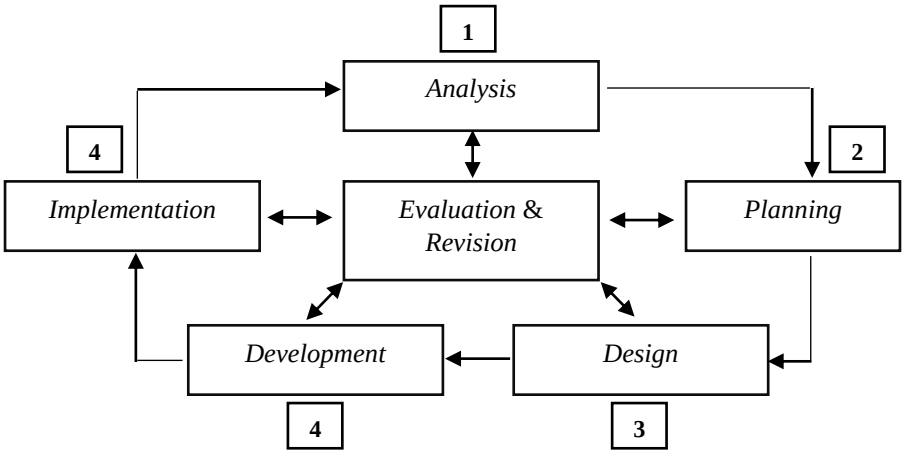

Figure 1. The Fenrich Development Cycle Scheme (1997)

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The study used the research and development method. The framework of this research refers to the Fenrich instructional development cycle model which composed of analysing, planning, designing, developing, along with implementing, each cycle of which goes through an evaluation and revision stage (Fenrich, 2005). The Fenrich model was chosen because of its structure, which is clear and straightforward when developing teaching materials and is consistent in each phase, as well as adaptive to interactive media, integrates audio, visual, and real-time feedback elements, and is flexible informative evaluation at every phase. The Fenrich instructional development cycle model as depicted in Figure 1. The sequence of phases in the PBL e-module based development process, as stated by Fenrich's (1997) development cycle model as depicted in Figure 2.

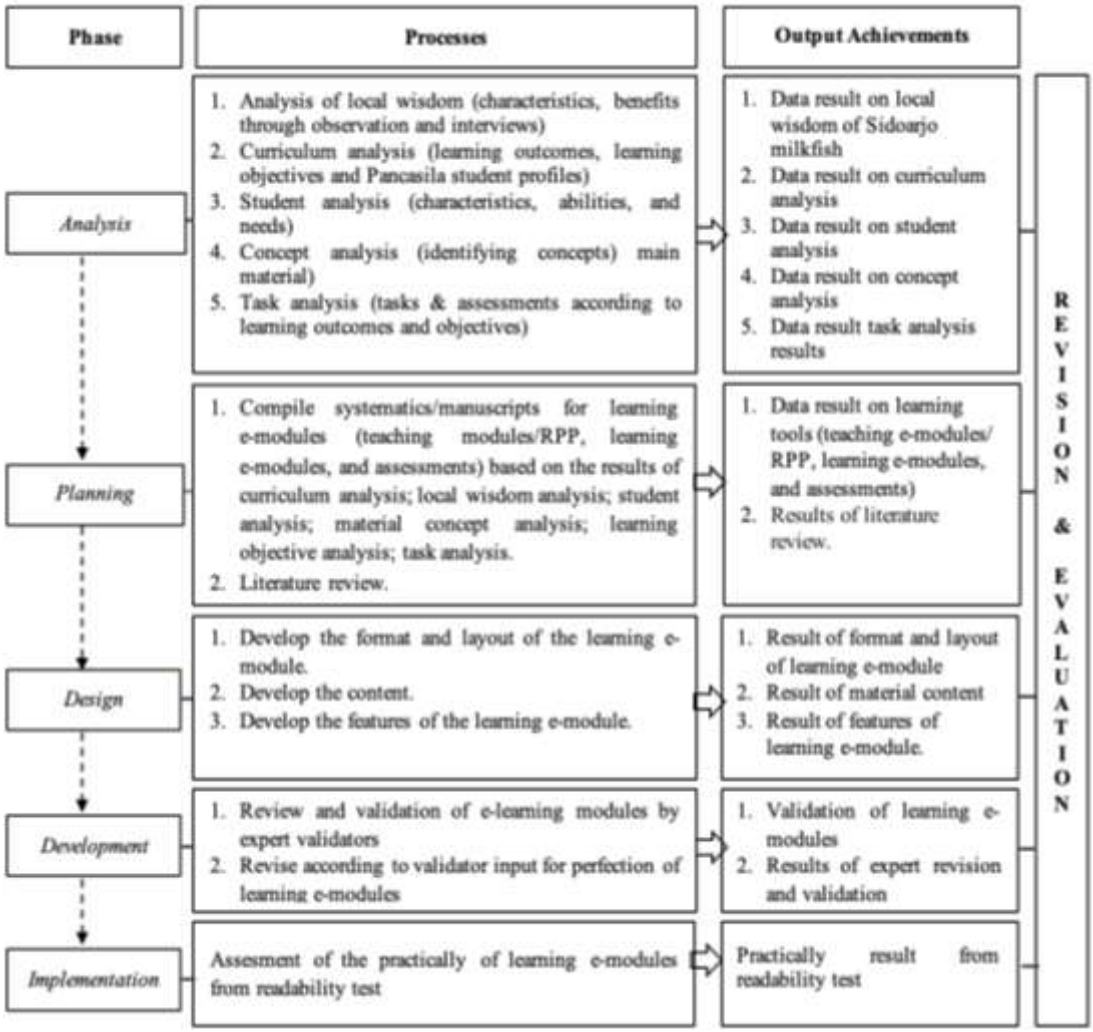

Figure 2. Procedure of Fenrich Development Cycle

The study was conducted in Biology education, faculty of mathematics and natural sciences at Universitas Negeri Surabaya, Indonesia. The data comes from the instruments developed, namely non-testing instruments specifically validity and readability forms. The validity form which was evaluated by a panel of experts comprising two university lecturers and one high school biology teacher, the readability form based on text modules tested to 10th-grade high school students of Sidoarjo. The validation form uses the Likert scale to evaluate three aspects: (1) presentation, (2) content, and (3) linguistic dimensions. The

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readability form was utilized to determine the PBL e-module's practicality, that was subsequently input into the Fry chart.

The validation outcomes were evaluated both descriptively and quantitatively. The validity of the PBL e-module is examined after gaining scores from validators along with finding the mean score for each criteria. The data of PBL e-module validation results will be measured on a Likert scale as in Table 1.

Table 1. Likert Scale Criteria

Scale	Criteria
4	Very Highly Valid
3	Valid
2	Moderately Valid
1	Invalid

Thereafter, the overall mean score for all validation aspects is computed. This score is obtained from the validator. The average result can be calculated using formula 1.

$$Average\ Score = \frac{\Sigma The\ sum\ of\ the\ score\ from\ each\ criterion\ of all\ validators}{\Sigma\ Total\ Number\ of\ Validators} \quad (1)$$

The average score of all validation aspects is employed to define the validity's level of the PBL e-module. The acquired value is categorized using the validity interpretation guidelines as in Table 2.

Table 2. Interpretation Criteria for Average Score of Likert Scale

Range of average score	Criteria
$3.6 \leq P \leq 4.0$	Very Highly Valid
$2.6 \leq P \leq 3.5$	Valid
$1.6 \leq P \leq 2.5$	Moderately Valid
$1 \leq P \leq 1.5$	Invalid

The readability of the PBL e-module integrating Sidoarjo milkfish local wisdom was calculated using a 100-word text sample drawn from the constructed PBL e-module, then the total of sentences along with words is calculated. If any of the 100 words terminates mid-sentence, the resulting incomplete sentence is factored into the calculation using formula 2.

$$Number\ of\ emaining\ sentences\ = \frac{Number\ of\ words\ in\ sentences\ that\ reach\ 100\ words}{Number\ of\ words\ in\ the\ last\ sentences} \quad (2)$$

According to the calculation data, the remaining sentences count are mapped onto the vertical axis on the Fry graph, whereas the syllables count is multiplied by 0.6 and and subsequently mapped onto the horizontal axis on the Fry graph.

Results and Discussion

The study produced the PBL e-module integrating Sidoarjo milkfish local wisdom for enhancing students' critcal thinking skills. The concept of material in this PBL e-module is ecosystem, which is presented in five subchapters, including ecosystem components, component interactions in ecosystem, energy flow, biogeochemical cycles, and ecosystem balance. The local issue in Sidoarjo which is directly related to the ecosystem materials is milkfish pond, due to a direct effect on the milkfish and local surroundings. The acquired content is embedded within critical thinking's indicators based on the actual phenomena from analysing that can be utilised as a foundation for developing the PBL e-module integrating Sidoarjo milkfish local wisdom for enhancing students' critical thinking skils. This study refers to the Fenrich Instructional Development Cycle model where each phase goes through a revision and evaluation process to produce a better PBL e-module developed.

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Phase 1: Analysing

The analysing phase was initially carried out by identifying learning needs related to the PBL e-module to be developed through curriculum, student, concept material, tasks, and local wisdom. The required data were gathered through teacher-students interviews related to teaching materials and fishermen interviews related to local wisdom content. Conducting a needs analysis guarantees that the e-module is suitable, accurate, and aligned with current field conditions to effectively address targeted challenges in learning (Bayu *et al*., 2023).

Phase 2: Planning

The planning phase was carried out by compiling systematics/manuscripts for PBL e-module such as lesson plan, e-module, assessments, and literature review. The planning phase and extensive literature review served as the foundation for the e-module, ensuring that the instructional content was scientifically accurate, structurally coherent, and tailored to address specific learning gaps in the classroom (Anggis, 2023).

Phase 3: Designing

The designing phase was carried out by developing the format along with layout of the PBL e-module, developing the content and the features of the PBL e-module. A well-executed design phase is crucial for effective e-module development, as a structured layout directly enhances visual appeal, drives independent study, and maximizes student engagement (Irianti *et al*.,2020). Furthermore, the prototype design of the PBL e-module integrating Sidoarjo milkfish local wisdom is presented in Figure 3 to 5.

Figure 3. Display of Front & Back Cover of PBL E-module Prototype

Figure 4. Display of Feature Mapping

Figure 5. Display of Local Wisdom-Based Student Worksheet

Phase 4: Developing

The developing phase was carried out through a validation process for the PBL e-module prototype that has been created at the previous designing phase. The PBL e-module developed was validated by two expert lecturers and a high school biology teacher based on three aspects: (1) presentation, (2) content, and (3) linguistic dimensions. The primary objective of expert validation is to verify that the e-module meets established educational standards while determining its feasibility, practical usability, and learning effectiveness. The validation ensures compliance with instructional standards while assessing the module's feasibility, practicality, and effectiveness (Elsoraya & Yerimadesi, 2022). The results of validation are presented as in the following Figure 6.

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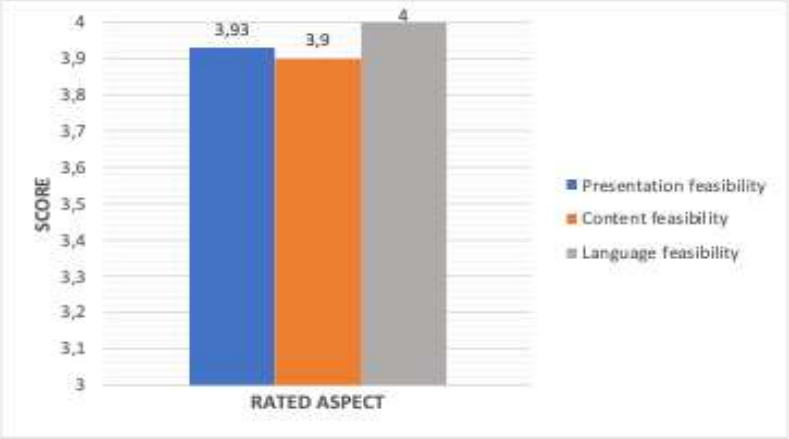

Figure 6. Graphic of PBL E-module Validation

The validation results of the PBL e-modul showed that obtained the validity category in all aspects of the assessment including presentation, content, and lisunguistic dimensions with average scores respectively 3,93; 3,9; and 4. The validator assigned the highest score to linguistic dimension is 4; whereas content dimension scored lowest which gained 3,9. Linguistic scored highest due to its clear phrasing, whereas content structure lagged due to repetitive information. High linguistic validity and clear, precise language in an e-module directly enhance readability, minimize misinterpretation, and optimize teacher-student engagement, ultimately facilitating the seamless achievement of learning objectives. (Devitska & Horvat-Choblya, 2024). The recapitulation results of the PBL e-modul's validity demonstrate that overall obtained average value of 3.94 which categorized as very highly valid as in the following Table 3**.**

Table 3. Recapitulation of PBL E-module Validation

Content component	Validity score	Criteria
Presentation feasibility	3,93	Very Highly valid
Content feasibility	3,9	Very Highly valid
Language feasibility	4	Very Highly valid
Average score	**3,94**	**Very Highly valid**

The validity of PBL e-module for presentation is presented in the following Table 4, overall obtained average value of 3.93 which categorized as very highly valid. In the presentation showed that obtained the validity category in all aspects of the assessment including the quality of, visual, text and layout, image, video, and feature with average scores 4, whereas the quality of presentation scores 3,6. This PBL e-modul was developed neatly organized and arranged using hd pictures and video as well as using clear font to make it readable and well-structured for students. The quality of using letters that are easy to read and appropriate for students can increases enthusiasm for learning (Duke, 2022). Furthermore, PBL e-modul was developed with files in HTML format that facilitate access through all devices (laptops, computers, tabs, and smartphones) without downloading the application to make it easier to use. In line with Suprapto *et al*. (2022), the HTML format is easily accessible across devices without needing Flip PDF Professional, featuring smooth page transitions and realistic sound effects can enhance learning experience. However, the quality of presentation scored lowest due to a slight revision based on minor feedback from the expert validator, the cover colors should be made brighter and more attractive to better engage student. An aesthetically appealing cover and a well-aligned visual design significantly heighten students' interest and motivation to engage with the module, thereby positively influencing their learning outcomes (Plass & Hovey, 2021).

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Table 4. Recapitulation of PBL E-module on Presentation Validity

Content component	Validity score	Criteria
Quality of presentation	3,6	Very Highly valid
Quality of visual	4	Very Highly valid
Quality of text and layout	4	Very Highly valid
Quality of image	4	Very Highly valid
Quality of video	4	Very Highly valid
Quality of feature	4	Very Highly valid
Average score	**3,93**	**Very Highly valid**

The validity of the PBL e-module for content is presented in the following Table 5, overall obtained average value of 3.9 which categorized as very highly valid. In the content showed that obtained the validity category in all aspects of the assessment including the quality of ecosystem concept, implementation of Problem Based Learning (PBL), and indicators of critical thinking skill with average scores 4, whereas the quality of integrating local wisdom of Sidoarjo milkfish scores 3,6. The accuracy of the ecosystem material is supported by recent literature and real-world issues from the nearby Sidoarjo milkfish ponds to stimulate students' critical thinking skills and elevate academic performance. In line with Shaw *et al*. (2020) stated that integrating local wisdom into biology learning contextualizes abstract scientific concepts, making learning more meaningful and significantly improving both student academic achievement and core competency skills. However, the integration local wisdom of Sidoarjo milkfish scored lowest due to a slight revision based on minor feedback from the expert validator, required a more direct mapping between local wisdom practices and core biology concepts. Directly mapping local wisdom practices to biological concepts simplifies the module's structure, allowing students to navigate and comprehend the content more effortlessly (Varenina *et al*., 2021).

Table 5. Recapitulation of PBL E-module on Content Validity

Content component	Validity score	Criteria
Quality of ecosystem concept	4	Very Highly valid
Contains implementation of Problem-Based Learning (PBL) syntax	4	Very Highly valid
Practicing critical thinking skill according to its indicators	4	Very Highly valid
Integrating local wisdom of Sidoarjo milkfish	3,6	Very Highly valid
Average score	**3,9**	**Very Highly valid**

The validity of the PBL e-module for linguistic is presented in the following Table 6, overall obtained average value of 4 which categorized as very highly valid. In the linguistic showed that obtained the validity category in all aspects of the assessment including the linguistic sturcture, language usage, and use of terminology with average scores 4. The language used in this PBL e-module was written in clear, simple, and proper grammatically correct Indonesian that is easy to understand, while unfamiliar terms are defined in the glossary. Using precise language and correct grammar in an e-module can simplify students' comprehension, helping them easily process instructional material delivered by teachers and ultimately enhancing their academic outcomes (Ormancı and Çepni, 2020). Wang *et al*. (2023) stated that using good and correct language makes it easy for learners to understand the contents of the studied book.

Table 6. Recapitulation of PBL E-module on Linguistic Validity

Content component	Validity score	Criteria
Linguistic sturcture	4	Very Highly valid
Language usage	4	Very Highly valid

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Use of terminology	4	Very Highly valid
Average score	**4**	**Very Highly valid**

Phase 5: Implementing

The implementing phase was carried out by testing PBL e-module that is valid through a trial involving 10th-grade students as direct users and learning targets. This trial aimed to measure the practicality of the PBL e-module using a readability test. At this phase, the assessment focused on the readability of the text module in each sub-chapter of the ecosystem material developed as in the following Table 7.

Table 7. Recapitulation of PBL E-module Readability

No.	Section	Page	Number of sentences	Number of Syllables	Level
1)	Ecosystem Components	2	6	163.2	11
2)	Component Interactions in an Ecosystem	21	5	161.4	11
3)	Energy Flow	28	6	150.6	9
4)	Biogeochemical Cycles	39	6	155.4	10
5)	Ecosystem Balance	44	5	157.2	11
Total Average			**5,6**	**157,5**	**10**

Table 7 presents the readability assessment of five sample sections from each sub-chapter that revealed the readability of PBL e-module is at level 10. Based on the data, the readability of the PBL e-module integrating Sidoarjo milkfish local wisdom was calculated using the text module by counting number of sentences per hundred words on every sub-chapter section which gained total average number of sentences 5,6 and by counting number of syllables per hundred words of every sub-chapter section then multiplied by 0,6 which gained total average number of syllables 157,5. The total average number of sentences was mapped onto the vertical axis on the Fry graph, whereas the total average number of syllables was mapped onto the horizontal axis on the Fry graph. The meeting point between the vertical and horizontal lines indicates the level of readability of the PBL e-module developed as in the following Figure 7.

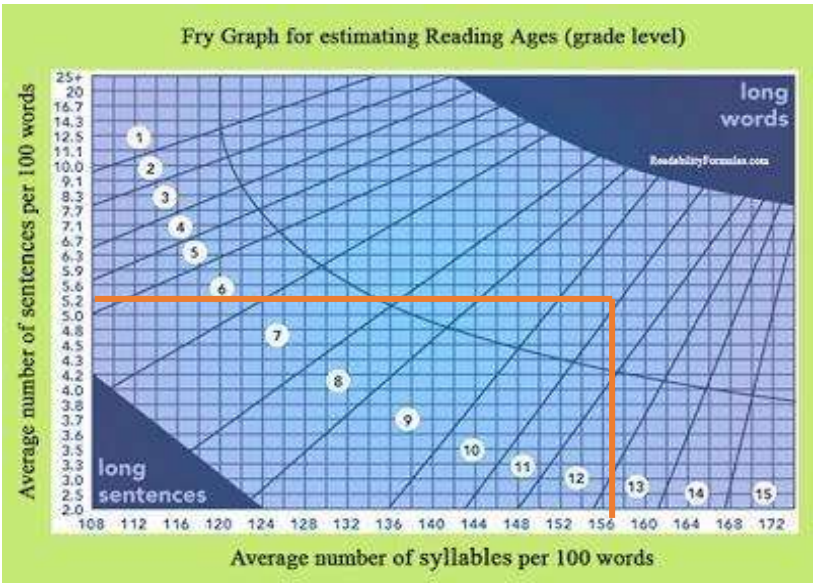

Figure 7. Fry's graph of PBL E-module

Figure 7 showed that the readability of the PBL e-module is at level 10 by showing the meeting point between the vertical and horizontal lines on Fry graph based on average

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number of sentences per hundred words and average number of syllables per hundred words. The fry readability of this PBL e-module is at level 10, it demonstrates that the instructional material is perfectly aligned with the cognitive and reading comprehension capabilities of 10th-grade students. The readability at level 9-11 range is ideal for 10th-grade students because levels 9–10 match students' independent reading ability, while Level 11 content offers a guided challenge that builds scientific literacy for advanced coursework (Nguyen *et al*., 2023; *Hidayati et al*., 2018). The readability levels vary across subsections due to greater complexity of terminology. Dense topics like biogeochemical cycles require technical terms and longer sentences, multi-syllabic terminology such as nitrification, lithosphere, and transpiration that raising readability metrics. In contrast, topics like energy flow use intuitive concepts and linear models such as producers, consumers, and eating that allowing for shorter sentences and lower readability score. The e-module are decent if the total sentences and syllables in the text are appropriate for the grade level and can be understood by students (Aristyasari *et al*., 2023). In line with Mahendri *et al*. (2022) stated that an optimal readability level in an e-module ensures that the instructional content aligns perfectly with the cognitive abilities and reading comprehension of students, allowing them to navigate and master the material more effortlessly. Appropriately leveled texts allow teachers to effectively embed local issues into learning that has the potential to be an important approach in empowering students' critical thinking skills (Tohri *et al*., 2022; Pamenang, 2021). Hence, this PBL e-module integrating Sidoarjo milkfish local wisdom can enhance students' critical thinking skills through analyzing the issues of Sidoarjo milkfish pond and implement solutions to preserve the local environment.

Conclusion

This study successfully developed and evaluated a Problem-Based Learning (PBL) e-module integrated with the local wisdom of Sidoarjo milkfish cultivation for 10th-grade biology instruction. The expert evaluation confirms that the developed e-module meets high standards of validity across presentation, content, and linguistic dimensions. Furthermore, the Fry readability assessment demonstrates that the instructional material is perfectly aligned with the cognitive and reading comprehension capabilities of 10th-grade students (Level 10). By contextualizing complex ecosystem concepts within authentic local environmental issues, the e-module provides a structured platform to engage students in critical analysis and problem-solving.

Recommendation

Acording to the research findings, teachers are advised to align local wisdom and problem-based learning with e-module in biology learning to reinforce contextual understanding and foster students' critical thinking skills, whilst adapting their use to student character and available technological resources. Future studies are encouraged to broaden implementation to wider educational contexts, enhance electronic modules with more interactive digital features, and explore other forms of local wisdom to further amplify the relevance and effectiveness of culturally integrated learning media.

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