Jurnal Kependidikan:
Jurnal Hasil Penelitian dan Kajian Kepustakaan di Bidang Pendidikan, Pengajaran dan Pembelajaran
https://e-journal.undikma.ac.id/index.php/jurnalkependidikan/index

Vol. 12, No. 2 : June 2026
E-ISSN: 2442-7667
pp. 981-993
Email: jklppm@undikma.ac.id

Designing a Pedagogical Deep Learning-Oriented Problem-Based Learning E-Module for Human Circulatory System Learning: Development, Validation, and Students' Responses

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Abstract: This study aims to develop a Problem-Based Learning (PBL)-based e-module integrated with a Pedagogical Deep Learning approach, evaluate its feasibility, and examine students' responses through a limited trial involving 36 students. The research was conducted at SMP Negeri 04 Siak Hulu using the ADDIE development model, with a particular focus on the development phase. The evaluation process involved four experts, consisting of one media expert, one subject-matter expert, and two learning experts. Data were collected using validation sheets and student response questionnaires and were analyzed through descriptive calculations of validation and response scores. The findings revealed that the developed e-module achieved a high level of validity, with average scores of 96% from the media expert, 91% from the subject-matter expert, and 92% from the learning experts. Furthermore, students' responses yielded an average score of 94%, which was categorized as excellent. The e-module was specifically designed for circulatory system content in science education and featured an interactive interface that could be accessed both online and offline. These findings indicate that the PBL-based e-module integrated with a Pedagogical Deep Learning approach is a feasible and highly accepted instructional resource. Therefore, it is recommended as an innovative technology-enhanced learning material to support more effective, interactive, and meaningful learning experiences.

Article History
Received: 20-04-2026
Revised: 24-05-2026
Accepted: 31-05-2026
Published: 20-06-2026

Key Words:
Digital Learning Media; E-Module; Human Circulatory System; Pedagogical Deep Learning Approach; Problem-Based Learning.

How to Cite: Siregar, A. S. K., & Hidayati, N. (2026). Designing a Pedagogical Deep Learning-Oriented Problem-Based Learning E-Module for Human Circulatory System Learning: Development, Validation, and Students' Responses. *Jurnal Kependidikan : Jurnal Hasil Penelitian Dan Kajian Kepustakaan Di Bidang Pendidikan, Pengajaran, Dan Pembelajaran*, *12*(2), 981-993. https://doi.org/10.33394/jk.v12i2.20778

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Introduction

Instruction in lower secondary biology that learners of scientific understanding while also comprehending the interconnections among biological principles and physiological mechanisms within the human organism (Damerau et al., 2022; Snapir et al., 2017). The human circulatory system constitutes one of the most intricate physiological networks, encompassing numerous interrelated biological mechanisms. This complexity often leads to students' difficulties in developing conceptual understanding and a tendency to rely on memorization rather than meaningful comprehension (Gaylan et al., 2024; Raved & Yarden, 2014; Wesra et al., 2025). These difficulties indicate that circulatory system learning is still dominated by memorization-oriented instructional patterns, where students tend to learn information for assessment purposes rather than developing conceptual understanding. This condition limits their ability to connect biological concepts with real-life phenomena (Aleknavičiūtė et al., 2023; Klymkowsky, 2021). As a result, students often struggle to explain contextual problems such as hypertension, anemia, and heart diseases based on scientific concepts learned in class.

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The progression of digital technologies in education opens pathways for the creation of more dynamic and personalized learning innovations. Technology integration enables students to experience more flexible, visual, and participatory learning processes (Alenezi et al., 2023; Zou et al., 2025). One of the rapidly growing digital innovations is the e-module, which presents learning materials through an interactive multimedia platform. E-modules support independent learning and have the potential to enhance student engagement and learning motivation (Bilynska et al., 2024; Karagöz et al., 2023; Staneviciene & Žekienė, 2025). Nevertheless, digitalization of instructional materials alone does not guarantee meaningful learning. In practice, many e-modules are still limited to digital conversions of textbooks without pedagogical design that promotes higher-order thinking skills, resulting in passive learning experiences among students (Li & Zhan, 2022).). Therefore, e-module development needs to be integrated with learning approaches that actively engage students in knowledge construction (Gunawan et al., 2024).

Problem-Based Learning (PBL) emerges as a suitable strategy, utilizing contextual real-world challenges as the stimulus for learning while fostering student engagement in investigative inquiry, discussion, and problem-solving tasks (Gürses et al., 2022). In addition, Pedagogical Deep Learning emphasizes deep conceptual understanding through reflective thinking, analysis, interpretation, and the ability to connect concepts with real-life contexts, in contrast to surface learning that focuses on memorization (Dolmans et al., 2016). Students engaged in deep learning are more capable of constructing knowledge, linking concepts, and applying understanding in new situations, making it a relevant approach for science education that requires conceptual and scientific reasoning (Dolmans et al., 2016; Sugden et al., 2021).

Prior research has demonstrated that e-modules in science learning, particularly biology, improve learning flexibility and student engagement (Irdawati et al., 2023; Nurulita & HB, 2022). while PBL enhances critical thinking, conceptual understanding, and problem-solving skills (Nugraha et al., 2023). These studies have generally examined e-module development and PBL separately, without integrating them with a Pedagogical Deep Learning approach. This limited integration is mainly due to challenges in aligning digital instructional design with problem-based activities and deep learning processes such as understanding, applying, and reflecting, which are required to support higher-order thinking skills. In addition, implementing these three components simultaneously requires complex instructional planning, adequate technological support, and carefully designed learning activities, which are often difficult to achieve in previous studies. Therefore, integrating e-modules, PBL, and Pedagogical Deep Learning is essential to create a unified learning resource that promotes critical and reflective thinking through meaningful learning experiences (Sukackė et al., 2022).

Research on PBL-based e-modules for circulatory system learning still shows limitations, as many studies focus on cognitive outcomes without exploring instructional design that supports Pedagogical Deep Learning (Mustafa et al., 2024; Smith et al., 2022). Moreover, studies integrating Pedagogical Deep Learning into science e-module development at the junior high school level remain limited, despite its potential to promote active, reflective, and contextual learning. In addition, e-module quality must ensure content validity, language, presentation, and pedagogical appropriateness (Hamidah et al., 2022). while product validity and student responses are important indicators of feasibility and usability in learning implementation (Suwandi et al., 2023; Delita et al., 2022). Based on these problems, there is a need to develop digital instructional materials capable of integrating technology, PBL, and Pedagogical Deep Learning approaches within a comprehensive instructional design. The development of a PBL-based e-module with a

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Pedagogical Deep Learning approach is expected to help students understand circulatory system concepts more deeply through contextual, interactive, and reflective learning activities. The developed e-module is not only intended as a medium for delivering information but also as a means of constructing learning experiences.

The novelty of this study lies in the development of a PBL e-module that integrates a Pedagogical Deep Learning approach into circulatory system learning. The circulatory system topic was selected because it involves abstract and complex physiological processes that are difficult for students to understand through conventional modules alone. Students need not only to memorize organ structures and functions, but also to understand the relationships among circulatory processes and their relevance to real-life health issues. Previous studies reported that circulatory system learning is still dominated by lecture-based and textbook-oriented instruction, resulting in limited student engagement and weak conceptual understanding (Siregar & Hidayati, 2026). Therefore, this study is oriented not only toward digital media development but also toward designing meaningful learning experiences through contextual problem-solving and deeper conceptual understanding.

Research Method

This research was conducted at SMP Negeri 04 Siak Hulu. The school was selected because it possesses adequate learning support facilities and granted permission for the researcher to conduct the study directly. The current study undertook a Research and Development approach within the ADDIE model, encompassing five ordered phases: analysis, design, development, implementation, and evaluation. Nevertheless, the study was conducted solely through the development phase, owing to constraints pertaining to time availability and limited research resources.

The analysis phase was carried out to determine educational requirements trough direct students needs and learning materials questionnaire and conversational dialogues with science/biology educators, focusing on learning challenges associated with the human circulatory system content. The design phase involved the preparation of the PBL based e-module, encompassing material organization, interface design, selection of supporting media, and structuring of learning activities aligned with PBL syntax. Subsequently, during the development phase, the e-module product was created and then subjected to expert validation to assess its feasibility prior to implementation in actual learning activities.

Data gathering tools utilized in this investigation consisted of evaluation forms and surveys designed to capture student perspectives. Product validation was conducted by four expert validators, including one subject matter expert, one media expert, and two instructional design expert, drawn from university lecturers and science educators. The validation instrument for the subject matter expert encompassed aspects of material appropriateness, conceptual accuracy, and consistency between the educational material and the designated learning outcomes. The media expert validation instrument included aspects of appearance, layout, image quality, color usage, and ease of navigation. Meanwhile, the learning expert validation instrument covered aspects of language, readability, instructional presentation, and the appropriateness of implementing the PBL model (Saputri et al., 2023). In addition, student response questionnaires were used to determine students' responses toward the developed e-module (Cahaya et al., 2024).

The analysis was conducted using descriptive quantitative methods. The obtained percentage scores were converted into qualitative validity categories. Scores ranging from 85,01%–100% were classified as very valid, 70,01%–85% as valid, 50,01%–70% as less valid, and 01,00%–50% as invalid. The percentage results of students' responses were

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collected from 36 purposively selected eighth-grade students at SMPN 04 Siak Hulu and categorized into poor, fairly good, good, and excellent criteria. This analysis aimed to determine the feasibility level of the development PBL-based e-module on human circulatory system material.

Results and Discussion

This study successfully developed a PBL-based e-module integrated with a Pedagogical Deep Learning approach for the topic of the Human Circulatory System. The main findings revealed that the developed e-module was able to support meaningful, interactive, and student-centered learning experiences. Results showed that uniting problem-based learning with Pedagogical Deep Learning concepts stimulated more dynamic student participation in the learning journey and improved their grasp of fundamental principles. The reflective activities integrated into the e-module also support the development of meaningful learning, enabling students not only to memorize concepts but also to understand and apply them in real-life contexts (John & Thomas, 2018; Rotgans & Schmidt, 2011). Furthermore, the developed e-module provided learning resources that were practical, accessible, and suitable for supporting independent learning across institutional and non-institutional environments.

The findings from the initial investigation revealed several important aspects underlying the development of the e-module. First, the educational framework implemented in this research utilized the Merdeka Curriculum incorporating a Pedagogical Deep Learning approach. Second, both teachers and students expressed the need for comprehensive and time-efficient learning resources that integrate Pedagogical Deep Learning principles while supporting autonomous learning outside the classroom environment. Third, the topic of the human circulatory system was identified as particularly difficult for students to understand due to the abstract nature of the concepts and the limited visualization provided by existing instructional materials. Fourth, the currently available learning resources were still inadequate, indicating the need for instructional media that provide dynamic visualization and encourage active student participation according to teachers' and students' learning needs. such as on printed textbooks based on revised curriculum editions, with only limited copies available (Figure 1).

Figure 1. Example of the Use of Pedagogical Deep Learning Lesson Plans and Textbooks in Schools

Therefore, the development of digital instructional materials oriented toward conceptual understanding, contextual learning, and interactive engagement becomes essential to create more meaningful learning experiences. This approach also plays an important role in improving student motivation, learning continuity, and deeper conceptual understanding, which may contribute to more optimal learning outcomes (Sugden et al., 2021; Teng & Wang, 2021; Vilca & Yucra, 2025).

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During the design stage, the Canva platform was utilized to develop the graphical interface of the e-module. Various font styles, including Bree Serif, Bobby Jones, Rubik One, Alice, Lilita One, Open Sans, and Times New Roman, were selected to enhance readability and visual attractiveness. In addition, the color combinations applied in the PBL-integrated e-module design were carefully adjusted to create a harmonious and non-distracting learning environment, predominantly using a pink theme complemented by supporting colors. The font sizes ranged from 17 to 30 (Canva units) to ensure readability across different devices. The e-module was designed to be accessible through smartphones and desktop computers via an online hyperlink, while also being available offline in PDF format to support flexible learning access. Furthermore, the flipbook format developed using Flip PDF Professional and integrated with the Heyzine Flipbooks webpage provided a more interactive and engaging digital learning experience for students. The overall design of the e-module is presented in Figure 2.

Figure 2. Display of the E-Module in the Flip PDF Professional Heyzine Flipbooks

This e-module encompasses multiple sections organized according to the established framework, comprising the front cover, table of contents, introduction, educational goals, dimensions of the Pancasila Student Profile, substantive explanations, structured learning experiences corresponding to PBL syntax integrated with Pedagogical Deep Learning methodology, contemplative exercises, assessments inclusive of solution guides, self-evaluation instruments, terminology reference, and bibliographic references. The PBL electronic module incorporating Pedagogical Deep Learning principles was constructed in the Indonesian language, with its substance derived from the currently operational Merdeka Curriculum. The resulting e-module product is displayed in Figure 3.

Figure 3. Visualization of Several E-Module Layout Formats

The third stage was the development phase. In this phase, the developed e-module had been integrated with the PBL model and a Pedagogical Deep Learning approach, ensuring that both the PBL syntax and Pedagogical Deep Learning principles were embedded within its structure. Every learning unit within the electronic module was methodically developed in accordance with the instructional guides, educational targets, and anticipated academic achievements. Multiple research investigations have established that learner enthusiasm for education can be significantly improved through the implementation of creative, diverse,

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interactive, and learner-centric teaching resources and pedagogical approaches (Teng & Wang, 2021). Practical learning modules that are perceived as beneficial and meaningful for students can help foster and sustain situational interest in learning. As a result, this e-module was constructed consistent with the instructor's teaching materials and the content areas of the human circulatory system with the aim of ensuring improved availability and operational practicality for educators and students.

The combination of PBL techniques with Pedagogical Deep Learning methodology is visible across all tasks featured in the e-module (Figure 4). The first phase of PBL centers on problem orientation. This stage promotes experiential understanding as the initial phase of learning and integrates one of the Pancasila Student Profile dimensions, namely collaboration. Educators can thereby improve the effectiveness of PBL integrated with a Pedagogical Deep Learning approach and support students' success in problem-solving tasks (Saqr & López-Pernas, 2023).

Figure 4. Visualization of the Product

The organization of students displayed within the e-module represents the second syntax of PBL. In this phase, educators offer instructional support or directional assistance as mechanisms for organizing collaborative groups, providing students with opportunities to operate independently, either individually or through collective collaboration. The objective is to facilitate students in collaborating effectively, developing mutual responsibility, and designing systematic strategies for independent, critical, and meaningful problem-solving in which the learning material is connected to real-life contexts.

The next stage involves syntax that supports independent investigation through collaboration. At this stage, the Pedagogical Deep Learning approach is integrated into the learning process. Students acquire essential data and information necessary to resolve the issues they have pinpointed, with problem formulations being developed by learners who substantively participate in the instructional processes. This stage also encourages students to develop structured problem-solving methodologies as part of the hands-on learning journey wherein they apply acquired knowledge. This is consistent with the view of experience and education, which emphasizes that learning becomes more meaningful when students are actively involved in inquiry processes, direct experiences, and problem-solving based on real-life situations (Franceschini, 2023).

The e-module, which incorporates syntax containing the stages featuring a framework comprising the phases of producing and displaying task outcomes, illustrates the research processes that have been undertaken. The outcomes are then documented in group work reports and presented as part of the evaluation process, reflecting the learning experience of reflection and encompassing the principle of mindfulness in becoming active and self-regulated learners. The integration of electronic modules into instruction not only enhances learners' capacities for critical analysis and cooperative problem-solving through structured activities but also reinforces Pedagogical Deep Learning through investigative and reflective

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activities that enable students to construct more meaningful understanding of the learning material (Fullan & Langworthy, 2014; Hamidah et al., 2022).

The subsequent phase involves analyzing and evaluating. This phase represents the final syntax of the PBL learning model. The provided instructions function as guidance while students evaluate the investigation process and engage in discussions and feedback sessions with teachers. This interaction strengthens students' understanding and involvement in Pedagogical Deep Learning processes. Reflection has been proven to positively influence students' academic performance because it encourages deeper learning engagement, enhances intrinsic motivation, and helps students construct more meaningful understanding in completing academic tasks, including writing activities (Radović et al., 2023).

The e-module developed in this study demonstrated high quality, as evidenced by the results of the media expert validation presented in Figure 5. The consistently high scores across most aspects suggest that the e-module has been well designed to support effective learning experiences. However, the "e-module standards" indicator obtained a score of 75%, indicating that several technical and structural components may still require minor revisions. In particular, the high ratings for interactivity and design aspects indicate that the e-module is capable of fostering student engagement and facilitating more meaningful learning interactions. This is important because well-designed digital learning media can enhance students' motivation and persistence in learning activities. Students who are actively engaged tend to demonstrate higher participation, greater effort, and stronger perseverance in facing academic challenges (Alonso-Tapia et al., 2023; Sedova & Sedlacek, 2023).

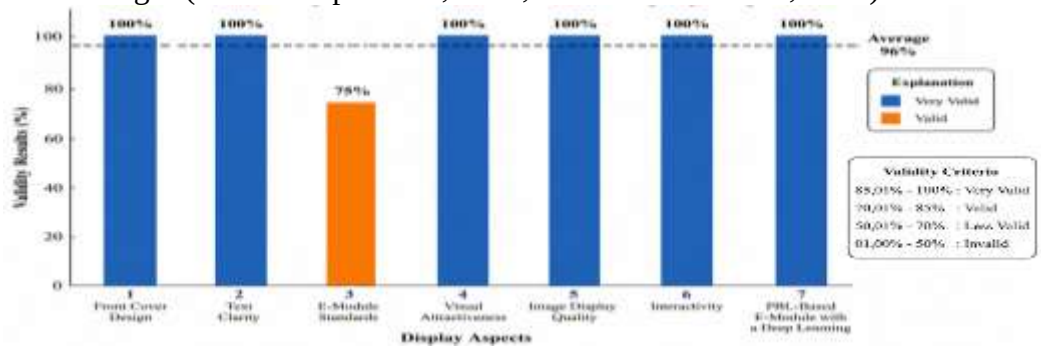

Figure 5. Media Expert Assessment outcomes

Validation testing conducted by material expert also constituted an important aspect in the development of the PBL-integrated electronic module with a Pedagogical Deep Learning approach, particularly in ensuring the suitability of the content for understanding the human circulatory system. The results of the subject matter expert validation are presented in Figure 6. In the first validation stage, several aspects required improvement, especially the "Completeness of Material" indicator, which only reached 50%. This low score indicated that some essential subtopics, detailed explanations, and supporting learning examples were still incomplete. In addition, the "Accuracy of Material" aspect (75%) showed that several concepts needed refinement to improve scientific correctness and clarity.

Based on these findings, revisions were carried out by completing missing subtopics, enriching explanations of key concepts such as blood circulation and heart function, adding contextual examples, and correcting conceptual inaccuracies based on updated references. After revision, the second validation stage showed a significant increase, where all indicators reached 100% and were categorized as highly valid. Consequently, the average score increased to 91%, indicating that the e-module met the required standards and was feasible for use in learning. The validation process is essential to ensure the quality and feasibility of

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instructional materials so that they are effective and appropriate for use by both teachers and students in educational settings (Laksana, 2024; Zafrullah et al., 2024).

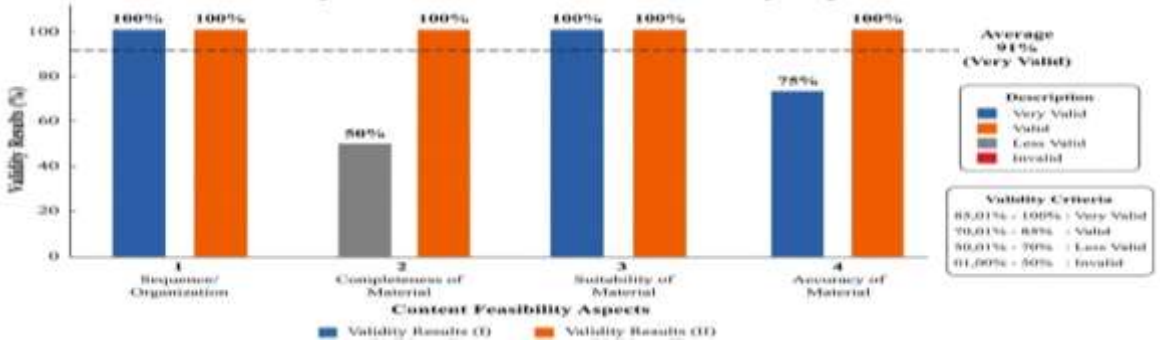

Figure 6. Results of Material Expert Validation

Learning experts also played an important role in this development process. These experts ensured that, in addition to being of high quality, the e-module effectively integrated PBL with a Pedagogical Deep Learning approach. Several studies referring to Nienke Nieveen (1999) indicate that the viability validity of an electronic module, based on expert evaluation, is determined by the degree to which the digital module satisfies the predetermined criteria (Zafrullah et al., 2024). By emphasizing its benefits within the educational process, the PBL-based e-module integrated with a Pedagogical Deep Learning was ensured to have been implemented optimally, consequently rendering the learning experience more effective when complemented by the developed e-module through dynamic and meaningful pedagogical interactions. The validation outcomes from the learning expert are outlined in Table 1.

Table 1. Pedagogical Expert Validation Outcomes

No	Aspect	Indicators	Val 1 (%)	Description	Val 2 (%)	Description
1.	Display Structure	Appearance	75	Very Valid	100	Very Valid
		Clarity of Learning objectives	100	Very Valid	100	Very Valid
		Suitability of Learning Objectives with LO	100	Very Valid	100	Very Valid
		Suitability of Materials with Learning Objectives	100	Very Valid	100	Very Valid
		Systematic Organization and Clear Logical Flow	100	Very Valid	100	Very Valid
		PBL-Based E-Module with a Pedagogical Deep Learning Approach	100	Very Valid	100	Very Valid
2.	Language	Language Use	75	Very Valid	100	Very Valid
3.	Readability	Ease of Reading	75	Very Valid	100	Very Valid
		Ease of Understanding	100	Very Valid	100	Very Valid
Average				**96**		**VeryValid**

Displayed in Table 1, the validator assessments show highly positive ratings from both reviewers, producing an average result of 96%. These results indicate that both the design and content fulfilled optimal quality standards. The integration of the PBL model with the implementation of the Pedagogical Deep Learning approach presents a problem-solving process that is relevant and connected to real-life experiences develop more meaningful conceptual understanding, and engage in reflective activities that enhance rational thinking abilities. These findings are consistent with Ariani & Sari., (2026), who stated that the

implementation of PBL assisted by e-modules effectively improves students' critical thinking skills and promotes active engagement in learning through contextual and meaningful problem-solving activities. These educational resources are deemed appropriate for pedagogical application upon meeting the stipulated validation requirements.

Figure 7. Students' Use of the E-Module

Aside from expert validation, students also contributed feedback upon experiencing the problem-based learning digital module embedded within Pedagogical Deep Learning frameworks. The produced e-module remained readily available to learners through their smartphone devices. The developed e-module could be accessed by students using their smartphones (Figure 7). Students who accessed the digital module were subsequently requested to fulfill a questionnaire. Table 2 presents the survey responses obtained from learners following utilization of the electronic module.

Table 2. Results of the Student Response Test

No	Aspect	Response Test Results	Description
1	E-Module Design	92	Excellent
2	Text Readability	93	Excellent
3	Clarity of Presentation	94	Excellent
4	Font Usage	95	Excellent
5	Clarity of Images and Material	95	Excellent
6	Language Usage	95	Excellent
7	Sequence/Organization	96	Excellent
8	Material Presentation	95	Excellent
9	Learning Content	93	Excellent
10	Level of Attractiveness	94	Excellent
Average (%)		**94**	**Excellent**

Referencing the data in Table 2, the learner responses subsequent to interacting with the developed e-module reflected an average rating of 94%. This score indicates that the responses provided by students were highly positive. This can be observed from the high scores achieved in each aspect, which serve as evidence of the successful design of an effective and practical e-module. Further, the mean scoring outcomes indicated that participants found this e-module highly appealing, particularly with respect to compositional layout, aesthetic background elements, font usage, sequence/organization and the incorporation of images alongside video content, the inclusion of barcodes and hyperlinks, and it being accessible in both PDF and Flip PDF Professional file versions. These features were perceived as increasingly interactive because the pages could be flipped like a conventional book while remaining in digital form. Such features facilitated ease of use for students, enhancing the electronic module's interactivity and user-friendliness. Additionally, the creation of this e-module also considered factors that could enhance students' motivation and interest in learning through the careful selection of colors and design elements.

The developed electronic module specifically addressed topics considered difficult for students to understand, namely the human circulatory system material, and was designed according to students' needs. In addition to completing the questionnaire, Students also

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contributed multiple comments subsequent to engaging with the e-module, as displayed in Figure 8.

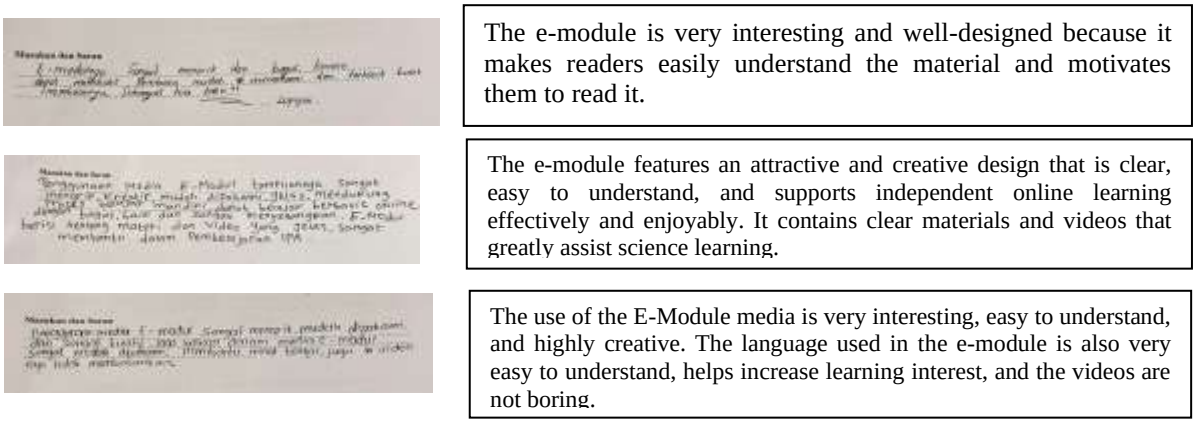

Figure 8. Excerpts of Students' Comments and Suggestions

The comments and suggestions presented in Figure 6 yielded affirmative responses regarding the developed electronic module, Student feedback revealed positive reception of the e-module's visual layout, instructional content, and its alignment with problem-based learning principles integrated with Pedagogical Deep Learning approaches. Students' comments reflected positive perceptions of the developed e-module, including its design, content, and alignment with the PBL model. These findings indicate that effective visual design, layout organization, image-text integration, and multimedia components can enhance students' attention, motivation, and understanding in digital learning environments. Furthermore, Integrating scannable codes and embedded hyperlinks within the electronic module can foster advancements in digital literacy while increasing learner involvement in technology-mediated instruction (Laily, 2022; Law & So, 2010). This research offers valuable implications for instructional and educational implementation. Conceptually, the PBL e-module integrated with Pedagogical Deep Learning supports cognitive development theory by fostering active student involvement in exploration and problem-solving. Practically, results show the module provides accessible usability, interactive features, and enhanced engagement while helping teachers deliver content more effectively.

Conclusion

This research and development study effectively developed a PBL digital module integrated with a Pedagogical Deep Learning approach on the topic of the human circulatory system through validation procedures conducted by multimedia experts, subject matter specialists, and educational professionals. Assessment findings revealed that the created e-module possessed high practicality for integration into instructional environments. Student responses also showed a very good level of satisfaction, particularly in terms of ease of use, clarity of content, and visual appeal. The incorporation of the problem-based learning framework was executed through sequential phases encompassing problem orientation, learning arrangement, investigative inquiry, product creation, analytical review, and outcome assessment. At each stage, the Pedagogical Deep Learning approach incorporated components such as graduate profile dimensions, the principles of mindful, meaningful, and joyful learning, as well as learning experiences involving understanding, applying, and reflecting. These components effectively promoted students' active engagement in deep learning processes.

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Recommendation

This study recommends PBL-based e-modules with a Pedagogical Deep Learning approach to enhance student engagement in the learning process. The optimal implementation of the e-module is suggested to apply a flipped classroom strategy, where students independently learn through the e-module before class and engage in problem-solving and collaborative activities during classroom sessions. This approach may be supported by blended learning and peer assessment to strengthen interaction and reflective learning. Future research should evaluate the effectiveness of this e-module across various learning contexts and develop more innovative technological features. In addition, the module can also be adapted for other subject areas.

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pp. 981-993
Email: jklppm@undikma.ac.id

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