

DEVELOPING INTERACTIVE MICROLEARNING E-MODULES FOR THIRD-GRADE IPAS METAMORPHOSIS INSTRUCTION AT BINTORO 16 ELEMENTARY SCHOOL

Galang Satrya Virguspara Habibi^{1a*}, Khairul Arifin²

¹²Universitas Negeri Semarang, Indonesia

^aE-mail: galangsatryavirgusparahabibi@gmail.com

(*) Corresponding Author
galangsatryavirgusparahabibi@gmail.com

ARTICLE HISTORY

Received : 23-07-2026

Revised : 28-08-2026

Accepted : 10-09-2026

KEYWORDS

*Interactive E-Module,
Microlearning, IPAS,
Metamorphosis of Living
Organisms, Elementary
School*

ABSTRACT

The implementation of Natural and Social Sciences (IPAS) learning on the topic of metamorphosis in living organisms requires instructional media that can facilitate students' understanding of abstract and sequential biological processes. Conventional learning resources, such as textbooks, remain insufficient in providing interactive and engaging learning experiences for elementary school students. This study aims to develop a microlearning-based interactive e-module for IPAS learning on metamorphosis in living organisms for third-grade students at Bintoro 16 Public Elementary School in Demak and to determine its feasibility. This research employed a Research and Development (R&D) approach using the ADDIE development model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. Data were collected through observation, interviews, documentation, questionnaires, and expert validation sheets. The data were analyzed using descriptive quantitative and qualitative analysis techniques based on percentage calculations from Likert-scale assessments. The results showed that the developed e-module obtained a feasibility score of 90.00% from material experts and 95.54% from media experts, with an overall expert validation score of 92.77%, categorized as very feasible. The implementation stage also demonstrated positive student responses with an average score of 91.25%, categorized as very feasible. These findings indicate that the microlearning-based interactive e-module is a feasible digital learning resource that supports student engagement, conceptual understanding, and independent learning in IPAS instruction on metamorphosis.

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INTRODUCTION

Rapid advances in digital technology have transformed educational practices and encouraged the development of learning environments that are more interactive, student-centered, and responsive to learners' needs. Within the implementation of the Merdeka Curriculum, Natural Sciences (IPA) and Social Sciences (IPS) are integrated into the subject of Ilmu Pengetahuan Alam dan Sosial (IPAS), which is intended to foster students' critical thinking and problem-solving abilities through contextual learning experiences (Utami et al., 2024). Despite these objectives, the implementation of IPAS learning in elementary schools continues to face substantial challenges. Teacher-centered instruction, limited utilization of digital learning resources, and insufficient adaptation to technological developments remain common obstacles that reduce student participation and hinder conceptual understanding (Viola and Rizvi, 2025; Zahra, 2024).

One of the topics that frequently presents learning difficulties is metamorphosis, which requires students to understand sequential biological transformations that cannot be directly observed in everyday situations. The abstract nature of metamorphosis concepts often creates learning barriers for elementary school students who generally require concrete, visual, and interactive representations to facilitate comprehension (Rolff et al., 2019; Truman, 2019). These challenges become more significant among third-grade students, whose learning characteristics are closely associated with visual stimulation, experiential learning, and relatively limited attention spans (Utaminingsih & Purwati, 2024). Consequently, instructional resources that rely primarily on textbooks are often insufficient to support meaningful understanding of metamorphosis concepts.

Several previous studies have attempted to address these instructional challenges through the development of alternative learning media. Fauziah et al. (2025) reported that pop-up book media improved students' understanding of metamorphosis concepts, while Khalimatus Sya'diah et al. (2024) demonstrated positive learning outcomes through interactive diorama media. Digital learning innovations have also shown promising results. Fitriah et al. (2025) found that Genially-based learning media enhanced students' engagement and conceptual understanding, whereas Herlina et al. (2025) and Pratama Putra and Linda (2021) highlighted the effectiveness of interactive e-modules in improving learning outcomes and scientific literacy.

Although these studies confirm the educational benefits of interactive learning media, several limitations remain evident. Existing studies on metamorphosis learning predominantly focus on specific media formats such as pop-up books, dioramas, or general interactive digital media, while limited attention has been given to the integration of microlearning principles within interactive e-modules for elementary IPAS instruction. Furthermore, previous studies generally emphasize learning effectiveness without systematically examining the development process and feasibility of microlearning-based e-modules designed according to the characteristics of lower-grade elementary students. This condition indicates a research gap concerning the development of interactive learning resources that combine multimedia features, curriculum alignment, and microlearning strategies within a single instructional product.

Microlearning has emerged as a promising instructional approach because it organizes learning content into concise and focused learning units, thereby reducing cognitive overload and improving information retention (Nugraha et al., 2021; Díaz-Redondo et al., 2023). Previous studies have demonstrated that microlearning contributes positively to learning achievement, engagement, and retention in digital learning environments (Alya & Purwaningsih, 2025; Haliem et al., 2026). Nevertheless, empirical studies investigating the application of microlearning-based interactive e-modules in elementary IPAS learning, particularly on the topic of metamorphosis, remain limited. Educational benefits become even more substantial when e-modules are designed according to differentiated learning principles, enabling instruction to accommodate diverse learner characteristics as emphasized by Avivah et al. (2025)

Preliminary observations conducted at SD Negeri Bintoro 16 Demak revealed that IPAS learning continues to depend largely on conventional teaching methods and printed learning materials, with limited utilization of interactive digital resources. These conditions reduce opportunities for active student engagement and do not fully accommodate students' preferences for visual and technology-supported learning experiences. Based on these considerations, this study aims to develop a microlearning-based interactive e-module for the topic of living organism metamorphosis and to evaluate its feasibility through expert validation. The study is expected to contribute to the development of innovative instructional media that support more engaging, meaningful, and learner-centered IPAS learning in elementary schools.

METHOD

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of Analysis, Design, Development, Implementation, and Evaluation stages. The research was conducted during the second semester of the 2025/2026 academic year at SD Negeri Bintoro 16 Demak. The analysis stage focused on identifying learning needs, student characteristics, and instructional challenges related to the topic of living organism metamorphosis in IPAS learning. The design stage involved preparing microlearning-based content, designing the e-module interface, and developing research instruments. During the development stage, the interactive e-module was created by integrating multimedia elements, including illustrations, animations, videos, and interactive quizzes, followed by expert validation. Implementation was conducted through a limited field trial, while evaluation was carried out to determine the feasibility of the product and identify necessary revisions.

Participants in this study consisted of third-grade students of SD Negeri Bintoro 16 Demak selected through purposive sampling, as they represented the target users of the developed instructional media and had prior experience learning metamorphosis within the IPAS curriculum. The population comprised all third-grade students at the school, while data were collected from multiple sources, including classroom observations, interviews with the classroom teacher, documentation, student questionnaires, and expert validation instruments. Observation and interviews were employed to identify instructional conditions, media utilization, and learning needs, whereas documentation served to support and verify research findings. Questionnaires were administered to gather data regarding learning needs, expert evaluations, and student responses toward the developed e-module. Data validity was ensured through expert validation and triangulation techniques involving multiple sources of evidence. Qualitative data obtained from observations, interviews, and documentation were analyzed descriptively to explain instructional conditions and user needs, while quantitative data collected through needs assessment questionnaires, expert validation forms, and student response surveys were analyzed using percentage-based descriptive statistics derived from Likert-scale measurements. The resulting percentages were subsequently interpreted according to predetermined feasibility and response criteria to determine the appropriateness, attractiveness, and educational value of the developed microlearning-based interactive e-module.

Data were collected through observations, interviews, documentation, questionnaires, and expert validation sheets. Observation and interviews were conducted to identify instructional conditions and learning needs, while questionnaires were used to obtain data on student needs, expert assessments, and student responses to the developed e-module. Qualitative data were analyzed descriptively, whereas quantitative data from validation and response questionnaires were analyzed using percentage-based descriptive statistics derived from Likert-scale measurements. The resulting scores were interpreted according to predetermined feasibility criteria to determine the validity and practicality of the microlearning-based interactive e-module.

RESULT AND DISCUSSION

Analysis of Learning Needs and the Rationale for Developing a Microlearning-Based Interactive E-Module

The development of a microlearning-based interactive e-module in this study originated from an empirical examination of the instructional realities encountered in Grade III IPAS learning at SD Negeri Bintoro 16 Demak. Findings obtained through classroom observations and interviews with the classroom teacher revealed that learning activities remained predominantly dependent on printed textbooks and student worksheets, while the utilization of digital instructional media was still limited in both frequency and scope. Educational transformation in the digital era requires learning resources that are adaptive to students' cognitive development and technological exposure, a view that aligns with the findings reported by Herlina and Abidin (2024) regarding the strategic role of interactive e-modules in strengthening scientific literacy. Classroom observations further indicated that students demonstrated greater enthusiasm when visual and multimedia resources were incorporated into instruction. Learning conditions of this nature highlighted the necessity of developing a more integrated and engaging instructional medium capable of supporting both classroom learning and independent study.

The urgency of developing a new instructional medium became increasingly evident when examining the characteristics of metamorphosis as a science topic within the IPAS curriculum. Concepts concerning the life cycle and

transformation stages of insects involve dynamic biological processes that cannot be directly observed by learners within the classroom environment. Scientific discussions presented by Truman (2019), Truman and Riddiford (2019), and Rolff et al. (2019) emphasize that insect metamorphosis encompasses complex developmental transitions requiring sequential visualization to facilitate conceptual understanding. Traditional printed materials frequently fail to adequately represent these gradual biological transformations because they provide only static images and limited explanatory narratives. Conceptual abstraction therefore becomes a significant challenge for elementary students whose cognitive development still relies heavily on concrete and visual learning experiences.

Student needs analysis conducted through questionnaires provided additional evidence supporting the necessity of instructional innovation. Results demonstrated that learners possessed a strong interest in IPAS learning while simultaneously expressing a preference for more enjoyable and technology-supported instructional experiences. Positive responses toward digital learning opportunities indicated that students were already familiar with technology-based learning environments despite the limited availability of integrated digital resources within their school context. Findings of this nature correspond with the observations of Utaminingsih and Purwati (2024), who argue that third-grade elementary students exhibit strong curiosity and responsiveness toward visually stimulating learning experiences. Learning resources designed according to these developmental characteristics are therefore more likely to sustain engagement and enhance comprehension.

Microlearning emerged as a particularly relevant pedagogical approach because it addresses cognitive load challenges frequently experienced by elementary learners. Research conducted by Nugraha et al. (2021) explains that microlearning enables knowledge acquisition through concise and focused learning units, thereby reducing information overload while maintaining learner attention. Similar conclusions were advanced by Díaz-Redondo et al. (2023), who found that the integration of microlearning content within digital learning environments contributes positively to learning accessibility and retention. Educational practices increasingly recognize the importance of delivering information in manageable segments rather than lengthy instructional sequences. Learning design decisions adopted in this study were therefore grounded in contemporary theoretical perspectives regarding digital learning effectiveness.

The curriculum analysis conducted during the preliminary phase also confirmed the compatibility of the proposed e-module with the requirements of the Merdeka Curriculum. Alignment with Learning Outcomes (CP), Learning Objectives (TP), and Learning Objective Flow (ATP) ensured that instructional content remained pedagogically valid and curriculum-oriented. Educational innovation should not merely focus on technological sophistication but must also maintain instructional coherence and curricular relevance. Perspectives advanced by Nursyamsi et al. (2025) and Azizah et al. (2025) emphasize that meaningful IPAS learning requires instructional resources capable of connecting scientific concepts with authentic learning objectives. Curriculum alignment consequently became a fundamental principle guiding product development. The results of the initial needs assessment are summarized in Table 1, which illustrates students' perceptions regarding existing learning practices and their expectations for future instructional experiences.

Table 1. Summary of Initial Student Needs Analysis

Indicator	Percentage (%)
Enjoy learning IPAS	100.0
Enthusiastic during IPAS lessons	83.3
Teacher uses media beyond textbooks	83.3
Experience using digital learning media	83.3
Difficulty understanding metamorphosis material	0.0
Feeling bored during metamorphosis lessons	16.7
Textbook explanations are understandable	83.3
Difficulty remembering metamorphosis stages	0.0
Need learning media with images, videos, and animations	33.3
Desire more enjoyable learning experiences	100.0
Overall Needs Analysis Percentage	58.32

Source: Researcher (2026)

The overall needs analysis score of 58.32% indicates that students generally perceived existing IPAS learning positively; however, the findings simultaneously reveal unmet instructional needs that justify the development of a new learning medium. Although students reported that metamorphosis material was understandable through existing resources, all respondents expressed a desire for more enjoyable learning experiences and showed positive attitudes toward digital learning environments. This pattern suggests that the issue is not merely conceptual difficulty but rather the limited capacity of existing learning resources to sustain engagement and accommodate contemporary learning preferences.

These findings are consistent with previous studies reporting that elementary students respond more positively to visually rich and interactive learning experiences than to conventional text-based instruction (Utaminingsih & Purwati, 2024; Fitriah et al., 2025). However, unlike previous studies that primarily emphasized learning outcomes, the present findings demonstrate that instructional innovation is also required when students already understand the material but seek more meaningful and motivating learning experiences. This distinction is important because educational effectiveness is not determined solely by cognitive achievement but also by learner engagement and motivation.

From a theoretical perspective, the findings support the principles of constructivist learning, which emphasize active knowledge construction through interaction with learning resources. Students at the elementary level tend to learn more effectively when information is presented through concrete visual representations rather than abstract verbal explanations. Consequently, the decision to develop a microlearning-based interactive e-module was not merely a technological adaptation but a pedagogical response to students' developmental characteristics and learning preferences. These results imply that future IPAS instruction should prioritize interactive and multimedia-supported learning environments capable of maintaining student attention and participation.

The convergence of observational findings, questionnaire results, curriculum analysis, and teacher perspectives ultimately established a strong foundation for the development of a microlearning-based interactive e-module. Empirical evidence indicated that students required instructional experiences characterized by visual richness, interactivity, accessibility, and concise content organization. Theoretical perspectives from contemporary educational technology literature consistently support the effectiveness of interactive e-modules and microlearning environments in addressing these instructional demands, as demonstrated by Alya and Purwaningsih (2025), Yudiantoko et al. (2025), and Herlina et al. (2025). Development efforts undertaken in this research therefore represented a data-driven response to clearly identified educational needs rather than a technology-centered innovation implemented without contextual justification. Subsequent stages of design and development were consequently positioned to translate these identified needs into a pedagogically meaningful instructional product.

Development Process and Feasibility of the Microlearning-Based Interactive E-Module

The development stage represented the core phase of this research because it transformed the instructional needs identified during the analysis stage into a tangible learning product designed for Grade III IPAS instruction. Product development was systematically conducted following the Development component of the ADDIE model, which emphasizes the translation of instructional plans into operational educational resources. Contemporary educational technology literature increasingly highlights the importance of integrating pedagogical principles, multimedia design, and learner-centered approaches within digital learning materials, as discussed by Lase and Sudarma (2023). Development activities in the present study therefore extended beyond simple content digitization and focused on creating an interactive learning environment capable of facilitating meaningful engagement. Product construction was consequently guided by both empirical needs analysis and theoretical foundations derived from recent educational research.

Material organization within the e-module adopted a microlearning structure characterized by concise instructional units that focused on specific concepts related to butterfly metamorphosis. Learning content was divided into several short segments covering the definition of metamorphosis, the egg stage, larval development, pupal transformation, and the emergence of adult butterflies. Research conducted by Díaz-Redondo et al. (2023) demonstrates that microlearning content becomes more effective when instructional information is segmented into focused learning objects that can be processed sequentially. Similar conclusions were reported by Dinihari et al. (2025), who emphasized that digital microlearning

environments support literacy and conceptual retention through manageable learning episodes. Instructional content in the developed e-module was therefore deliberately organized to align with these principles.

Visual design constituted another critical component of the development process because elementary learners rely heavily on visual representations when constructing scientific understanding. Graphic elements, illustrations, icons, and learning interfaces were developed using Canva and subsequently refined to ensure consistency with the cognitive characteristics of Grade III students. Findings reported by Jannah et al. (2024) indicate that interactive electronic modules become significantly more effective when visual design elements support content comprehension rather than merely serving decorative functions. Educational media designed for younger learners must therefore balance aesthetic appeal with pedagogical clarity. Development decisions within this study reflected this principle through the careful selection of colors, typography, and visual hierarchy.

Artificial intelligence technologies were integrated into the production process to enhance the quality and realism of visual learning resources. Leonardo AI was utilized to generate three-dimensional representations of metamorphosis stages, thereby enabling the creation of vivid and scientifically accurate visualizations that would have been difficult to produce through conventional illustration methods. Educational innovation increasingly recognizes the potential of artificial intelligence to support the development of personalized and visually rich learning materials, as highlighted by Alya and Purwaningsih (2025). Learning resources that incorporate high-quality visualizations are particularly beneficial for science education because they assist learners in conceptualizing abstract biological processes. Product development in this study therefore reflected emerging trends in AI-assisted educational design.

Multimedia integration further strengthened the instructional value of the e-module by combining textual explanations, illustrations, animations, and instructional videos within a unified learning environment. Video animations were developed using CapCut and were designed according to microlearning principles, ensuring that each video remained concise and focused on a specific learning objective. Research by Fitriah et al. (2025) demonstrated that interactive multimedia resources significantly improve students' engagement and comprehension when compared with conventional instructional materials. Similar findings were reported by Herlina et al. (2025), who observed substantial improvements in student creativity and participation following the implementation of interactive science e-modules. Multimedia integration within the present product therefore served both motivational and cognitive functions.

The quality of the developed e-module was subsequently examined through expert validation procedures involving material experts and media experts. Validation activities were designed to evaluate content accuracy, curriculum alignment, instructional appropriateness, visual quality, usability, and technical performance before classroom implementation. Educational product development studies consistently emphasize the necessity of expert review as a mechanism for ensuring instructional validity and reducing design weaknesses prior to field testing, a position supported by Mira Kartika Ananda et al. (2026). Feedback provided by validators also functions as an important source of formative evaluation for product refinement. Validation outcomes therefore became a crucial indicator of the product's overall feasibility. The results of expert validation are presented in Table 2, which summarizes the quantitative evaluations obtained from material experts and media experts.

Table 2. Summary of Expert Validation Results

Validation Aspect	Score/Percentage	Category
Material Expert Validation	90.00%	Very Feasible
Media Expert Validation	95.54%	Very Feasible
Overall Feasibility	92.77%	Very Feasible

Source: Researcher (2026)

The overall feasibility score of 92.77% indicates that the developed e-module successfully met both pedagogical and technological quality standards. The high material validation score suggests that the content was considered accurate, relevant, and aligned with curriculum requirements, whereas the higher media validation score reflects the effectiveness of

the visual design, navigation structure, and multimedia integration. These findings suggest that the success of the product was not solely attributable to content quality but also to the way the content was presented to learners.

The findings are consistent with previous studies demonstrating that interactive e-modules tend to receive high feasibility ratings when instructional content is integrated with learner-centered multimedia features (Pratama Putra & Linda, 2021; Jannah et al., 2024). Nevertheless, the present study extends previous findings by incorporating microlearning principles into the instructional design. Rather than presenting information in lengthy learning units, content was segmented into concise learning episodes that were more compatible with the cognitive characteristics of elementary students.

The effectiveness of this design can be explained through Cognitive Load Theory, which argues that learning becomes more efficient when instructional materials minimize unnecessary cognitive burden. By dividing metamorphosis content into smaller learning units and combining it with visual and audiovisual representations, the e-module reduced information overload and facilitated knowledge processing. Educationally, these findings indicate that the integration of microlearning and multimedia design can serve as an effective strategy for developing digital instructional resources in elementary science education.

Development outcomes ultimately demonstrate that the microlearning-based interactive e-module successfully integrated curriculum requirements, multimedia technologies, instructional design principles, and learner characteristics into a coherent educational product. High feasibility scores from both material and media experts indicate that the e-module possesses substantial potential to support effective IPAS instruction concerning metamorphosis concepts. Findings from this stage are consistent with broader literature emphasizing the effectiveness of interactive e-modules in enhancing elementary science learning, including studies by Lase and Sudarma (2023), Jannah et al. (2024), and Mira Kartika Ananda et al. (2026). Product development within the present research therefore represents a meaningful contribution to the growing body of evidence supporting digital learning innovation in primary education. Subsequent implementation findings provide an opportunity to examine whether these promising design characteristics translated into positive learner responses during actual classroom use.

Implementation Outcomes and Educational Implications of the Microlearning-Based Interactive E-Module

The implementation phase served as the empirical testing stage through which the practicality and user acceptance of the developed e-module were examined in an authentic learning environment. Product implementation was conducted with six Grade III students of SD Negeri Bintoro 16 Demak after the e-module had successfully passed expert validation procedures and undergone several revisions based on formative feedback. Educational development research emphasizes that implementation constitutes a critical bridge between theoretical design quality and actual classroom effectiveness, because learning products may perform differently when used by real learners, as noted by Jannah et al. (2024). Learning activities during implementation involved independent exploration of instructional materials, observation of visual content, interaction with embedded videos, and completion of interactive exercises. Classroom observations during this stage provided important insights into how students responded to the microlearning-based instructional approach.

Student engagement emerged as one of the most visible outcomes observed during implementation activities. Learners demonstrated considerable enthusiasm when interacting with the e-module, particularly during activities involving animations, illustrations, and video-based explanations of butterfly metamorphosis. Educational studies consistently indicate that visually enriched digital environments can stimulate curiosity and sustain learner attention more effectively than conventional text-centered instructional approaches, a conclusion supported by Fitriah et al. (2025). Learning engagement is particularly important in elementary science education because motivation frequently influences the extent to which learners actively construct conceptual understanding. Classroom observations suggested that the e-module succeeded in creating a more dynamic and participatory learning atmosphere.

Conceptual understanding also appeared to improve through the use of multimedia-supported instructional sequences embedded within the e-module. Scientific concepts associated with metamorphosis involve gradual biological transformations that are often difficult for elementary students to imagine through textual descriptions alone. Research conducted by Fauziah et al. (2025) demonstrated that instructional media capable of visualizing metamorphosis processes significantly improve conceptual comprehension among elementary learners. Similar findings were reported by Khalimatus

Sya'diah et al. (2024), who observed that interactive representations of biological transformations facilitated deeper understanding of life-cycle concepts. Learning experiences observed during implementation therefore align with broader evidence regarding the educational value of visualization in science instruction.

Microlearning design characteristics played a significant role in facilitating learner comprehension and maintaining instructional focus throughout the learning process. Information was delivered in concise segments that allowed students to concentrate on one concept at a time without experiencing excessive cognitive demands. Educational theories concerning cognitive load management suggest that younger learners benefit substantially from instructional structures that reduce informational complexity while preserving conceptual coherence, as discussed by Nugraha et al. (2021). Research by Haliem et al. (2026) further indicates that microlearning strategies can improve learning accessibility because students are able to engage with content in manageable and meaningful units. Student responses observed during implementation support these theoretical assumptions.

Independent learning behavior represented another important outcome generated by the use of the interactive e-module. Learners were able to navigate instructional content, access multimedia resources, and complete learning activities with minimal external assistance after receiving introductory guidance. Digital learning environments that encourage learner autonomy are increasingly viewed as essential components of contemporary education because they support the development of self-regulated learning habits. Findings reported by Yudiantoko et al. (2025) indicate that usability and learner independence are strongly associated with positive evaluations of digital microlearning platforms. Classroom implementation within the present study demonstrated similar tendencies among participating students.

Quantitative evidence regarding student perceptions was obtained through response questionnaires administered after completion of learning activities. Questionnaire results revealed consistently high scores across indicators measuring attractiveness, usability, readability, motivational impact, and perceived learning benefits. These findings provide empirical confirmation that the instructional design principles embedded within the e-module were successfully translated into positive learner experiences. Educational product evaluations frequently regard user response data as an important indicator of practical feasibility because positive perceptions often influence continued usage and instructional effectiveness. Student response outcomes therefore constitute a significant component of the overall evaluation process. The detailed results of student responses are summarized in Table 3, which presents the percentage scores obtained across each evaluation indicator.

Table 3. Student Response Results During Implementation

Evaluation Indicator	Percentage (%)
E-module is interesting to learn	95.83
Images and videos increase enjoyment	95.83
Material is easy to understand	87.50
Text readability	83.33
Ease of use	83.33
Exercises support understanding	91.67
Increased motivation to learn IPAS	100.00
Supports independent learning	87.50
Improved understanding of metamorphosis stages	91.67
Desire to use similar e-modules in future learning	95.83
Overall Response Percentage	91.25

Source: Researcher (2026)

The overall student response score of 91.25% demonstrates a high level of acceptance of the developed e-module. Particularly noteworthy is the perfect score obtained for learning motivation, suggesting that the instructional design successfully transformed learning from a passive activity into a more engaging experience. High scores on attractiveness,

conceptual understanding, and willingness to use similar media in future learning further indicate that students perceived the e-module as both enjoyable and educationally valuable.

These findings are in line with previous studies showing that interactive e-modules and digital microlearning environments positively influence learner engagement and motivation (Alya & Purwaningsih, 2025; Yudiantoko et al., 2025). However, the present study provides additional evidence that the effectiveness of microlearning is particularly relevant for younger learners. Elementary students generally possess shorter attention spans; therefore, learning materials organized into concise and focused segments are more likely to maintain concentration and reduce fatigue during learning activities.

Theoretically, the findings can be explained through Cognitive Theory of Multimedia Learning, which proposes that students learn more effectively when information is presented through coordinated verbal and visual channels. The integration of animations, videos, illustrations, and interactive exercises enabled students to visualize metamorphosis processes that are otherwise difficult to observe directly. Simultaneously, the microlearning structure reduced cognitive overload by limiting the amount of information processed in a single learning session. These mechanisms help explain why students reported high levels of motivation, understanding, and satisfaction.

The implications of these findings extend beyond the topic of metamorphosis. The positive responses suggest that microlearning-based interactive e-modules have the potential to support broader implementation of learner-centered instruction in elementary schools. Such resources may be particularly beneficial for science topics involving abstract, sequential, or process-oriented concepts that require visualization and gradual conceptual development.

The implementation findings can be interpreted within a broader body of microlearning research that positions microlearning not merely as the presentation of shortened content but as a deliberate instructional design strategy characterized by focused objectives, manageable learning units, accessibility, and coherent sequencing. Systematic and conceptual studies have emphasized that effective microlearning requires careful alignment between content segmentation, learning activities, learner characteristics, and instructional purposes (Alias & Abdul Razak, 2023; Leong et al., 2021; Monib et al., 2025; Silva et al., 2025). Evidence from different educational contexts further indicates that short digital learning units may support engagement, motivation, flexibility, and knowledge processing when they are incorporated into a structured learning design rather than presented as isolated fragments (Al-Zahrani, 2024; Allela et al., 2020; Fidan, 2023; Kohnke et al., 2024; Nikou & Economides, 2018). Microlearning has also been examined in relation to teacher digital competence and social-media-supported learning, demonstrating the adaptability of concise learning structures across different digital environments (Betancur-Chicué & García-Valcárcel Muñoz-Repiso, 2023; Conde-Caballero et al., 2024; Denojean-Mairet et al., 2024; Sa'diah & Muliandari, 2024). These studies involve populations and instructional contexts that differ from Grade III elementary education, yet they provide theoretical support for interpreting the concise and accessible organization of the present e-module as an intentional pedagogical feature rather than simply a reduction in content length.

The positive perceptions of illustrations, animation, video, and concise instructional sequences can also be understood through contemporary multimedia learning and cognitive load perspectives. Multimedia learning theory emphasizes that words and visual representations can support meaningful learning when they guide learners toward relevant information without imposing unnecessary processing demands (Mayer, 2024). Cognitive Load Theory similarly highlights the limited capacity of working memory and the importance of organizing instructional information in ways that reduce avoidable cognitive demands (Sweller et al., 2019; Skulmowski & Xu, 2022; Mutlu-Bayraktar et al., 2019; Anmarkrud et al., 2019). Reviews of multimedia learning principles further demonstrate that segmentation, signaling, modality, and coherence are important considerations when designing technology-supported instructional materials (Alpizar et al., 2020; Çeken & Taşkın, 2022). Animation and instructional video may be particularly relevant to a sequential biological process such as metamorphosis because dynamic visual representations can make temporal changes more observable, although their instructional value remains dependent on appropriate design and integration with learning tasks (Berney & Bétrancourt, 2016; Fiorella & Mayer, 2018; Noetel et al., 2021). Recent meta-analytic evidence also cautions that multimedia design principles can operate differently according to learner age, medium, domain, and intended learning outcome, reinforcing the need to adapt multimedia resources to the characteristics of elementary learners rather than applying technological features uniformly (Cromley & Chen, 2025).

The educational relevance of the developed e-module is further strengthened by broader research concerning digital technology in science and elementary education. Meta-analytic evidence indicates that technology-supported instruction can contribute positively to elementary learning when digital tools are integrated with pedagogically appropriate activities rather than used as stand-alone technological additions (Chauhan, 2017; Sung et al., 2016). Similar findings have been reported for digital learning materials in science education and for technology-supported mathematics and science instruction, although variations in educational level, intervention design, and learning context should be considered when relating those findings to the present study (Aligo & Prudente, 2025; Hillmayr et al., 2020; Yeung et al., 2021). Research concerning augmented and interactive representations likewise demonstrates both the instructional possibilities and usability challenges associated with technology-rich learning environments (Akçayır & Akçayır, 2017). Within the Indonesian elementary-school context, the development of puzzle media for metamorphosis and differentiated technology-supported IPAS instruction similarly reflects the continuing diversification of media intended to make science concepts more accessible and engaging to young learners (Sari & Mustika, 2025; Azkiya et al., 2025). The present e-module extends this instructional direction by combining visual representation, interactive activity, multimedia content, and microlearning organization within one learning resource rather than relying on a single media format.

The interpretation of these findings nevertheless requires distinction between positive user responses and experimentally demonstrated learning effectiveness. Interactive exercises and motivational features may contribute to students' favorable perceptions, and meta-analytic research has shown that gamified instructional features can generate positive cognitive, motivational, and behavioral outcomes under particular design conditions (Sailer & Homner, 2020). The biological content itself also requires accurate representation of metamorphosis as an ordered developmental process, and entomological literature demonstrates the evolutionary and developmental complexity underlying complete insect metamorphosis (Nel, 2019; Rolff et al., 2019; Truman, 2019; Truman & Riddiford, 2019). Nevertheless, the present study evaluated expert-assessed feasibility and student acceptance through a limited implementation involving six learners rather than conducting an experimental comparison of achievement before and after exposure to the e-module. Consequently, the 91.25% student response score should be interpreted as evidence of strong acceptance and practical feasibility, not as a causal estimate of improvement in learning achievement. Future experimental studies with larger samples, comparison groups, and measures of conceptual retention are therefore necessary to determine whether the favorable design characteristics identified in this development study translate into measurable and sustained learning gains.

CONCLUSION

This study concludes that the development of a microlearning-based interactive e-module for the IPAS topic of living organism metamorphosis is both feasible and pedagogically relevant for third-grade elementary school students. The development process, conducted through the ADDIE model, successfully produced an instructional medium that integrates concise learning content, multimedia elements, and interactive activities tailored to the characteristics of young learners. The product achieved a material expert validation score of 90.00%, a media expert validation score of 95.54%, and an overall student response score of 91.25%, all of which fall within the "Very Feasible" category. These findings indicate that the integration of microlearning principles with interactive e-module design can effectively support student engagement, facilitate conceptual understanding, and encourage independent learning in IPAS instruction. The findings provide practical implications for elementary education by demonstrating that microlearning-based digital learning resources can serve as an effective alternative to conventional textbook-centered instruction, particularly for science topics involving abstract and sequential concepts such as metamorphosis. The study also contributes to the growing body of literature on digital learning innovation by providing empirical evidence regarding the feasibility of combining microlearning strategies with interactive e-module development in elementary school settings.

Despite these positive outcomes, this study has several limitations. The implementation stage involved only six students from a single elementary school, limiting the generalizability of the findings. In addition, the study primarily focused on product development and feasibility assessment rather than measuring learning effectiveness through experimental comparison or long-term learning outcomes. Future studies are therefore recommended to involve larger and more diverse

samples, implement broader field trials across different educational contexts, and examine the effectiveness of microlearning-based interactive e-modules through experimental or quasi-experimental research designs. Further investigations may also explore the application of similar instructional approaches to other IPAS topics and different grade levels to strengthen the evidence base for digital learning innovation in elementary education.

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