



Practicality Evaluation of TPACK-Integrated Vertebrate Zoology Teaching Materials Developed Using the Plomp Model

Nurul Fauziah^{1*}, Putri Ade Rahma Yulis¹, Mellisa¹, Iffa Ichwani Putri¹, Erfina¹, Diana Molly¹,
Ennike Gusti Rahmi²

¹Islamic University of Riau, Pekanbaru, Indonesia

²Palangka Raya University, Palangka Raya, Indonesia

*Email: fauziahnurul@edu.uir.ac.id

Received: January 29th 2026 Revised: February 6th 2026 Accepted: April 10th 2026

Abstract

The availability of relevant, user friendly, and technology integrated teaching materials is an essential requirement in biology learning, particularly in the vertebrate zoology course. However, many learning resources are still dominated by conventional teaching materials that do not adequately integrate Technological Pedagogical Content Knowledge (TPACK) aspects. This condition may limit students' meaningful, context-rich learning experiences. This study aimed to evaluate the practicality of TPACK-integrated vertebrate zoology teaching materials in biology learning. The study employed a research and development approach using the Plomp model, focusing on the prototyping phase. Practicality evaluation was conducted through three stages: one-to-one evaluation, small group evaluation, and field testing. Data were collected using practicality questionnaires and analyzed descriptively using percentage calculations to determine the practicality category of the teaching materials. The results consistently indicated that the developed teaching materials fall within the very practical category across all evaluation stages. These findings suggest that the TPACK-integrated vertebrate zoology teaching materials are highly usable in the learning process. Therefore, the developed materials have the potential to serve as supporting learning resources in higher education biology instruction and provide a foundation for further effectiveness testing in subsequent research stages.

Keywords: biology learning; practicality; teaching materials; TPACK; vertebrate zoology

INTRODUCTION

The rapid development of science and technology has significantly influenced learning processes in higher education, including biology education. Biology learning is no longer limited to the mastery of scientific concepts it also requires the integration of pedagogical strategies and technology to foster meaningful learning experiences. In this context, the availability of relevant, user friendly, and technology integrated teaching materials becomes essential, particularly for complex courses such as vertebrate zoology. Such materials can assist students in visualizing abstract biological concepts while promoting more interactive and engaging learning environments. Previous studies have shown that well designed teaching materials contribute to increased student engagement, improved conceptual understanding, and enhanced learning outcomes (Chisunum & Nwadiokwu, 2024; Verma, 2024; Fadillah *et al.*, 2025).

Vertebrate zoology is a core subject in biology education programs that encompasses abstract concepts related to vertebrate classification, morphology, and physiology. However, learning practices in this course are often dominated by conventional teaching materials that are less interactive and insufficiently integrated with technology. Consequently, students may experience difficulties in

understanding complex concepts and engaging actively in the learning process. This condition highlights the need to develop teaching materials that integrate scientific content with appropriate pedagogical approaches and technological support. Recent studies have reported similar challenges and emphasized the importance of innovative teaching materials that are contextual, interactive, and aligned with the characteristics of higher education learners (Gallagher & Savage, 2023; Bell, 2024; Galdames-Calderón *et al.*, 2024).

One promising approach to addressing these challenges is the integration of Technological Pedagogical Content Knowledge (TPACK) in the development of teaching materials. The TPACK framework promotes the meaningful integration of content, pedagogy, and technology to create effective learning environments. Empirical evidence indicates that TPACK-based teaching materials enhance instructional quality by ensuring that technology meaningfully supports pedagogical objectives and subject matter understanding, rather than functioning merely as a supplementary tool (Koh *et al.*, 2017; Lu & Chen, 2025; Siregar, 2025). Therefore, the development of TPACK-integrated vertebrate zoology teaching materials represents a strategic effort to support biology learning that meets the demands of 21st century education.

This study is part of a broader development research project employing the Plomp model. The preliminary research phase has been completed, including needs analysis, curriculum analysis, and analysis of student characteristics. Findings from this phase revealed a strong need for structured, contextually relevant, and technology integrated teaching materials to support vertebrate zoology learning, as reported in previous studies (Fauziah *et al.*, 2025; Sirojuddin *et al.*, 2025). The research then progressed to the prototyping phase, during which the initial version of the teaching materials was developed and subjected to expert validation. The validation results indicated that the materials met the required criteria in terms of content accuracy, language clarity, presentation, and technological integration (Astuti *et al.*, 2020; Fauziah *et al.*, 2025). Despite meeting validity criteria, teaching materials that have undergone expert validation do not automatically ensure successful implementation in real learning contexts. A critical aspect that requires further investigation is practicality, which refers to the extent to which the materials are easy to use, understandable, and applicable in actual learning situations.

Educational design research highlights that practicality testing is a crucial step prior to effectiveness evaluation, as a valid product may still encounter usability challenges when implemented by students or instructors (Plomp & Nieveen, 2013; Lu *et al.*, 2022). However, empirical studies examining the practicality of TPACK-integrated vertebrate zoology teaching materials through systematic stages such as one-to-one evaluation, small group testing, and field testing remain limited. Based on this gap, there is a clear need to investigate the practicality of TPACK-integrated teaching materials in authentic learning contexts. Previous research has predominantly focused on needs analysis and expert validation, with limited attention to how these materials function in practice. Therefore, this study aims to evaluate the practicality of TPACK-integrated vertebrate zoology teaching materials through one-to-one, small group, and field testing. The findings are expected to provide empirical evidence regarding their usability and feasibility, as well as to contribute to the advancement of TPACK-based teaching materials in biology education.

METHOD

This study employed a Research and Development (R&D) approach to evaluate the practicality of TPACK-integrated vertebrate zoology teaching materials in biology learning. The R&D approach was selected because the study aimed not only to examine an educational phenomenon but also to develop, refine, and evaluate a learning product that can effectively support the teaching and learning process. This approach enables researchers to systematically design educational products, test their quality, and ensure their suitability for practical implementation in classroom settings. The development process followed the Plomp model, which provides systematic stages and emphasizes iterative evaluation to produce learning products that are valid, practical, and feasible for implementation in real educational contexts (Plomp & Nieveen, 2013). The Plomp model was chosen because it allows continuous revision through formative

evaluation at each development stage, ensuring that the resulting teaching materials meet users' needs and achieve the expected quality standards.

This study represents a continuation of previous research that completed the preliminary and prototyping phases up to the expert validation stage. In the present study, the development proceeded within the prototyping phase by conducting one-to-one evaluation, small group evaluation, and field testing to assess the practicality of teaching materials that had previously been declared valid. Prototype 1 involved a one-to-one evaluation with nine students (three from each cohort). Participants were asked to review the teaching materials and provide feedback through a practicality questionnaire. The results from this stage were used to revise the materials. Prototype 2 consisted of a small group evaluation involving 15 students (five from each cohort). Students provided assessments, suggestions, and feedback using the practicality questionnaire, which informed further revisions. Prototype 3 was conducted through a field test involving 62 students in a classroom setting that closely resembled actual learning conditions. This stage aimed to determine the overall practicality of the teaching materials in real instructional contexts. Students completed the practicality questionnaire and provided feedback, which was used for final refinement of the product.

The population of this study comprised all biology education students at Islamic University of Riau who had taken the vertebrate zoology course totaling 86 students. The sampling technique used was simple random sampling, ensuring that participants were randomly selected from each cohort to represent diverse perspectives. The sample distribution followed the stages of the prototyping phase: nine students in the one-to-one evaluation, 15 students in the small group evaluation, and 62 students in the field test. Thus, the total number of participants involved in the practicality testing remained 86 students, allowing for comprehensive and representative data collection across different stages of implementation. Data were collected using a practicality questionnaire administered during each stage of evaluation: one-to-one, small group, and field testing. The questionnaire was designed to capture students' perceptions of the usability, clarity, and applicability of the developed teaching materials. The indicators of the one-to-one evaluation, small group evaluation, dan field test stages questionnaire are presented in Table 1.

Table 1. Indicators of the student practicality questionnaire used in the one-to-one evaluation, small group evaluation, and field test stages

Aspect	Indicators
Display	Book design Text readability Clarity of presentation Font usage Quality of images and writing
Language	Language usage
Content	Logical sequence Content presentation Learning materials
Presentation	Learning motivation
TPACK-integrated vertebrate zoology teaching materials	

Source: Modified by the authors based on (Cahaya *et al.*, 2024).

Each statement in the practicality questionnaire was measured using a five point Likert scale to capture students' perceptions of the developed teaching materials. The scoring of each response was based on the level of agreement expressed by respondents toward the provided statements. In this scale, a score of 5 was assigned to responses indicating strongly agree, a score of 4 for agree, a score of 3 for slightly disagree, a score of 2 for disagree, and a score of 1 for strongly disagree. This scoring system was used to quantify students' responses for further analysis of the practicality of the developed teaching materials. Data obtained from the one-to-one evaluation, small group evaluation, and field test were analyzed by

calculating the percentage of the total score obtained from respondents' answers relative to the maximum possible score. In this analysis, the obtained score refers to the total score generated from students' responses to the practicality questionnaire, while the maximum score represents the highest score that could be achieved. This calculation was used to determine the practicality level of the developed teaching materials based on students' responses. Higher percentage values indicate a higher level of practicality (Fatma *et al.*, 2025).

The resulting percentages were interpreted using predetermined practicality criteria. Percentage scores ranging from 85% to 100% were categorized as very practical, indicating that the teaching materials were highly feasible and easy to use in the learning process. Scores between 69% and 84% were categorized as practical, while scores ranging from 53% to 68% indicated that the teaching materials were less practical. Scores between 37% and 52% were categorized as not practical, and scores ranging from 20% to 36% were considered very impractical. These criteria were used to determine the overall practicality level of the developed teaching materials. The implementation of staged practicality testing through one-to-one evaluation, small group evaluation, and field test is consistent with the principles of educational design research, which emphasize the importance of formative evaluation to ensure that learning products can be optimally used before proceeding to the effectiveness testing stage (Plomp & Nieveen, 2013; Kurniawan, 2022).

RESULT AND DISCUSSION

This section presents the results of the practicality evaluation of the TPACK-integrated vertebrate zoology teaching materials, obtained through the one-to-one, small group, and field test stages. The results of the one-to-one evaluation are quantitatively described based on students' responses to the practicality questionnaire and presented in Table 2.

Table 2. Practicality test results of the one-to-one evaluation of TPACK-integrated vertebrate zoology teaching materials

Aspect	Assessed indicators	Average score (%)
Display aspect	Design of TPACK-integrated vertebrate zoology teaching materials	96
	Text readability	92
	Clarity of presentation	94
	Clarity of image display	94
Readability aspect	Font usage	94
Language aspect	Language usage	90
Content aspect	Logical sequence	94
	Content presentation	94
Presentation aspect	Learning motivation	88
	TPACK-integrated vertebrate zoology teaching materials	92
Overall average		92

The display aspect of the TPACK-integrated vertebrate zoology teaching materials achieved an average percentage of 94%, which is categorized as very practical. This result indicates that the teaching materials effectively meet students' initial needs in terms of ease of use and clarity of information presentation. The display aspect was assessed based on four indicators, namely design layout, text readability, presentation clarity, and visual image clarity. The high score on the design indicator shows that students have a positive perception of the overall structure and layout of the materials. An effective instructional design is not only concerned with aesthetics but also serves as a medium for integrating technology into content delivery. Within the TPACK framework, visual design plays an important role in combining technological knowledge with content knowledge to present vertebrate zoology concepts in a

structured and accessible way. This indicates that TPACK-based instructional design enhances user comfort and supports learning effectiveness when technology is aligned with pedagogical goals and content characteristics. These findings are consistent with previous studies highlighting the importance of coherent integration of technology, pedagogy, and content in instructional design (Jibril & Shittu, 2024; Teknowijoyo, 2024; Zahroh, 2025).

The text readability indicator also achieved a very practical category, indicating that font type, font size, and text spacing were appropriate for students' learning needs. Text readability is a crucial component of both printed and digital teaching materials, as it directly influences learners' cognitive load. From a TPACK perspective, readability reflects pedagogical knowledge in designing learner friendly instructional materials. Studies by Nilson & Goodson (2020) have shown that well designed text readability in technology based learning materials can enhance learning focus and reduce misunderstandings, particularly in complex biology topics. Furthermore, the clarity of presentation indicator received a high practicality score, demonstrating that the sequence and organization of content were perceived as logical and easy to follow. In the context of TPACK, clarity of presentation reflects the integration of pedagogical knowledge and content knowledge, ensuring that subject matter is delivered in accordance with sound instructional principles. Systematically organized TPACK-based teaching materials facilitate students' conceptual understanding by guiding them through learning content in a structured and meaningful way (Baran & Uygun, 2016; Bariroh & Surtikanti, 2024; Siregar, 2025).

The final indicator within the display aspect, clarity of visual images, also achieved a very practical category. This result indicates that the images used in the teaching materials were clear, relevant, and supportive of content comprehension. Visual representations play a significant role in biology learning, particularly in illustrating structures and characteristics of organisms that are difficult to observe directly. Within the TPACK framework, the appropriate use of visual elements reflects the integration of technological knowledge in the delivery of visual content that supports pedagogical intentions. Previous research has demonstrated that clear, contextually relevant visual materials in technology enhanced learning environments positively contribute to students' conceptual understanding and memory retention (Vasodavan, 2020; Duterte, 2024; Zahroh, 2025).

The readability of the TPACK-integrated vertebrate zoology teaching materials was 94%, categorized as very practical. This result indicates that the developed teaching materials were perceived by students as easy to read and comfortable to use as initial users. In this study, the readability aspect focused on the use of fonts or typefaces, which play an important role in supporting content comprehension and learning efficiency. The appropriate use of fonts contributes directly to text readability and students' visual comfort when studying vertebrate zoology materials. Clear, consistent, and proportionally sized fonts help students concentrate on the content without being distracted by unsupported visual elements. Within the TPACK framework, font usage is not merely related to technical display aspects (technological knowledge) but also reflects pedagogical knowledge in the design of teaching materials that consider learners' characteristics and needs. Appropriately selected fonts serve as part of a pedagogical strategy to reduce cognitive load and enhance learning focus (Juanda *et al.*, 2021; Bell, 2024; Siregar, 2025).

The high practicality level in the readability aspect indicates that the teaching materials were designed with sound readability principles, including appropriate font sizes, easily readable font types, and consistent font usage throughout. That simple and consistent text design can enhance comprehension and information retention in multimedia based learning (Maryansyah, 2016; Yulianto, 2019; Liu, 2024). That good text readability in technology based teaching materials contributes to improved learning comfort and student engagement in biology learning (Ami *et al.*, 2021; Hidayatullah *et al.*, 2022; Indra *et al.*, 2023). From a content knowledge perspective, readability is particularly important in vertebrate zoology materials, which often use scientific terminology and complex biological concepts. The appropriate use of fonts helps students understand these terms more easily and reduces the potential for misinterpretation. The integration of content knowledge and pedagogical knowledge through appropriate font selection reflects a holistic application of the TPACK framework in the development of teaching materials. This demonstrates that readability is not merely an aesthetic consideration but also a pedagogical strategy to support effective content delivery.

Indicate that the language aspect of the TPACK-integrated vertebrate zoology teaching materials achieved an average percentage of 90%, categorized as very practical. This finding suggests that the language used in the teaching materials was perceived as clear, communicative, and appropriate for students as initial users. Appropriate language use plays an important role in supporting students' understanding of vertebrate zoology concepts, which involve scientific terminology and relatively complex biological concepts. Within the TPACK framework, language use reflects the integration of pedagogical and content knowledge, with content delivery aligned with students' cognitive levels and instructional objectives. Concise, consistent, and unambiguous language helps students process information more effectively, particularly in technology integrated teaching materials. That language quality in technology based teaching materials positively influences content comprehension and learning comfort (Jibril & Shittu, 2024; Fauziah *et al.*, 2025).

The content aspect of the TPACK-integrated vertebrate zoology teaching materials achieved an average of 94%, indicating it is very practical. This result indicates that the content presented in the teaching materials was perceived as well structured and clearly delivered, thereby facilitating students' understanding of vertebrate zoology concepts. In this study, the content aspect comprised two main indicators: content sequencing and content presentation. The content sequencing indicator shows that the order of concept delivery in the teaching materials was systematic, progressing from basic to more complex concepts. Content sequencing is particularly important in vertebrate zoology learning, as the subject involves classifications and organism characteristics that are conceptually interrelated. Within the TPACK framework, content sequencing integrates content knowledge and pedagogical knowledge, with disciplinary content organized according to instructional principles that support students' gradual conceptual development. That well sequenced content in developed instructional materials contributes to ease of use and improved conceptual understanding (Husnin, 2017; Nafiati, 2021; Fauziah *et al.*, 2025).

The content presentation indicator also received a very practical rating, indicating that the material was presented clearly and concisely, and aligned with the learning objectives. Effective content presentation enables students to connect vertebrate zoology concepts with the learning context in a more meaningful way. From a TPACK perspective, content presentation reflects the integration of pedagogical knowledge and technological knowledge, where technology is utilized to deliver content effectively without obscuring its substance. Showing that well structured content presentation supported by appropriate technology enhances conceptual understanding and student engagement in Biology learning. The presentation aspect of the TPACK-integrated vertebrate zoology teaching materials achieved an average score of 90%, indicating very practical (Siregar, 2025; Ekasiadi, 2026).

This result indicates that the way the teaching materials were presented attracted students' attention, motivated them to learn, and effectively supported content comprehension. In this study, the presentation aspect comprised two main indicators, namely learning motivation and the overall quality of the TPACK-integrated vertebrate zoology teaching materials. The motivation indicator shows that the developed teaching materials stimulated students' interest and engagement in learning vertebrate zoology. An engaging presentation, supported by clear structure and relevant visual elements, plays an important role in fostering learning motivation. Within the TPACK framework, the motivation aspect reflects the integration of pedagogical and technological knowledge, in which pedagogical strategies are combined with technology to create more interactive and meaningful learning experiences. That pedagogically designed technology based teaching materials can enhance students' motivation and engagement in science learning (Mellisa & Yanda, 2019; Sapriyah, 2019; Zhan *et al.*, 2022).

Students also appreciated the overall design and accessibility of the teaching materials, which enabled them to learn more independently and confidently. The combination of concise explanations, systematic content organization, and technology supported learning features helped reduce cognitive difficulties when studying complex vertebrate zoology concepts. This finding suggests that the teaching materials not only captured students' attention but also facilitated sustained engagement throughout the learning process. In the context of TPACK, such effectiveness demonstrates how the integration of content, pedagogy, and technology can support a learner centered environment that promotes active knowledge construction and improves the overall quality of learning experiences. Moreover, the digital format allowed

students to access learning resources more flexibly according to their individual learning pace and needs. The positive responses toward the presentation aspect indicate that well designed TPACK-based teaching materials can contribute to creating a more engaging, effective, and student centered learning environment in higher education (Juanda *et al.*, 2021; Bell, 2024; Siregar, 2025). The results of the small group evaluation are quantitatively described based on students' responses to the practicality questionnaire and presented in Table 3.

Table 3. Practicality test results of the small group evaluation of TPACK-integrated vertebrate zoology teaching materials

Aspect	Assessed indicators	Average score (%)
Display aspect	Design of TPACK-integrated vertebrate zoology teaching materials	96
	Text readability	90
	Clarity of presentation	92
	Clarity of image display	96
Readability aspect	Font usage	94
Language aspect	Language usage	94
Content aspect	Logical sequence	96
	Content presentation	96
Presentation aspect	Learning motivation	94
	TPACK-integrated vertebrate zoology teaching materials	94
	Overall average	94

The results of the small group evaluation indicate that the TPACK-integrated vertebrate zoology teaching materials achieved a very high level of practicality, with an overall percentage of 94% and a rating of very practical across all assessed aspects. Unlike the one-to-one evaluation, which primarily focuses on identifying the product's initial weaknesses, the small group evaluation aims to assess the consistency of teaching material quality after initial revisions and to assess product acceptability among a larger group of users. The high practicality percentage at this stage indicates that the teaching materials have undergone significant refinement and have become more stable for use in real learning contexts. In the display aspect, the teaching materials received a 94% rating in the very practical category, indicating that visual design, text readability, clarity of presentation, and clarity of image display were perceived as increasingly optimal by students.

Compared to the one-to-one evaluation, assessments at the small group stage show more consistent perceptions among students, suggesting that the earlier design revisions were effective in improving the overall visual quality of the teaching materials. Within the TPACK framework, display quality reflects the integration of technological and content knowledge, with technology effectively used to present vertebrate zoology content in a systematic, easily understandable manner. That during small group evaluations, revised TPACK-based teaching materials tend to show greater consistency in users' perceptions of visual quality and presentation structure (Bell, 2024; Fauziah *et al.*, 2025; Siregar, 2025). The readability aspect at the small group evaluation stage also achieved 94% in the very practical category, indicating that font usage and text layout were perceived as comfortable by most students. At this stage, readability was evaluated collectively rather than individually, reflecting the broader acceptability of the text design.

From a TPACK perspective, readability is the integration of pedagogical and technological knowledge, with text design aligned with students' cognitive needs in a technology based learning environment. Demonstrating that high text readability in digital teaching materials enhances learning efficiency and reduces cognitive load, particularly when large amounts of content are presented (Yulianto, 2019; Irianti & Mahrudin, 2021; Surbakti *et al.*, 2024). The language aspect showed a 94% score, categorized as very practical. This indicates that the language used in the teaching materials was consistently understood by students with diverse academic backgrounds. The language aspect at the small-group stage reflects the suitability of language use for the academic context and the collective student

abilities. Within the TPACK framework, effective language use involves integrating content and pedagogical knowledge, with scientific terminology in vertebrate zoology communicated clearly without compromising conceptual accuracy. That the quality of language in science teaching materials plays a crucial role in preventing misconceptions and enhancing students' learning comfort (Syamsinar & Yusuf, 2019; Astuti *et al.*, 2020; Ramdoni *et al.*, 2021).

The content aspect at the small group evaluation stage achieved 96% in the very practical category for both content sequencing and content presentation indicators. This result indicates that the sequence of vertebrate zoology concepts was perceived as logical and easy to follow, and that the content was presented clearly and aligned with the learning objectives. At this stage, students not only evaluated the ease of understanding the content but also its relevance to their overall learning experience. From a TPACK perspective, the content aspect reflects the integration of content knowledge and pedagogical knowledge, strengthened by the use of technology for content delivery. Plomp & Nieveen (2013) stated that during the small group evaluation stage, revised teaching materials typically demonstrate improved content structure and readiness for testing in broader learning contexts. The presentation aspect at the small group evaluation stage also achieved 94% in the very practical category, indicating that the teaching materials motivated students and provided engaging learning experiences.

Compared to the one-to-one evaluation, the motivation aspect at this stage appeared more stable, as students interacted with the teaching materials in a group context, resulting in reflections that were more representative of actual learning situations. Within the TPACK framework, the presentation aspect reflects the synergy among technological, pedagogical, and content knowledge, which collectively shape meaningful learning experiences. That pedagogically designed technology based teaching materials can enhance student motivation and engagement, particularly in collaborative learning settings (Koh *et al.*, 2017; Aliyu *et al.*, 2022; Suripah & Susanti, 2022). The results of the small group evaluation demonstrate that the TPACK-integrated vertebrate zoology teaching materials have reached a very high, more stable level of practicality compared to the one-to-one evaluation stage. This indicates that revisions made in the previous stage were effective in refining the product. Therefore, the teaching materials are considered ready to proceed to the field test stage to examine further their practicality on a larger scale and under conditions that more closely resemble actual learning environments. The results of the field test evaluation are quantitatively described based on students' responses to the practicality questionnaire and presented in Table 4.

Table 4. Practicality test results field test of TPACK-integrated vertebrate zoology teaching materials

Aspect	Assessed indicators	Average score (%)
Display aspect	Design of TPACK-integrated vertebrate zoology teaching materials	96
	Text readability	90
	Clarity of presentation	94
	Clarity of image display	92
Readability aspect	Font usage	90
Language aspect	Language usage	92
Content aspect	Logical sequence	94
	Content presentation	94
Presentation aspect	Learning motivation	92
	TPACK-integrated vertebrate zoology teaching materials	92
Overall average		92

The field test results show that the TPACK-integrated vertebrate zoology teaching materials achieved a very high level of practicality with an average score of 92%, categorized as very practical. This stage represents the final phase of the prototyping process aimed at examining the stability, acceptability, and usability of the teaching materials in classroom like conditions. The field test focuses on evaluating the consistency of the product after revisions from previous stages. The high practicality score indicates that

the teaching materials are ready for wider implementation without major revisions. In the display aspect, the materials obtained a score of 93%, also categorized as very practical. This reflects that visual design, text readability, presentation clarity, and image clarity were consistently perceived as effective by students during learning. At this stage, evaluation emphasizes sustained user experience rather than initial impressions. Within the TPACK framework, display quality represents the integration of technological and content knowledge to support structured presentation of vertebrate zoology concepts. This integration helps maintain consistent learning experiences and supports students' conceptual understanding during classroom implementation (Baran & Uygun, 2016; Bariroh & Surtikanti, 2024).

The readability aspect achieved 90%, categorized as very practical, indicating that font usage and text layout were perceived as comfortable and did not hinder students' learning. From a TPACK perspective, readability represents the integration of pedagogical and technological knowledge, with text design aligned with students' cognitive needs and the demands of technology based learning. That good text readability in digital teaching materials contributes to learning efficiency and sustained learning focus (Ramdoni *et al.*, 2021; Astri *et al.*, 2024). The language aspect scored 92%, categorized as very practical, indicating that the language used in the teaching materials was appropriate for the academic context and consistently understood by students. The language aspect was evaluated not only for clarity but also for alignment with the learning flow and students' interactions with the materials. The language aspect reflects the integration of content and pedagogical knowledge, with scientific terminology in vertebrate zoology communicated effectively without compromising conceptual accuracy. The importance of language quality in science teaching materials for supporting conceptual understanding and preventing misconceptions (Maryansyah, 2016; Imam *et al.*, 2018; Arsanti *et al.*, 2022).

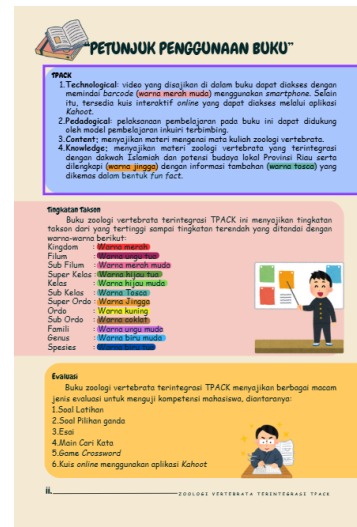
The content aspect achieved 94% in both content sequencing and content presentation indicators, categorized as very practical. This result indicates that the sequence of vertebrate zoology concepts was perceived as logical, easy to follow, and relevant to learning objectives in real use contexts. Unlike the one-to-one and small group stages, evaluations at the field test stage reflect students' experiences with the teaching materials as a primary learning resource. From a TPACK perspective, the content aspect reflects the integration of content knowledge and pedagogical knowledge, strengthened by the use of technology as a medium for content delivery. That teaching materials demonstrating stability during field testing indicate readiness for broader implementation (Edgerton & Desimone, 2018; Siregar, 2025). The presentation aspect achieved 92% and was categorized as very practical, indicating that the teaching materials motivated students and supported meaningful learning experiences in authentic classroom situations.

At this stage, learning motivation emerged more authentically, as students interacted with the teaching materials within real classroom contexts. Within the TPACK framework, the presentation aspect reflects the synergy among technological, pedagogical, and content knowledge in creating effective learning experiences. Pedagogically designed technology based teaching materials enhance student motivation and engagement in science learning (Baran & Uygun, 2016; Alegre, 2023; Fauziah *et al.*, 2025). To support the practicality test results, a sample of the TPACK-integrated vertebrate zoology teaching materials is presented in Figure 1 to illustrate the integration of content, pedagogy, and technology in the presentation of the materials. This illustration clearly demonstrates how complex biological concepts are transformed into interactive digital formats to facilitate student comprehension. Furthermore, such visual integration serves as a concrete benchmark for developing future technology enhanced learning resources in higher education.

Students also perceived that the organization of the materials, the use of visual representations, and the availability of interactive features facilitated their understanding of complex zoological concepts. The integration of multimedia elements, such as images, diagrams, and digital learning activities, enabled students to connect theoretical knowledge with observable characteristics of vertebrate organisms, thereby promoting deeper conceptual understanding. This finding aligns with the principles of TPACK, which emphasize that technology integration should not only digitize content but also strengthen pedagogical approaches and support meaningful learning experiences. Consequently, the teaching materials functioned not merely as a source of information but also as an interactive learning resource that fostered active participation, independent exploration, and sustained engagement throughout the learning process.



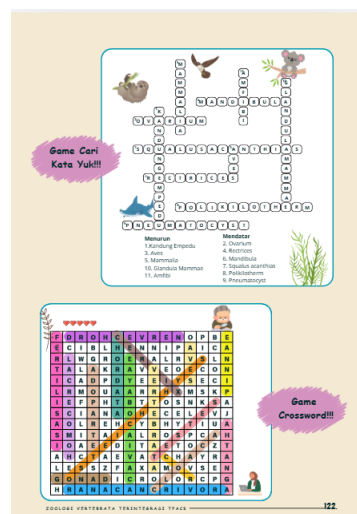
a.



b.



c.



d.

Figure 1. (a) Cover of the TPACK-integrated vertebrate zoology teaching materials; (b) User guide of the TPACK-integrated vertebrate zoology teaching materials; (c) Sample of Phylum Chordata content presentation in the TPACK-integrated vertebrate zoology teaching materials; (d) Sample of learning activities in the TPACK-integrated vertebrate zoology teaching materials

The results of the staged evaluations including one-to-one, small group, and field tests demonstrate that the TPACK-integrated vertebrate zoology teaching materials experienced consistent quality improvement and achieved a very high level of practicality as the final product in the prototyping phase. Each evaluation stage contributed complementarily to the refinement process, ranging from initial identification of weaknesses, reinforcement of quality consistency, to testing usage stability in authentic learning contexts. The high practicality across all aspects display, readability, language, content, and presentation indicates that the integration of technology, pedagogy, and content was implemented coherently and functionally. These findings confirm that the developed teaching materials are not only technically feasible but also support meaningful learning experiences and are ready to proceed to the effectiveness testing stage to examine their impact on improving students' competencies and skills

CONCLUSION

This study concludes that the TPACK-integrated vertebrate zoology teaching materials developed using the Plomp model at the prototyping phase demonstrate a very practical level of usability in biology learning. The results of the one-to-one evaluation, small group evaluation, and field test consistently indicate high practicality, confirming that the teaching materials are easy to use, clearly presented, and well accepted by students. These findings affirm that the developed teaching materials are feasible as supporting learning resources for vertebrate zoology courses in higher education. Moreover, the results of this study provide strategic benefits for national education development by offering innovative teaching materials that integrate technology, pedagogy, and content knowledge, thereby contributing to the improvement of biology education quality, the strengthening of future teacher competencies, and the advancement of education that is responsive to technological developments and the demands of the digital era.

ACKNOWLEDGMENTS

The author would like to express sincere gratitude to the Directorate of Research and Community Service (DPPM), Universitas Islam Riau, for providing financial support for this research through Contract Number 1461/KONTRAK/P-NK-PD/DPPM-UIR/07-2025. The author also extends appreciation to all Biology Education students of the Faculty of Teacher Training and Education, Universitas Islam Riau, who willingly participated as research respondents and contributed valuable input to this study.

REFERENCES

- Alegre, E. M. (2023). Technology-driven education: Analyzing the synergy among innovation, motivation, and student engagement. *International Journal of Membrane Science and Technology*, 10(2), 1477–1485.
- Aliyu, J., Osman, S., Kumar, J. A., Talib, C. A., & Jambari, H. (2022). Students' engagement through technology and cooperative learning: A systematic literature review. *International Journal of Learning and Development*, 12(3), 23–40.
- Ami, M. S., Ummah, K., & Meishanti, O. P. Y. (2021). Pengembangan modul pembelajaran biologi berbasis Reading, Questioning, and Answering (RQA) materi virus kelas X. *Jurnal Biologi dan Pembelajarannya (JB&P)*, 8(1), 19–25.
- Arsanti, M., Wardani, O. P., Zulaeha, I., Subyantoro, Setyaningsih, N. H., & Hasanudin, C. (2022). Kebutuhan pengembangan buku ajar analisis kesalahan berbahasa berdasarkan kompetensi abad-21. *Jurnal Pendidikan Edutama*, 9(1), 41–50.
- Astri, Z., Noni, N., & Halim, A. (2024). Integrating digital learning in english reading classes: Experiences of Indonesian higher education lecturers. *Seltics Journal: Scope of English Language Teaching Literature and Linguistics*, 7(1), 1–16.
- Astuti, F. N., Suranto, S., & Masykuri, M. (2020). The appropriateness of developing the media: Experts' validation and students' response of learning media based on augmented reality technology for natural science lesson. *Journal of Physics: Conference Series*, 1567(4), 42023.
- Astuti, L., Wihardi, Y., & Rochintaniawati, D. (2020). The development of web-based learning using interactive media for science learning on levers in human body topic. *Journal of Science Learning*, 3(2), 89–98.
- Baran, E., & Uygun, E. (2016). Putting Technological, Pedagogical, and Content Knowledge (TPACK) in action: An integrated TPACK-Design-Based Learning (DBL) approach. *Australasian Journal of Educational Technology*, 32(2).
- Bariroh, G., & Surtikanti, H. K. (2024). The potential of TPACK-based biology learning to improve students' habits of mind. *Jurnal Mangifera Edu*, 8(2), 27–40.
- Bell, J. C. B. (2024). *Taking a closer look at TPACK: Examining teacher perspectives of the knowledge, competencies, and context needed for improved remote education in grades 4-8*. The University of Nebraska-Lincoln.

- Cahaya, N., Fauziah, N., Ferazona, S., & Hidayati, N. (2024). Lembar praktikalitas: Instrumen yang digunakan untuk menilai produk yang dikembangkan pada penelitian pengembangan bidang pendidikan. *Biology and Education Journal UIR*, 4(1), 48–68.
- Chisunum, J. I., & Nwadiokwu, C. (2024). Enhancing student engagement through practical production and utilization of instructional materials in an educational technology class: A multifaceted approach. *NIU Journal of Educational Research*, 10(2), 81–89.
- Duterte, J. P. (2024). Technology-enhanced learning environments: Improving engagement and learning. *International Journal of Research and Innovation in Social Science*, 8(10), 1131–1305.
- Edgerton, A. K., & Desimone, L. M. (2018). Teacher implementation of college-and career-readiness standards: Links among policy, instruction, challenges, and resources. *Aera Open*, 4(4), 1–22.
- Ekasiadi, ida A. A. (2026). Implementasi pendekatan Technological Pedagogical and Content Knowledge (TPACK) berbasis 4C dalam pembelajaran bahasa indonesia pada siswa kelas XI SMAN 3 Denpasar. *Widyadari*, 27(1), 91–102.
- Fadillah, M. A., Usmeldi, U., Festiyed, F., Lufri, L., & Mawardi, M. (2025). Assessment of teaching strategies, utilization of student worksheets, and student engagement in science education. *International Journal of Education, Information Technology, and Others*, 8(1), 198–207.
- Fatma, S. T., Retta, A. M., & Kuswidyanarko, A. (2025). Pengembangan e-LKD berbasis contextual teaching and learning pada materi geometri bangun datar kelas IV SD. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 10(03), 476–490.
- Fauziah, N., Ade, P., Yulis, R., & Fitri, R. H. (2025). Pengembangan booklet zoologi vertebrata terintegrasi TPACK: Studi pendahuluan dengan model Plomp. *Jurnal Perspektif Pendidikan dan Keguruan*, 16(2), 136–144.
- Fauziah, N., Ade, P., Yulis, R., & Fitri, R. H. (2025). TPACK-integrated zoology vertebrate booklet: Expert validation of a print media innovation supporting digital learning. *Journal Of Biology Education Research (JBER)*, 5(2), 39–50.
- Galdames-Calderón, M., Stavnskær Pedersen, A., & Rodriguez-Gomez, D. (2024). Systematic review: Revisiting challenge-based learning teaching practices in higher education. *Education Sciences*, 14(9), 1008.
- Gallagher, S. E., & Savage, T. (2023). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education*, 28(6), 1135–1157.
- Hidayatullah, A., Mulyani, S., & Munir, S. (2022). The language validity and readability aspects in the development of indonesian language learning materials based on local wisdom. *Jurnal Pendidikan, Bahasa, dan Sastra*, 10(1), 134–140.
- Husnin, H. B. (2017). *Design and development of learning material with the ten steps to complex learning: A multiple case study*. University of Warwick.
- Imam, M. C., Laksono, K., & Suhartono. (2018). Keterbacaan teks dalam buku siswa kelas VI sekolah dasar. *Jurnal Review Pendidikan Dasar: Jurnal Kajian Pendidikan dan Hasil Penelitian*, 4(1), 594.
- Indra, M. H., Sutarto, S., Kharizmi, M., Nurmiati, A. S., & Susanto, A. (2023). Optimizing the potential of technology-based learning increases student engagement. *Al-Fikrah: Jurnal Manajemen Pendidikan*, 11(2), 233–244.
- Irianti, R., & Mahrudin, M. (2021). Validity analysis of popular scientific books fish type diversity as environmental material tor vertebrate zoology course. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan*, 3(2), 126.
- Jibril, M., & Shittu, N. A. A. (2024). Enhancing education: A comprehensive framework for integrating Technological Pedagogical Content Knowledge (TPACK) into teaching and learning. *Indonesian Journal of Multidiciplinary Research*, 4(1), 181–188.
- Juanda, A., Shidiq, A. S., & Nasrudin, D. (2021). Teacher learning management: Investigating biology teachers' tpack to conduct learning during the covid-19 outbreak. *Jurnal Pendidikan IPA Indonesia*, 10(1), 48–59.
- Koh, J. H. L., Chai, C. S., & Lim, W. Y. (2017). Teacher professional development for TPACK-21CL: Effects on teacher ict integration and student outcomes. *Journal of Educational Computing Research*,

- 55(2), 172–196.
- Kurniawan, H. (2022). *Pengantar praktis penyusunan instrumen penelitian*. Deepublish.
- Liu, D. (2024). The effects of segmentation on cognitive load, vocabulary learning and retention, and reading comprehension in a multimedia learning environment. *BMC Psychology*, 12(4), 1–12.
- Lu, C., & Chen, W. (2025). *Unpacking technological pedagogical content knowledge for classroom practice*. Springer.
- Lu, J., Schmidt, M., Lee, M., & Huang, R. (2022). Usability research in educational technology: A state-of-the-art systematic review. *Educational Technology Research and Development*, 70(6), 1951–1992.
- Maryansyah. (2016). An analysis on readability of english reading texts for grade IX student at MTsN 2 Kota Bengkulu. *Premise Journal*, 5(1), 37–39.
- Mellisa, M., & Yanda, Y. D. (2019). Developing audio-visual learning media based on video documentary on tissue culture explant of *Dendrobium bigibbum*. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 5(3), 379–386.
- Nafati, D. A. (2021). Revisi taksonomi Bloom: Kognitif, afektif, dan psikomotorik. *Humanika*, 21(2), 151–172.
- Nilson, L. B., & Goodson, L. A. (2020). Online teaching at its best: Merging instructional design with teaching and learning research. *Journal on Teaching*, 1(3), 127.
- Plomp, T., & Nieveen, N. (2013). *Educational design research*. Enschede: SLO.
- Ramdoni, F., Meliasanti, F., & Setiawan, H. (2021). Analisis diksi dan gaya bahasa iklan layanan masyarakat divisi humas polri serta relevansinya sebagai bahan ajar tingkat SMP. *Edukatif: Jurnal Ilmu Pendidikan*, 3(6), 3852–3865.
- Sapriyah. (2019). Peran media pembelajaran dalam proses belajar mengajar. *Prosiding Seminar Nasional Pendidikan FKIP*, 2(1), 470–477.
- Siregar, T. (2025). The effectiveness of TPACK-based cabri 3D learning media in the Problem-Based Learning (PBL) model on students' geometric conceptual understanding. *Zenodo-Research & Development*, 4(2), 1–30.
- Sirojjuddin, Prabawati, R., Jaharudin, Hidayat, F. A., & Malwat, S. W. (2025). Integration of ethnozoology and technology in e-module development for animal structur courses. *Journal of Engineering Science and Technology*, 20(3), 145–152.
- Surbakti, R., Umboh, S. E., Pong, M., & Dara, S. (2024). Cognitive load theory: Implications for instructional design in digital classrooms. *International Journal of Educational Narratives*, 2(6), 483–493.
- Suripah, & Susanti, W. D. (2022). Alternative learning during a pandemic: Use of the website as a mathematics learning media for student motivation. *Infinity Journal*, 11(1), 17–32.
- Syamsinar, S., & Yusuf, M. J. (2019). Analysis of instructional material based on english for specific purposes on the needs of management students at STIE Tri Dharma Nusantara. *Exposure: Jurnal Pendidikan Bahasa Inggris*, 8(2), 228–244.
- Teknowijoyo, F. (2024). Exploring the role of TPACK in promoting inquiry-based learning in 21st-century science learning. *KnE Social Sciences*, 9(2), 1088–1100.
- Vasodavan, V. (2020). *Development of collaborative TPACK module for continuing professional development in a higher education institution*. University of Malaya (Malaysia).
- Verma, S. (2024). Effectiveness of various teaching strategies in promoting student engagement and understanding. *Perspectives in Education, Curriculum and Pedagogy*, 76.
- Yulianto. (2019). An analysis on readability of english reading texts for eighth grade students. *J-SHMIC Journal of English for Academic*, 6(1), 81–91.
- Zahroh, L. (2025). Effectiveness of the implementation of an innovative Problem-Based Learning (PBL) model based on TPACK to enhance student engagement and learning outcomes in IPAS. *Jurnal Penelitian Pendidikan IPA*, 11(2), 525–530.
- Zhan, X., Sun, D., Wen, Y., Yang, Y., & Zhan, Y. (2022). Investigating students' engagement in mobile technology-supported science learning through video-based classroom observation. *Journal of Science Education and Technology*, 31(4), 514–527.