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Limited Trial of 3D Map Integrated Mobile Learning App for Ecology and Conservation Education in the Eastern Aceh Region of the Leuser Ecosystem

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ABSTRACT

Environmental degradation and biodiversity loss in the Leuser Ecosystem highlight the urgent need for effective ecology and conservation education that is contextually grounded and technologically supported. This study aims to develop and evaluate a mobile learning application integrated with 3D map visualization to support ecology and conservation education in the Eastern Aceh region of the Leuser Ecosystem. The research adopted a research and development approach using the ADDIE model, with the present study focusing on the implementation stage through a limited trial. The validity of the developed media was evaluated by experts in content, instructional design, media, and language, while practicality was assessed through user responses involving university students and senior high school students. The validation results showed high levels of validity, with average scores of 84% for content validity, 81% for instructional validity, 87% for media validity, and 87% for language validity, indicating that the application is highly valid. Practicality testing also yielded very high results, with an overall practicality score of 86%, demonstrating that the application is easy to use, efficient, attractive, and supportive of the learning process. These findings indicate that the 3D map integrated mobile learning application is both valid and practical for use in ecology and conservation education. The study contributes to the development of technology enhanced conservation learning media and provides a foundation for broader implementation and further effectiveness testing in diverse educational settings.

INTRODUCTION

Environmental degradation and biodiversity loss have become increasingly urgent global challenges, particularly in tropical regions where ecological richness coincides with intense anthropogenic pressure. Education plays a crucial role in addressing these challenges by fostering ecological literacy, conservation awareness, and pro environmental behavior among younger generations. In this context, conservation education is no longer limited to the transmission of biological concepts but must also cultivate spatial understanding, systems thinking, and contextual awareness of human environment interactions (Fitriana et al., 2025; Hayati et al., 2025).

The Leuser Ecosystem Area in Aceh, Indonesia, represents one of Southeast Asia's most critical conservation landscapes, hosting exceptional biodiversity and providing essential ecosystem services, including watershed protection and flood regulation. However, the region has experienced increasing ecological disturbances due to deforestation, land use change, and escalating human wildlife conflict, particularly in lowland and eastern parts of Aceh (Figel et al., 2023; Hayati et al., 2025). These dynamics highlight the importance of place based conservation education that enables learners to understand ecological processes spatially and contextually, especially in regions directly

connected to protected ecosystems such as East Aceh, Langsa, and Aceh Tamiang. learners to understand ecological processes spatially and contextually, especially in regions directly connected to protected ecosystems such as East Aceh, Langsa, and Aceh Tamiang.

Recent studies emphasize that effective conservation and disaster related education benefits significantly from the integration of geospatial technologies. Web based Geographic Information Systems (Web GIS), 3D mapping, and spatial visualization tools have been shown to enhance students understanding of complex environmental phenomena, including ecosystem dynamics, land-use change, and natural hazards (Li et al., 2022). By enabling learners to explore spatial data interactively, these technologies support inquiry based learning and strengthen connections between abstract ecological concepts and real world landscapes. Alongside advances in geospatial technology, mobile learning has emerged as a powerful approach to expand access to learning resources and support flexible, context aware education. Mobile learning applications allow students to engage with scientific content beyond the classroom, promote learner autonomy, and integrate multimedia representations that enrich conceptual understanding (Schmidthaler et al., 2025). In biological and environmental education, mobile learning has demonstrated potential to improve engagement, motivation, and learning outcomes, particularly when combined with visual and interactive features relevant to ecological contexts.

More recently, scholars have highlighted the importance of ecological and eco-learning environments that integrate digital technology, learner interaction, and sustainability principles. Big data assisted and ecological learning frameworks emphasize that learning environments should support interaction, contextual relevance, and inclusive access to environmental knowledge (Soon et al., 2025). These perspectives align with the need for conservation education tools that are not only informative but also interactive, spatially grounded, and responsive to local ecological realities. Despite these developments, several gaps remain in the existing literature. First, while Web GIS and 3D mapping have been widely applied in geography and disaster education (Li et al., 2022), their integration into mobile learning applications specifically designed for ecology and conservation education remains limited. Second, many studies focus on conceptual models or large scale implementations, while empirical evidence from small scale or limited trials particularly in biodiversity rich regions such as the Leuser Ecosystem is still scarce.

Furthermore, research in biology and environmental education increasingly stresses the need to connect cognitive learning with values, attitudes, and responsible environmental behavior. Contextualized learning approaches including the integration of local ecological issues, spatial representations, and culturally relevant perspectives have been shown to strengthen students' environmental awareness and sense of stewardship (Fitriana et al., 2025). However, the design and evaluation of digital learning media that explicitly combine these elements with advanced spatial visualization tools remain underexplored. In response to these gaps, this study focuses on the development and limited trial of a mobile learning application integrated with 3D map visualization for ecology and conservation education in the Eastern Aceh region of the Leuser Ecosystem. The study adopts a research and development perspective, with emphasis on the limited trial stage, specifically examining the validity and practicality of the developed learning media. By integrating mobile learning with 3D spatial representation of ecological landscapes, the application aims to support learners' understanding of ecosystem structure, conservation issues, and spatial relationships within the Leuser Ecosystem. Case based and context driven learning, as applied in conservation biology courses in the eastern Aceh region, has been shown to enhance students' ability to identify environmental problems, formulate solutions, and evaluate conservation strategies (Armanda fahmy, Wulandari Saputri, 2024).

This research is expected to provide both theoretical and practical contributions. Theoretically, this research enriches the discourse on technology-supported conservation education by demonstrating how mobile learning and 3D geospatial visualization can be integrated within an ecological learning framework. Practically, this research provides an empirically tested prototype of

learning media that can support conservation education in biodiversity rich areas and informs the development of smartphone based digital learning tools for ecological and environmental education.

MATERIALS AND METHODS

1. Time and Place of Research

The research was conducted from June to Auggust 2025, at the Biology education workspace, Faculty of Teacher Training and Education, Samudra University as a media development space. Media testing is located in the Smartclass Room at Faculty of Teacher Training and Education, Samudra University, and the Study Room at SMA Negeri 1 Peunaron, SMA Negeri 1 Langsa, and SMA Patra Nusa Aceh Tamiang.

2. Research Method

This study employed a research and development (R&D) approach using the ADDIE instructional design model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The ADDIE model was chosen because it provides a systematic and flexible framework for developing educational media and has been widely applied in the development of digital and mobile learning applications. However, this article focuses specifically on the limited trial stage, emphasizing the validity and practicality testing of the developed mobile learning application integrated with 3D map visualization.

3. Population and Sample

The population of this study consisted of: University students enrolled in ecology and conservation related courses, and senior high school students participating in ecology or environmental education learning in Biology or Science Learning. Experts validators in the fields of biology education, conservation education, and educational media. The research sample included three groups: Expert Validators consisting of: one material / content expert (ecology and conservation content), one media expert (mobile learning and 3D visualization), one instructional expert **(**learning objectives, scaffolding, and alignment with mobile learning principles), and one Language expert (redactional justification, and consistency of terminology). The validators assessed the content validity, media design, instructional suitability, and technical aspects of the developed application. University Student Users total of 20 undergraduate students who were actively participating in ecology and conservation learning were involved as users in the limited trial. These students evaluated the practicality, usability, clarity, and relevance of the mobile learning application. School Student Users total of 20 students from each participating school were involved in the limited trial. These students used the application during ecology and conservation learning activities and provided responses related to ease of use, learning support, and engagement. The sampling technique used for users was purposive sampling**,** based on participants involvement in ecology and conservation learning and their accessibility during the research period.

4. Research Procedure

The research procedure followed the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) development model, which is widely used in instructional media development. The ADDIE model provides a systematic framework to ensure that learning media are developed based on learners needs, instructional objectives, and contextual relevance (Puriadi & Surnjono, 2024). In the analysis stage, a needs analysis was conducted to identify ecological and conservation learning challenges in the Eastern Aceh region of the Leuser Ecosystem, including limitations in learning media that support spatial understanding and local ecological contexts. The design stage focused on planning the structure and features of the mobile learning application integrated with a 3D map. During the development stage**,** the mobile learning application was developed based on the design specifications. The development process involved creating learning content, integrating 3D map visualization of the Leuser Ecosystem area, and conducting expert validation to assess the content validity, media design, and technical quality of the application. The implementation stage, which is the primary focus

of this article, involved a limited trial of the developed mobile learning application. The trial was conducted with selected users to examine the practicality and usability of the application in real learning contexts. Users interacted with the application during ecology and conservation learning activities, and feedback was collected to evaluate its practicality. Finally, the evaluation stage was conducted in a limited scope, focusing on formative evaluation through expert validation results and user responses. This article specifically reports the implementation stage of the ADDIE development model, focusing on a limited trial to examine the validity and practicality of the developed mobile learning application. For details of procedures related to limited testing for validity and practicality testing, see the flow below.

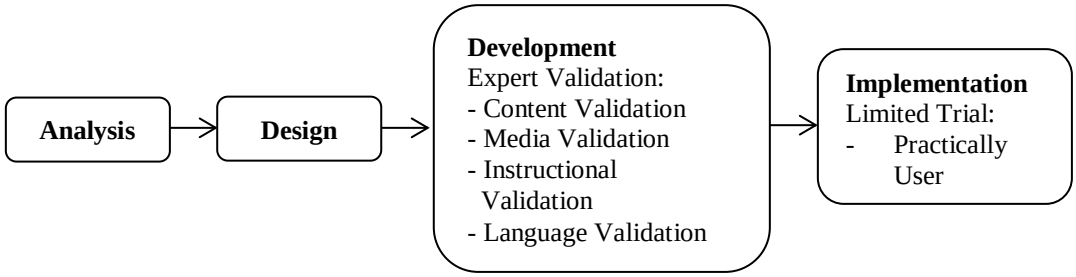


Figure 1. Flow of Research Procedure

5. Data Collection

Data were collected during the Implementation stage (limited trial) of the ADDIE based development to examine the validity and practicality of the 3D map integrated mobile learning application for ecology and conservation education.

a. Expert Validation Data (Validity)

Validity evidence was obtained through expert judgment using structured validation sheets. The validators assessed the product based on predetermined indicators, covering: 1) Content validity (ecology and conservation accuracy, conceptual depth, alignment with learning outcomes, contextual relevance to the Leuser/Eastern Aceh setting), 2) Instructional/design validity (learning objectives clarity, learning flow, appropriateness of activities, feedback/scaffolding, alignment with mobile learning principles), 3) Media/technical validity (interface design, navigation, functionality, stability, readability, multimedia quality, compatibility), 4) Language validity (clarity, correctness, appropriateness for learners, consistency of terminology). Each indicator was rated using a Likert scale, and validators provided qualitative comments for revision suggestions. The validation sheets were distributed in both print or digital form and collected after validators reviewed the application and supporting materials (user guide, learning content, and embedded 3D map features), Validation instrument modified from (Belladinna et al., 2025)

b. Practicality Data (Limited Trial Users)

Practicality data were collected from intended users to determine the feasibility of using the application in real learning settings. Participants included: 20 university students enrolled in ecology and conservation learning (user trial group), and 20 secondary school students in each partner school involved in the limited trial. Practicality was measured using a user practicality questionnaire that captured: Ease of use (navigation, menu clarity, operational simplicity), Efficiency and accessibility (loading speed, device compatibility, offline/online convenience), Attractiveness and engagement (visual appeal, interactivity, motivation), Instructional usefulness (clarity of explanations, support for understanding concepts, relevance of 3D map integration), and Learning support (self-learning support, task guidance, perceived benefits). Responses were recorded using a Likert scale. In addition, short open ended items were included to capture user suggestions, difficulties, and feature requests.

6. Data Analysis

The data analysis in this study was conducted to determine the validity and practicality of the developed mobile learning application integrated with 3D maps for ecology and conservation education. Data were analyzed quantitatively and descriptively, in accordance with the objectives of the limited trial stage in the ADDIE development model.

a. Validity Analysis

The validity of the mobile learning media was assessed through expert judgment, involving content experts, media experts, and language experts. Each validator evaluated the product using a structured validation questionnaire based on a Likert scale ranging from 1 (invalid) to 5 (very valid).

The validity score was calculated using the following formula:

$$V = \frac{\sum X}{N \; x \; X_{max}} X \; 100\%$$

Notes:

V = Validity percentage
∑X = total score obtained from users
N = number of questionnaire items
X_{max} = maximum score per item

This approach aligns with previous studies on practicality evaluation of instructional media and educational applications (Den Akker, 2013). The validity percentage was interpreted according to the criteria in table below.

Table 1. Validity Interpretation Catagory

Percentage (%)	Validity Category
81-100	Very Valid
61-80	Valid
41-60	Fairly Valid
21-40	Less Valid
≤ 20	Invalid

b. Practicality Analysis

The practicality of the developed mobile learning application was evaluated through user responses involving 20 university students enrolled in ecology and conservation learning and 20 students from each participating school in the Eastern Aceh region. Practicality assessment aimed to determine the ease of use, efficiency and accessibility, attractiveness and engagement, instructional usefulness, and learning support. User responses were collected using a practicality questionnaire with a Likert scale (1–5). The practicality score was calculated using the following formula:

$$P = \frac{\sum X}{N \; x \; X_{max}} X \; 100\%$$

Notes:

P = Practicality percentage
∑X = total score obtained from users
N = number of questionnaire items
X_{max} = maximum score per item

This approach aligns with previous studies on practicality evaluation of instructional media and educational applications (Den Akker, 2013). The practicality percentage was interpreted according to the criteria in table below.

Table 2. Practicality Interpretation Catagory

Percentage (%)	Practicality Category
81-100	Very Practical
61-80	Practical
41-60	Fairly Practical
21-40	Less Practical
≤ 20	Not Practical

RESULTS AND DISCUSSION

This section presents the results obtained from the limited trial of the 3D map integrated mobile learning application developed for ecology and conservation education in the Eastern Aceh region of the Leuser Ecosystem. The results are organized to reflect the outcomes of the implementation stage of the ADDIE development model, focusing on empirical evidence derived from expert evaluation and user responses during the trial phase. The validity and practicality are important test in educational instruction (Fauziah et al., 2020). The data presented in this section were obtained through systematic validation by experts and practicality testing involving actual users of the learning media. Validation data reflect expert assessments of the media in terms of content accuracy, instructional design, language clarity, and technical quality, while practicality data describe users' perceptions of ease of use, attractiveness, and applicability of the mobile learning application in learning activities. The average result of validation form the expert shown on figure below.

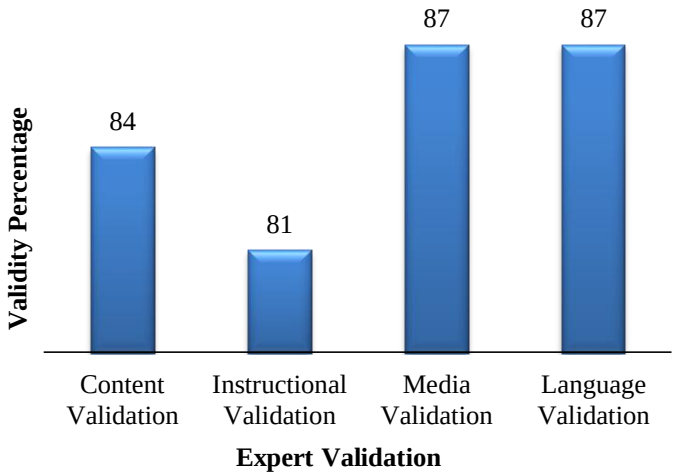


Figure 2. Average Results of Validity Analysis

The results of the validity assessment indicate that the developed learning media achieved a high level of validity across all evaluated aspects**.** The average validity score for content validation reached 84%, indicating that the ecological and conservation materials presented in the mobile learning application were accurate, relevant, and aligned with learning objectives. The instructional validation an average score of 81%, suggesting that the learning structure, instructional flow, and learning activities embedded in the application were pedagogically appropriate and supported meaningful learning processes. Furthermore, the media validation results showed an average score of 87%, reflecting that the visual design, 3D map integration, navigation, and technical functionality of the application were well-developed and met standards for digital learning media. Similarly, language validation achieved an average score of 87%, indicating that the language used in the

application was clear, communicative, and suitable for the target users. According to commonly accepted criteria in educational development research, validity scores above 80% fall within the *very valid* category and indicate that a product is feasible for implementation with minimal or no revision (Noris et al., 2023; Rizki & Fitri, 2024). Suggestions for improvement from content validation are that it is necessary to add cases of ecological damage that occurred in the last 5 years in 3 locations in the development of this media.

Suggestions for improvement from instructional validation are that this media needs to be given instructions or pointers to each part of this media. Meanwhile, suggestions for improvement from the media validator state that it is necessary to provide a distinction between the display design for learning media for students in universities and students in schools, and suggestions for improvement from the language validator state that there needs to be an explanation of the language editor who uses terms in biology into Indonesian so that users can easily understand Overall, the validation results demonstrate that the developed 3D map integrated mobile learning application is valid and appropriate for use in ecology and conservation education, particularly in the context of a limited trial within the Eastern Aceh region of the Leuser Ecosystem.

The practicality of the 3D map integrated mobile learning application was evaluated to determine its feasibility, ease of use, and applicability in real learning settings during the limited trial phase. Practicality testing is a crucial stage in educational media development, as it reflects users perceptions regarding whether a product can be effectively implemented without significant obstacles in authentic learning contexts (Lewis et al., 2019; Nicaise et al., 2000). The practicality assessment involved users from different perspectives (Janssen et al., 2015), including students participating in ecology and conservation learning activities depend on that learning media. The evaluation focused on five main aspects: and each aspect was assessed using a Likert-scale questionnaire, and the results were converted into percentage scores to determine the level of practicality. The average result of practicality test of the user shown on figure below.

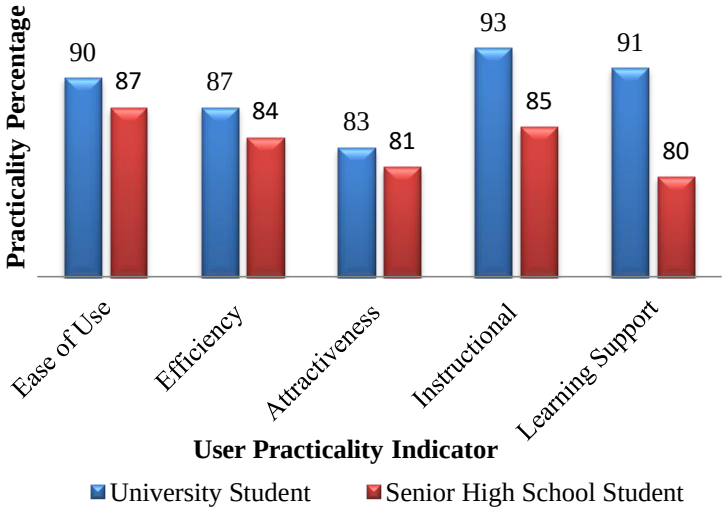


Figure 3. Average Results of Practicality Analysis

Based on the Figure 3, the *ease of use* aspect obtained a score of 90% from university students and 87% from senior high school students. These results indicate that the mobile learning application is easy to operate and user-friendly for both groups. Users reported that the navigation, menu structure, and access to learning content were clear and intuitive, allowing learners to use the application independently without significant difficulty. Ease of use of learning applications provides comfort to users so that the content in the application can be conveyed well (Bringman-rodenbarger, 2020; Stepanyuk et al., 2022) In terms of *efficiency*, the application achieved scores of

87% from university students and 84% from senior high school students. This suggests that the application enables users to access learning materials efficiently in terms of time and effort (Ahmed & Noraffandy, 2024; Strielkowski et al., 2025). The integration of concise learning content with 3D map visualization was perceived as helping learners quickly understand ecological concepts without requiring extensive external resources.

The *attractiveness* aspect received scores of 83% from university students and 81% from senior high school students. Although this aspect obtained slightly lower scores compared to other indicators, the results still fall within the very practical category. These findings indicate that the visual design, layout, and multimedia elements particularly the 3D map representation were engaging and capable of maintaining students interest during the learning process. (Ateş, 2025; Okyere et al., 2025). For the *instructional* aspect, high scores were achieved, with 93% from university students and 85% from senior high school students. This demonstrates that the learning objectives, content organization, and instructional guidance embedded in the application were clear and well-aligned with the learning outcomes of ecology and conservation education. The application was perceived as effectively supporting structured learning activities and conceptual understanding (Ateş & Gündüzalp, 2025).

The *learning support* aspect also showed strong results, with scores of 91% from university students and 80% from senior high school students. These results indicate that the application provides adequate support for the learning process, including clarity of explanations, relevance of examples, and alignment between visual representations and ecological concepts (Mccalla, 2004). The slightly lower score from senior high school students suggests differences in prior knowledge and learning experience, but the overall category still indicates high practicality. Overall, the practicality test showed figures indicating that users considered the 3D map integrated mobile learning media to be very good in terms of user practicality. It is hoped that with the practicality and ease of viewing real conditions from the 3D map, it can be a bridge connecting abstract concepts to area conservation material into real concepts with the presence of 3D maps in the media. Attractive design Digital based learning media is not just an interesting technological tool, but also a pedagogically powerful medium to bridge the gap between concepts and real conditions (Rosdiani et al., 2025). The design overview of the 3D Map Integrated Mobile Learning Application media for Ecology and Conservation Education in the East Aceh Leuser Ecosystem Region can be seen in the figure below.

Table 3. Overview Of Mobile Learning Media

Overview	Description
	This section is the front view of the mobile learning media which consists of 3 main learning menus, namely learning videos, quizzes, and 3D map displays.
	This section is the front view of the learning video menu which contains 6 main learning topics.

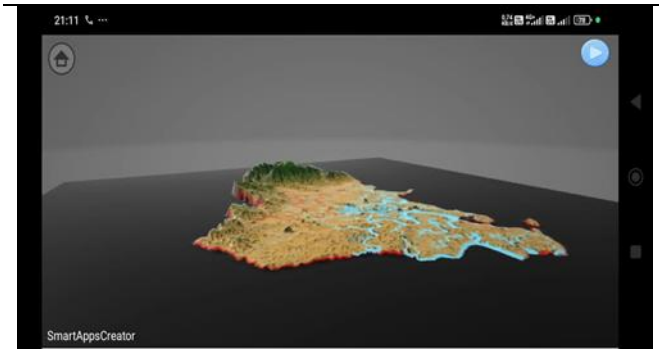
Overview	Description
	This section is a display of the 3D Map menu which is presented as a form of display of ecological conditions in several conservation areas.

Table 3 above shows an overview of the 3D integrated mobile learning media developed for ecological learning and conservation education in the Leuser ecosystem area in eastern Aceh. The media was developed based on research data related to the condition of the Leuser ecosystem in the eastern Aceh region, which consists of East Aceh, Langsa, and Aceh Tamiang. In recent years, the Leuser ecosystem area has experienced a lot of loss of land cover and a decline in its function as a forest area, so that this condition has the potential to influence disasters and negative interactions between wild animals and residential areas due to the animals losing their habitat (Figel et al., 2024; Opdyke, 2025; Safriansyah & Fauzan Baabud, 2021), 3D maps are presented to show the real conditions of land cover changes. (Ciampi et al., 2025).

The learning presented in the media is to introduce ecological learning to students which is linked to several real cases that occurred in the 3 areas above. The validation results from several experts, especially content or material validation, show a figure of 84% which is classified as very valid, this is because the content presented is very relevant to real conditions so that it can provide an understanding to students about ecological conditions and conservation efforts that need to be carried out, so it is hoped that this learning will shape the character of students who care about ecosystem conditions and are able to provide solutions to problems of ecosystem damage that occur (Armanda, Fahmy, 2025; Rahmatan et al., 2022). The mobile learning media above, after validation and practicality tests in limited testing, will continue to be developed until it is perfect and ready to be on the Playstore for the Android system and the Appstore for the iOS system, that it can reach a wider range of users.

CONCLUSION

This study examined the validity and practicality of a 3D map integrated mobile learning application for ecology and conservation education in the Eastern Aceh region of the Leuser Ecosystem through a limited trial at the implementation stage of the ADDIE development model. The findings indicate that the developed learning media meets the required quality standards for instructional use. The validation results show that the mobile learning application achieved high levels of validity across all evaluated aspects. The average content validity reached 84%, instructional validity 81%, media validity 87%, and language validity 87%. These results indicate that the learning content is scientifically accurate, instructionally appropriate, technically well-designed, and linguistically clear, suggesting that the application is suitable for use with only minor revisions, if necessary.

The practicality test further demonstrates that the application is highly practical from the users perspective. University students and senior high school students rated the application positively across all assessed aspects, including ease of use, efficiency, attractiveness, instructional quality, and learning support. The consistently high practicality scores indicate that the mobile learning application is user friendly, engaging, and capable of supporting learning activities effectively in both higher education and secondary school contexts. Overall, the results confirm that the 3D map integrated mobile learning application is both valid and practical as a learning medium

for ecology and conservation education. The integration of mobile technology with 3D spatial visualization provides meaningful learning support by enhancing learners' understanding of ecological concepts and spatial relationships within the Leuser Ecosystem. Future studies are recommended to conduct broader implementation trials and evaluate the effectiveness of the application in improving learning outcomes, environmental awareness, and conservation attitudes among students.

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REFERENCES

Ahmed, N., & Noraffandy, D. (2024). Investigating AI-based academic support acceptance and its impact on students ' performance in Malaysian and Pakistani higher education institutions. *Education and Information Technologies*, *29*(14), 18695–18744. https://doi.org/10.1007/s10639-024-12599-x

Armanda, Fahmy. (2025). Penyadartahuan Konservasi Habitat Satwa Liar Melalui Media Animasi Berbasis Android Untuk Siswa-Siswi SMP di Kawasan Ekosistem Leuser, Aceh Timur. *J-COSCIS : Journal of Computer Science Community Service*, *5*(2), 336–344. https://doi.org/10.31849/4ey6wk04

Armanda fahmy, Wulandari Saputri, M. D. (2024). *Conservation Biology Courses With A Local Wisdom Approach In Forming Environmental Care Attitudes And Environmental Problem Solving Ability*. *13*(03), 621–627.

Ateş, H. (2025). Integrating augmented reality into intelligent tutoring systems to enhance science education outcomes. *Education and Information Technologies*, *30*(4), 4435–4470. https://doi.org/10.1007/s10639-024-12970-y

Ateş, H., & Gündüzalp, C. (2025). Proposing a conceptual model for the adoption of artificial intelligence by teachers in STEM education. *Interactive Learning Environments*, *33*(6), 4020–4046. https://doi.org/10.1080/10494820.2025.2457350

Belladinna, S., Utami, P., Riska, N., Gumelar, A., & Jakarta, U. N. (2025). Evaluation of Content Validity for an Educational Media Instrument to Enhance Early Childhood Education (PAUD) Teachers ' Nutrition Knowledge. *Jurnal Pendidikan Dan Pembelajaran Indonesia (JPPI)*, *5*, 1801–1808. https://doi.org/https://doi.org/10.53299/jppi.v5i4.2531

Branch, R. M. (2009). *Instructional Design: The ADDIE Approach*. Springer Nature Link. https://doi.org/10.1007/978-0-387-09506-6

Bringman-rodenbarger, L. (2020). How students choose E-learning resources : The importance of ease , familiarity , and convenience. *FASEB BioAdvances*, *2*(December 2019), 286–295. https://doi.org/10.1096/fba.2019-00094

Ciampi, P., Maria, L., Carlo, G., & Siham, E. (2025). Reconstructing urban landscape evolution with historical maps and geophysical techniques : 3D time - sensitive and multi - source geomodelling. *Environmental Earth Sciences*, *84*(9), 1–16. https://doi.org/10.1007/s12665-025-12260-x

Den Akker, J. V. (2013). *Educational Design Research* (T. Nieveen, Nienke; Plomp (ed.)). SLO Netherlands institute for curriculum development.

Fauziah, A., Sciences, N., Ketintang, J., Rachmadiarti, F., Sciences, N., & Ketintang, J. (2020). Validity And Practicality Of Biodiversity Textbooks Based On Science, Technology, Environment, Society (Stes) To Train Students' Critical Thinking Skills. *Bioedu*, *9*(1), 207–216.

Figel, J. J., Safriansyah, R., Baabud, S. F., & Hambal, M. (2024). Intact, under-patrolled forests harbor widespread prey but a male-biased tiger population in the Ulu Masen Ecosystem,

Sumatra, Indonesia. *Scientific Reports*, *14*(1), 23612. https://doi.org/10.1038/s41598-024-75503-0

Figel, J. J., Safriansyah, R., Baabud, S. F., & Herman, Z. (2023). Clustered conflicts in disturbed lowlands characterize human–tiger interactions in Aceh, Indonesia. *Wildlife Letters*, *1*(2), 83–91. https://doi.org/10.1002/wll2.12016

Fitriana, F., Rahmatan, H., Evendi, E., Saminan, S., & Mentari, M. (2025). Integration of religious values in biology learning and its implications for students ' environmental awareness. *Jurnal Pendidikan Biologi Indonesia*, *11*(2), 716–727.

Hayati, D., Samsudin, Y. B., Armanda, F., Zikria, V., Muslih, A. M., Andini, S., & Rahman, S. A. (2025). Trends In Forest Conservation Research In Aceh Province , Indonesia Through 2023 : A Bibliometric Analysis. *Indonesian Journal of Forestry Research*, *12*(1), 83–98. https://doi.org/10.59465/ijfr.2025.12.1.83-98

Janssen, F., Westbroek, H., Doyle, W., Janssen, F., & Doyle, W. (2015). Practicality Studies : How to Move From What Works in Principle to What Works in Practice Practicality Studies : How to Move From What Works in Principle to What Works in Practice. *The Journal of the Learning Sciences*, *24*(1), 176–186. https://doi.org/10.1080/10508406.2014.954751

Lewis, D. G. R., Gerber, E. M., Carlson, S. E., & Easterday, M. W. (2019). Opportunities for educational innovations in authentic project - based learning : understanding instructor perceived challenges to design for adoption. *Educational Technology Research and Development*, *67*(4), 953–982. https://doi.org/10.1007/s11423-019-09673-4

Li, J., Xia, H., Qin, Y., Fu, P., Guo, X., & Li, R. (2022). Web GIS for Sustainable Education : Towards Natural Disaster Education for High School Students. *Sustainability Journal*, *14*(2694), 1–18.

Mccalla, G. (2004). The Ecological Approach to the Design of E-Learning Environments : Purpose-based Capture and Use of Information About Learners. *Journal of Interactive Media in Education*, *2004*(May), 1–23. https://doi.org/10.5334/2004-7-mccalla

Nicaise, M., Gibney, T., & Crane, M. (2000). Toward an Understanding of Authentic Learning : Student Perceptions of an Authentic Classroom. *Journal of Science Education and Technology*, *9*(1). https://doi.org/https://doi.org/10.1023/A:1009477008671

Noris, M., Saputro, S., Rahayu, A., Education, S., & Maret, U. S. (2023). Development of Biology Learning Media Assisted by Construct2 to Improve Critical Thinking Skills. *Journal of Research in Science Education*, *9*(2), 498–504. https://doi.org/10.29303/jppipa.v9i2.1921

Okyere, A., Emmanuel, D., & Ekwam, O. (2025). Enhancing Achievements in Biology Education in Ghana Using Culturo - Techno - Contextual Approach Plus. *Journal of Science Education and Technology*, *34*(6), 1483–1494. https://doi.org/10.1007/s10956-025-10232-1

Opdyke, A. (2025). *Inclusive and Integrated Disaster Risk Reduction* (A. Opdyke (ed.)). Springer Proceedings in Earth and Environmental Science. https://doi.org/10.1007/978-3-031-81072-5

Puriadi, P. G., & Surnjono, H. D. (2024). *Development of Interactive Learning Multimedia for Biology Subjects on the Human Blood Circulation System Material to Improve Motivation and Learning Outcomes in High School*. *10*(12), 10410–10416. https://doi.org/10.29303/jppipa.v10i12.9311

Rahmatan, H., Abdullah, A., Iswadi, I., Wahid, I., Gagarin, Y., & Zulfikar, Z. (2022). Application of Blended Learning in an Effort to Improve Public Understanding of Sumatran Elephant Conservation in Mila District, Aceh. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2808–2814. https://doi.org/10.29303/jppipa.v8i6.1988

Rizki, M., & Fitri, R. (2024). Meta-Analysis ' Validity of Booklet on the Human Reproductive System a s a Supplementary Biology Teaching Material for High School. *Bioilmi : Jurnal Pendidikan*, *X*(1), 43–50.

Rosdiani, F., Dewi, K., Yutiva, M., & Zannah, F. (2025). *Peatland Biodiversity Learning through Virtual Reality : a Case Study at Muhammadiyah Palangka Raya University*. *XI*(1), 42–51.

Safriansyah, R., & Fauzan Baabud, S. (2021). *An Update on Human Elephant Conflict in Aceh, Indonesia* (Issue December 2021). www.janinegrantconsulting.com

Schmidthaler, E., Corinna, H., Rottenhofer, M., Sabitzer, B., & Lavicza, Z. (2025). The implementation of learning apps in biological education : a quantitative study of the current situation in Austria. *Journal of Research in Innovative Teaching & Learning*, *18*(1), 95–122. https://doi.org/10.1108/JRIT-12-2022-0094

Soon, J. P., Lanlan, P., Ji, Y., Luo, J., Yuen, P. K., & Donghui, X. (2025). Big data assisted eco-learning environment framework for inclusive education. *International Journal of Advances in Applied Sciences*, *14*(1), 200–208. https://doi.org/10.11591/ijaas.v14.i1.pp200-208

Stepanyuk, A. V, Kormer, M. V, & Tsidylo, I. M. (2022). Integrated Use of the LearningApps . org Resourse and Information Devices in the Process of Biology School Course Studying. *Proceedings of the 1st Symposium on Advances in Educational Technology (AET2020)*, *2*(Aet 2020), 452–465. https://doi.org/10.5220/0010932800003364

Strielkowski, W., Grebennikova, V., Lisovskiy, A., & Vasileva, T. (2025). AI-driven adaptive learning for sustainable educational transformation. *Sustainable Development*, *33*(June 2024), 1921–1947. https://doi.org/10.1002/sd.3221