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Diving into Ocean Literacy: Android-Based Marine Biodiversity Learning for Enhancing Cognitive Abilities in Inclusive Elementary Schools

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Abstract

Inclusive primary education often faces serious constraints due to the limited availability of differentiated instruction and adaptive learning media tailored to diverse student needs. This study aimed to develop Android-based learning media on ocean literacy and marine biodiversity and to evaluate their effectiveness in improving students' cognitive abilities in an inclusive elementary school. A Design-Based Research (DBR) approach combined with a quasi-experimental design was employed. The participants were 60 third-grade students at SDN 7 Kota Serang, divided into an experimental class (n = 30) that used the Android-based learning media and a control class (n = 30) that received conventional instruction. Data were collected through pre-test and post-test then analyzed using descriptive statistics, t-tests, N-Gain, and Cohen's d. Results revealed that following the intervention, the experimental group (M = 66.03) significantly outperformed the control group (M = 45.10; $p < 0.001$) with a large effect size (Cohen's d = 1.68). The learning gain of the experimental class was in the medium category (N-Gain = 0.45), whereas that of the control class was in the low category (N-Gain = 0.20). Students also rated the media as highly feasible (M = 4.92 out of 5). In practical terms, these findings suggest that the developed multimedia Android applications provide an effective tool for differentiated instruction in inclusive school under the Merdeka Curriculum.

Keywords: Android-Based Learning, Cognitive Aspect, Inclusive Education, Ocean Literacy

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Abstrak

Pendidikan dasar inklusif sering kali menghadapi tantangan dan kendala serius akibat keterbatasan ketersediaan pengajaran yang terdiferensiasi serta media pembelajaran adaptif yang disesuaikan dengan beragam kebutuhan siswa. Penelitian ini bertujuan untuk mengembangkan media pembelajaran berbasis Android tentang literasi kelautan dan keanekaragaman hayati laut, serta mengevaluasi keefektifannya dalam meningkatkan kemampuan kognitif siswa di sebuah sekolah dasar inklusif. Pendekatan Penelitian Berbasis Desain (DBR) yang dikombinasikan dengan desain kuasi-eksperimental digunakan dalam penelitian ini. Partisipan penelitian terdiri dari 60 siswa kelas tiga di SDN 7 Kota Serang, yang dibagi menjadi kelas eksperimen (n = 30) yang menggunakan media pembelajaran berbasis Android dan kelas kontrol (n = 30) yang menerima pengajaran konvensional. Data dikumpulkan melalui pre-tes dan post-tes, kemudian dianalisis menggunakan statistik deskriptif, uji-t, N-Gain, dan Cohen's d. Hasil menunjukkan bahwa setelah intervensi, kelompok eksperimen (M = 66,03) secara signifikan lebih baik dari kelompok kontrol (M = 45,10; $p < 0,001$) dengan effect size besar (Cohen's d = 1,68). Peningkatan pembelajaran pada kelas eksperimen berada dalam kategori sedang (N-Gain = 0,45), sedangkan pada kelas kontrol berada dalam kategori rendah (N-Gain = 0,20). Para siswa juga menilai media tersebut sangat layak digunakan (M = 4,92 dari skala 5). Secara praktis, temuan ini menunjukkan bahwa aplikasi multimedia berbasis Android yang dikembangkan terbukti menjadi alat yang efektif untuk pembelajaran yang berdiferensiasi di sekolah inklusif di bawah Kurikulum Merdeka.

Kata Kunci: Pembelajaran Berbasis Android, Aspek Kognitif, Pendidikan Inklusif, Literasi Kelautan

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INTRODUCTION

Inclusive education embodies the principles of justice and equality in access to education, guaranteeing every child the right to quality learning without discrimination (Navas-Bonilla et al., 2025). However, its implementation in Indonesia still faces significant challenges. A report commissioned by UNICEF in coordination with BAPPENAS revealed that 36% of children with disabilities in Indonesia do not attend school, compared with only 8% of children without disabilities (UNICEF, 2023). The World Bank similarly reported that almost 30% of children with disabilities in Indonesia lack access to education. This gap highlights the urgency of building a more inclusive and equitable education system through innovative learning strategies that respond to student diversity (Mahmud et al., 2025).

The challenge of inclusive education lies not only in access but also in the quality of learning that can accommodate students' diverse needs. Recent research shows that technology can play a crucial role in creating inclusive learning environments that respond to individual differences among students (Fälth & Selenius, 2024). In this context, digital technologies, particularly mobile applications, have shown considerable potential to improve the accessibility and personalization of learning. The Fourth Industrial Revolution has also fundamentally transformed educational practice through digital technology (Haleem et al., 2022). Smartphones and tablets have become an integral part of everyday life, and students increasingly own and use them for learning (van Vliet, 2020). This creates new opportunities for mobile learning as a flexible, personalized strategy accessible anytime, anywhere.

Empirical research shows that mobile learning can engage students in tasks across all levels of cognitive demand, from remembering to creating (Crompton et al., 2019). A meta-analysis by Sung et al. (2016) confirmed that integrating mobile devices into teaching and learning positively affects students' learning performance. Mobile technology also enables differentiated instruction, which is essential to inclusive education, allowing each student to learn at their own pace and in their own way (Navas-Bonilla et al., 2025).

In inclusive schools, mobile technology offers ways to address the learning barriers faced by students with special needs. Navas-Bonilla et al. (2025) found that digital tools can remove barriers to learning, personalize the learning experience, and encourage the active participation of students with diverse abilities. This is consistent with Bulathwela et al. (2024), who argue that technology can enhance educational inclusivity when inclusive tools are designed with learners' contexts in mind.

While specialized assistive hardware often presents cost and accessibility barriers in inclusive settings, mobile devices offer affordable, accessible alternatives that support diverse learners' engagement and autonomy (Fernández-Batanero et al., 2022; Ismaili & Ibrahimi, 2017). However, empirical studies examining mobile learning as an assistive tool for domain-specific subjects like ocean literacy in inclusive primary classrooms remain scarce.

Android, the most widely used mobile operating system worldwide, provides a suitable platform for developing interactive learning media because it is widely accessible, user-friendly, and capable of integrating a range of multimedia formats. Previous research in Indonesia has shown that Android-based learning media can support students' critical thinking skills and scientific attitudes and are perceived by teachers and students as very helpful in the learning process (Isnaeni et al., 2021).

A study of assessment-based mobile learning in elementary school students by Hwang and Chang (2011) showed that a mobile learning approach involving authentic, real-world learning activities significantly improved students' learning achievement and attitudes. Mobile devices also extend learning beyond the classroom, giving students greater access to learning resources (van Vliet, 2020).

However, the effectiveness of mobile technology in learning depends heavily on sound pedagogical design. A randomized controlled trial by Outhwaite et al. (2019) showed that interactive apps designed around young children's developmental level, with

structured progression and immediate feedback, raised early mathematics achievement. Design features such as content sequencing, the type of feedback provided, and alignment between content and students' cognitive development levels are therefore crucial to the effectiveness of learning applications.

Cognitive abilities are an essential foundation for academic success and students' holistic development. Evidence synthesized from neuroscience and education research shows that digital technologies, when appropriately designed and implemented, can support the development of cognitive functions such as attention, memory, executive function, and problem-solving (Duraiappah et al., 2021). Technology can also facilitate higher-order cognitive processes by providing adaptive scaffolding, immediate feedback, and visual representations that support knowledge construction (Hwang et al., 2020).

In inclusive learning, developing cognitive abilities through digital media is particularly significant. Technology can provide support tailored to individual students' needs, allowing them to develop their cognitive abilities at the pace and in the manner that is most effective for them (Almufarreh & Arshad, 2023). Learning applications designed in line with cognitive load theory can optimize the learning process and improve knowledge retention (Sweller et al., 2019), and computer-based scaffolding has been shown to improve learning outcomes (Kim et al., 2018).

Although the literature has widely discussed the potential of mobile technology to support inclusive learning has been widely discussed in the literature, its practical implementation in Indonesia, particularly at the elementary school level, still faces several challenges. Preliminary observations at SDN 7 Kota Serang identified three crucial problems: (1) 50% of teachers had not planned differentiated instruction that could accommodate the diverse needs of students in inclusive classes; (2) 40% of teachers did not yet comprehensively understand how to implement inclusive learning; and (3) 30% of teachers had difficulty managing instructional time effectively.

These problems are compounded by a lack of interactive, adaptive learning resources that support inclusive learning. Instruction is dominated by conventional methods that do not use digital technology to support personalized learning. As a result, student engagement is low, and learning objectives are not fully achieved, especially in developing students' cognitive abilities.

Based on these problems, this study aimed to (1) develop Android-based learning media that suit the characteristics and needs of students in inclusive elementary schools; (2) evaluate the effectiveness of the Android-based learning media in improving students' cognitive abilities; and (3) analyze differences in learning achievement between students who used the Android-based learning media and those who received conventional instruction.

This study makes both theoretical and practical contributions. Theoretically, it enriches the literature on the use of mobile technology in inclusive education in Indonesia, particularly at the elementary school level. Practically, it produces an Android-based learning application that can serve as an alternative learning medium to improve the quality of inclusive education. Furthermore, its findings can serve as a reference for education stakeholders in designing policies and strategies for implementing inclusive and effective learning technology.

METHODS

This study employed a Design-Based Research (DBR) approach combined with a quasi-experimental nonequivalent control group design (Gopalan et al., 2020; Satibi, 2020). DBR enables researchers to develop learning solutions that respond to needs in real educational settings through iterative cycles of design, implementation, and refinement, while the quasi-experimental design allows the effectiveness of the intervention to be evaluated systematically (Anderson & Shattuck, 2012; Gopalan et al., 2020). Figure 1 illustrates the four interconnected stages of the DBR framework used in this study, as well as

the iterative nature of the design and development process.

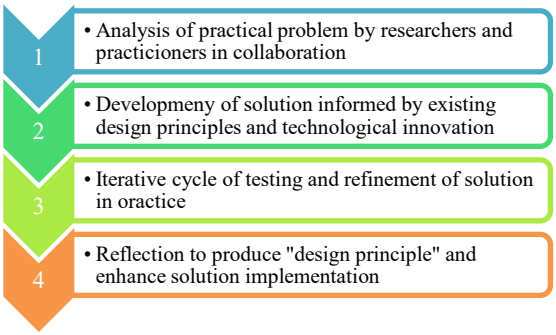

Figure 1. Design-Based Research Framework

The study was carried out in four DBR stages: (1) identification and analysis of problems through observations and interviews at SDN 7 Kota Serang; (2) development of a prototype Android application comprising a welcome screen, a main menu, a picture-guessing feature, a games menu, a material menu, and learning content; (3) trial and validation by media experts and subject-matter experts; and (4) implementation in the experimental class over nine weeks, accompanied by reflection and refinement of the design principles.

The participants were 60 third-grade students at SDN 7 Kota Serang, divided into an experimental class (n = 30) and a control class (n = 30). The experimental class used the Android-based learning media, whereas the control class received conventional instruction. SDN 7 Kota Serang was selected because it is a representative inclusive school in Serang City.

To clarify the inclusive character of the research setting, both classes comprised regular students and students with special needs (*Peserta Didik Berkebutuhan Khusus*/PDBK). The experimental class included 2 PDBK students (both with mild intellectual disabilities) and 28 regular students, and the control class likewise included 2 PDBK students (both with mild intellectual disabilities) and 28 regular students. Diagnostic classifications were obtained from the school's inclusive education assessment records, which are maintained by the classroom teacher and the school's inclusive education coordinator. The study used them only in aggregate, in accordance with the study's ethical clearance and data privacy procedures.

The Android-based learning media accommodated the needs of PDBK students differently from standard instruction through several built-in features: repeatable audio narration and visual illustrations that reduce dependence on text-based literacy; self-paced navigation that allows students to progress at their own speed rather than on a fixed classroom schedule; and immediate corrective feedback in the picture-guessing and game features that reduces reliance on continuous teacher scaffolding. Regular students, by comparison, benefited mainly from the enrichment and motivational value of the multimedia format rather than from these accommodations. Because each class had only 2 PDBK students in each class (n = 2), a separate comparison of learning gains between PDBK and regular students was beyond the scope of this study; such a comparison is recommended for future research with a larger PDBK sample, as noted in the Conclusion.

The research instruments comprised (1) a learning achievement test (pre-test and post-test) developed based on Bloom's taxonomy and validated by an expert panel; (2) a product feasibility questionnaire using a 5-point Likert scale; (3) structured observation sheets for monitoring implementation; (4) semi-structured teacher interview guidelines; and (5) documentation of learning activities.

The research procedure consisted of five steps: preparation and obtaining permits, pre-test administration to measure students' initial abilities, a nine-week intervention, post-test administration, and product feasibility evaluation. The application's APK file was distributed via WhatsApp for installation on students' smartphones.

Data were analyzed using descriptive statistics (mean, median, mode, and standard deviation) and inferential statistics. Prerequisite tests included normality (Kolmogorov–Smirnov) and homogeneity (Levene's test). Hypotheses were tested using an independent-samples t-test to compare learning achievement between groups and a paired-samples t-test to analyze improvement within the experimental group. All statistical tests used a significance level of $\alpha = 0.05$. The

magnitude of improvement was calculated using normalized gain (N-Gain = (post-test mean − pre-test mean)/(100 − pre-test mean)) and interpreted as low ($g < 0.30$), medium ($0.30 \leq g < 0.70$), or high ($g \geq 0.70$). Effect size was calculated using Cohen's d to evaluate the practical significance of the findings.

RESULTS AND DISCUSSION

The Android-based learning media were developed using the Design-Based Research model, which comprises problem identification and analysis, prototype development, trial, and implementation accompanied by reflection and refinement of the design principles (Satibi, 2020). In this study, reflection was embedded within the implementation process rather than treated as an isolated stage, consistent with the iterative character of DBR. Each stage, including the reflective findings and the resulting refinements of the design principles, is described below.

Design-Based Research Steps

Problem Identification and Analysis Stage

The study began with observations at inclusive elementary schools in Banten Province, particularly in Serang City, focusing on SDN 7 Kota Serang. The observations showed that teachers at SDN 7 Kota Serang still relied mainly on conventional methods. Although the Merdeka Curriculum, which aims to make students active participants and create engaging learning experiences, had been adopted, the school's implementation was not yet effective because many students had not adapted to the new teaching approach. Consequently, students lacked understanding of the material, especially during practical activities. To address these problems, the researchers sought to improve student learning achievement by developing engaging learning media in the form of Android-based learning videos.

Program Prototype Development Stage

The prototype development stage was the main design phase of the learning media. It included storyboarding, selecting the material, developing questions and answers, creating backgrounds and images, and integrating the tools used to develop the Android video and application. The application consists of six main components: a welcome screen, a main menu, a picture-guessing feature, a games menu, a material menu, and learning content. Figure 2 presents the storyboard for each application component.

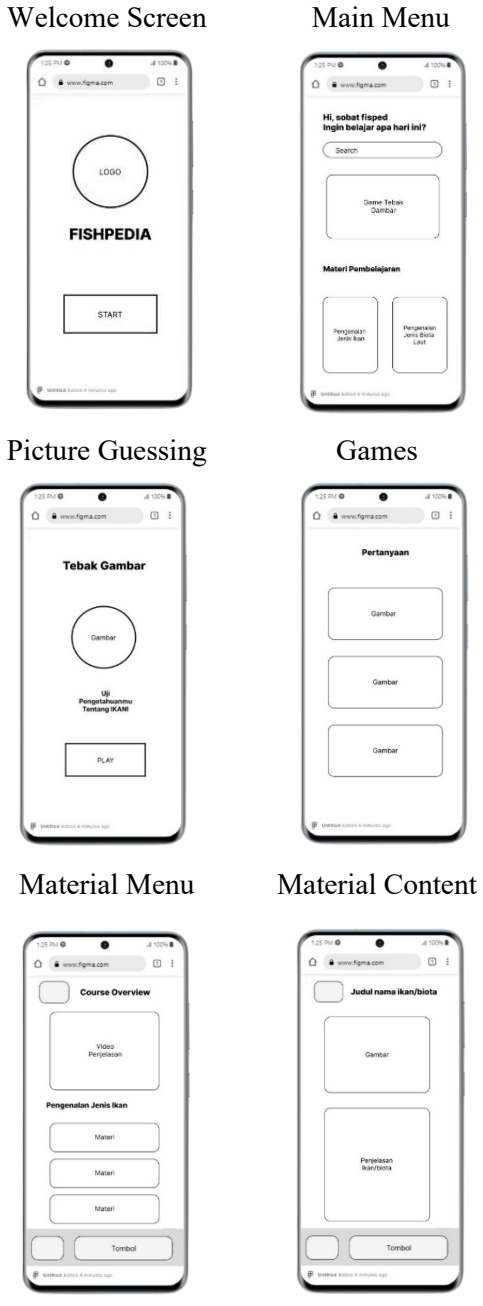

Figure 2. Storyboard of Six Main Interfaces

To build students' contextual understanding progressively, the Fishpedia application introduces aquatic biodiversity comparatively across freshwater, brackish, and

marine ecosystems, using familiar freshwater species as an initial cognitive bridge before delving into core marine biodiversity concepts.

Trial Stage

The trial stage is a critical phase that must be completed before a product is distributed to end users. At this stage, the media were validated by media experts and subject-matter experts to ensure that they met quality and usability standards. The experts' input and suggestions served as the basis for refining the product. After validation and revision, the final version of the Android application was produced with improved features and an improved user interface. Figure 3 presents the initial interface components, namely the welcome screen, main menu, and picture-guessing feature, and Figure 4 displays the interactive components, namely the games module, material menu, and learning content.

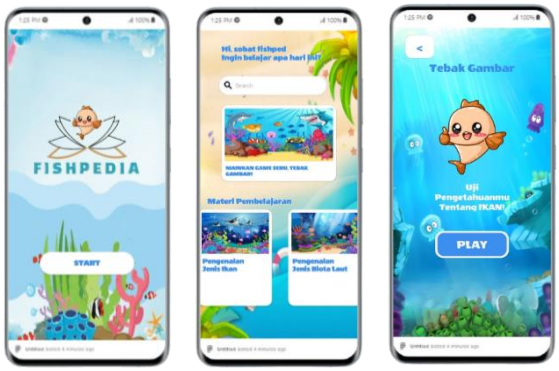

Figure 3. Welcome Screen, Main Menu, Picture Guessing

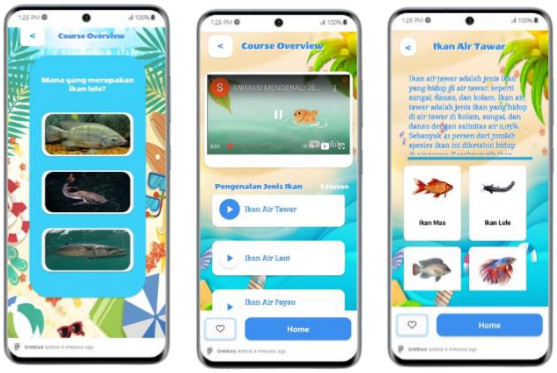

Figure 4. Games, Material Menu, Material Content

Implementation Stage

In the implementation stage, the validated Android-based learning media were deployed to the end users, namely 30 third-grade students at SDN 7 Kota Serang. Before the application was used, the researchers distributed its .apk file to the students via WhatsApp and instructed them to download and install it on their smartphones. Students whose devices were incompatible were given access through the researcher's smartphone, together with thorough guidance on the application's features. The implementation was documented through classroom observations, as shown in Figures 5 and 6: Figure 5 shows learning activities in the control class using conventional teaching methods, and Figure 6 shows learning activities in the experimental class using the Android-based learning application. After each lesson, students provided feedback through a structured questionnaire.

Reflection and Design Principle Refinement Stage

Although deploying the validated media to end users was the primary activity of this stage, reflection was carried out iteratively throughout the nine-week implementation period rather than as a single final step. Reflective data were drawn from the structured classroom observations and semi-structured teacher interviews described in the Methods section. This is consistent with the cyclical, self-correcting character of DBR, in which each implementation cycle is expected to generate empirically grounded refinements to the initial design principles (Anderson & Shattuck, 2012; Satibi, 2020).

The first refinement concerned device accessibility. Observations during the early weeks of implementation revealed that not all students owned compatible Android smartphones, which limited equal access to the learning media. In response, the initial design principle of universal accessibility was refined: students without compatible devices were given access through the researcher's device, together with individual guidance on navigating the application, as described above. This adjustment reflects the DBR principle that design solutions must respond to the practical constraints of the implementation

context rather than assume uniform access to technology.

A second refinement arose from feedback from media and subject-matter experts during the trial stage, leading to improvements to the application's features and user interface, as described in the Trial Stage section. This expert input functioned as a formative reflection cycle before classroom implementation, ensuring that design assumptions were tested against expert judgment before the application was deployed to students.

A third area of reflection concerned the extent to which the picture-guessing and educational game features supported students who needed additional time or simplified instructions to complete learning tasks. Teacher observations indicated that the self-paced structure and repeatable multimedia content were particularly helpful for students who needed more time to process information. They also suggested that future iterations could benefit from adjustable pacing controls and optional simplified visual cues for students with reading difficulties. These observations point to two refined design principles for subsequent iterations of the application: (1) providing adjustable pacing and repeatable audio instructions to accommodate different processing speeds, and (2) incorporating optional simplified visual cues to support students with reading or comprehension difficulties.

Owing to the time constraints of a single nine-week implementation cycle, a second full DBR cycle incorporating these refined design principles could not be completed within the scope of this study. The refinements identified above are therefore reported as reflective findings that inform recommendations for future iterative development, consistent with DBR's emphasis on cumulative, cycle-by-cycle knowledge building rather than a one-off intervention.

Figure 5. Control Class Activity

Figure 6. Experimental Class Activity

Product Feasibility Test Results

The product feasibility evaluation, conducted with a 5-point Likert-scale questionnaire administered to the 30 students in the experimental class, yielded a mean score of 4.92, equivalent to 98.4% of the maximum possible score. Based on the interval conversion criteria for a 5-point Likert scale (interval width = 0.80), namely 1.00–1.79 = very unfeasible, 1.80–2.59 = unfeasible, 2.60–3.39 = fairly feasible, 3.40–4.19 = feasible, and 4.20–5.00 = very feasible, this score falls into the "very feasible" category. This high level of

acceptance indicates that students found the application's interface user-friendly, its navigation intuitive, and its content engaging. These findings are consistent with Isnaeni et al. (2021), who found that teachers and students perceived Android-based learning media as very helpful in the learning process.

Student Learning Achievement Data

Student Learning Achievement before the Use of the Android Application

The pre-test was administered to assess students' baseline knowledge and cognitive abilities related to marine biodiversity. Analysis of the initial ability data showed that the experimental group had a significantly higher mean pre-test score than the control group before the intervention. Table 1 presents the descriptive statistics of the pre-test scores for both groups.

Table 1. Pre-test Data

Data	Control Class	Experimental Class
Mean	31.56	38.20
Median	32.84	39.80
Std. Deviation	10.09	11.01

Figure 7 compares the pre-test achievement of the experimental and control groups. The experimental class had a slightly higher mean score than the control class. An independent-samples t-test was performed to determine whether this difference was statistically significant and whether the two groups had equivalent initial abilities.

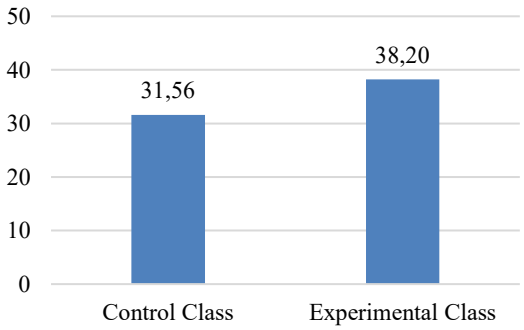

Figure 7. Comparison of Mean Pre-Test Scores

The independent-samples t-test yielded t-count = 2.436, which is greater than t-table = 2.00 at the 5% significance level (2.436 > 2.00; p = 0.018). Therefore, the hypothesis that there was no significant difference in learning achievement between the experimental and control classes before using the Android-based learning video media was rejected. The experimental class started with a slightly higher level of initial ability (mean difference = 6.64 points). This baseline difference is common in nonequivalent control group designs that use intact classes (Gopalan et al., 2020). Consequently, a comparison of post-test scores alone could overstate the effect of the intervention; therefore, the improvement of each class was also evaluated using the normalized gain (N-Gain), which expresses the gain relative to the maximum possible gain given each class's initial score.

Student Learning Achievement after the Use of the Android Application

A post-test was administered to evaluate students' understanding of marine biodiversity concepts after the intervention; the experimental class learned through Android-based learning videos, while the control class was taught using conventional methods. Both groups improved, but their performance levels differed markedly. Table 2 presents the descriptive statistics of the post-test results for both groups.

Table 2. Post-test Data

Data	Control Class	Experimental Class
Mean	45.10	66.03
Median	40.43	67.00
Std. Deviation	13.31	11.56

Figure 8 compares the post-test achievement of the experimental and control groups. The experimental class had a substantially higher mean score than the control class. An independent-samples t-test was performed to determine whether the experimental group's learning achievement was significantly higher than that of the control group.

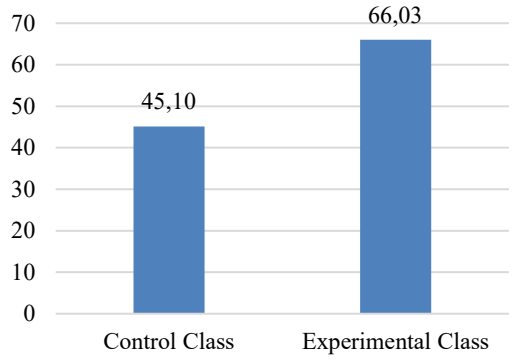

Figure 8. Comparison of Mean Post-Test Scores

The independent-samples t-test (see the calculation appendix) yielded t-count = 6.503, which is greater than t-table = 2.00 at a 5% significance level (6.503 > 2.00; p < 0.001). Therefore, the hypothesis stating that there was a significant difference in learning achievement between the experimental and control classes after the treatment with Android-based learning video media was accepted.

To assess the practical significance of this difference, the effect size was calculated as Cohen's d using the post-test means and the pooled standard deviation (SD pooled = 12.47). The resulting value, d = (66.03 − 45.10)/12.47 = 1.68, indicates a large effect according to Cohen's criteria (d ≥ 0.80). In other words, after the intervention, the mean score of the experimental class was 1.68 standard deviations higher than that of the control class.

Comparison of Pre-test and Post-test Mean Scores in the Experimental Class and Improvement in Learning Achievement

Table 3 presents the mean learning achievement scores of the experimental class before and after the Android-based learning media intervention, including the pre-test and post-test scores, the mean difference, and the percentage increase.

Table 3. Comparison of Pre-Test and Post-Test Scores

Data	**Experimental Class**	
	Pre-test	Post-test
Mean score	38.20	66.03
Difference	–	27.83
Increase (%)	–	72.85%

As shown in Table 3, the mean score of the experimental class increased by 27.83 points, representing a 72.85% increase relative to the pre-test mean. The one-tailed paired-samples t-test yielded t-count = 19.836, which is greater than t-table = 1.70 (df = 29) at a 5% significance level. Therefore, the hypothesis that learning achievement in the experimental class improved was accepted.

Because a simple percentage increase does not account for the room for improvement available to each group, the magnitude of improvement was also analyzed using the normalized gain (N-Gain). The experimental class obtained N-Gain = (66.03 − 38.20)/(100 − 38.20) = 0.45, which falls into the medium category, whereas the control class obtained N-Gain = (45.10 − 31.56)/(100 − 31.56) = 0.20, which falls into the low category. Thus, the normalized gain of the experimental class was more than twice that of the control class, confirming that the improvement associated with the Android-based learning media was substantially greater than that achieved through conventional instruction, even after the difference in initial ability is taken into account.

These results can be summarized as follows. (1) Before the treatment, the experimental class had a significantly higher pre-test mean than the control class (t = 2.436, p = 0.018); therefore, N-Gain was used as the primary measure of improvement. (2) After the treatment, the gap between the two classes widened considerably, from 6.64 points at pre-test to 20.93 points at post-test. Because this widening exceeds the initial difference, the higher post-test achievement of the experimental class can be attributed largely to the use of Android-based learning videos. The Android application can serve as a resource for independent learning both at school and at home, helping students improve their learning achievement. Students understood the material in different ways based on their individual abilities, and an application that includes learning materials, videos, and practice questions with answers can encourage students to learn more independently and explore the content more deeply. (3) Learning achievement in the experimental class increased by 72.85%, corresponding to a medium normalized gain (N-Gain = 0.45),

compared with a low normalized gain in the control class (N-Gain = 0.20). This indicates that Android-based learning video media can improve student learning achievement. The learning videos increased students' interest in learning, helped them focus on the lesson, reduced off-task chatting in class, facilitated their understanding of the material (especially practice-related material), and made learning more efficient and effective because teachers did not need to provide as many examples once the material had been presented through the videos.

Discussion

The significant improvement in students' cognitive achievement can be theoretically grounded in the Universal Design for Learning (UDL) framework, operationalized through mobile multimedia technology rather than generic multimedia consumption alone. While traditional instructional media often impose rigid, text-heavy barriers for struggling learners, the Fishpedia application embeds Multiple Means of Representation by coupling concrete visual illustrations with repeatable audio narrations (Fernández-Batanero et al., 2022). This multi-channel approach reduces extraneous cognitive load, especially for students with limited reading literacy or mild intellectual delays (Sweller et al., 2019). Furthermore, the app implements Multiple Means of Action and Engagement through interactive picture-guessing features that provide immediate corrective feedback without requiring complex verbal expression (Hwang et al., 2020; Outhwaite et al., 2019). By shifting mobile learning from an enrichment novelty to an adaptive cognitive scaffold, the intervention effectively bridges the gap between regular learners and students with learning challenges in an inclusive Merdeka Curriculum setting.

The effectiveness of Android-based learning media in improving students' cognitive abilities can be explained through several pedagogical mechanisms. First, the application supports multimedia learning by integrating text, images, audio, and video, in line with the principle that information presented through both verbal and visual channels is processed more effectively than information presented in words alone (Mayer, 2021).

Second, interactive features such as educational games and picture-guessing features provide immediate feedback, which is essential for consolidating learning (Hwang et al., 2020). These findings corroborate evidence that open-access mobile technologies can serve as viable, low-cost alternatives to dedicated assistive technology, effectively fostering learner engagement and autonomy in inclusive classrooms (Fernández-Batanero et al., 2022; Ismaili & Ibrahimi, 2017). By embedding self-paced navigation and visual-auditory scaffolding, the application mitigated extraneous cognitive barriers without requiring expensive assistive equipment

Third, the application allows self-paced learning in line with the principles of differentiated instruction, which are critical for inclusive education (Navas-Bonilla et al., 2025). Students can access the material at their own pace and in their preferred learning style, thereby reducing cognitive overload and increasing engagement (Mayer, 2019). Fourth, because the application is accessible on smartphones, it extends learning beyond the classroom, supports continuity of learning, and increases time on task (van Vliet, 2020).

For students who are slow learners or have special needs, the interactive features of the application, particularly the picture-guessing game and the educational games, are theorized to reduce extraneous cognitive load through several interrelated mechanisms consistent with cognitive load theory (Sweller et al., 2019). First, presenting content through combined visual and auditory channels, rather than text alone, reduces the processing burden of decoding written language, a common source of extraneous load for students with reading difficulties (Mayer, 2021). Second, the self-paced structure of the application allows these students to control the rate at which new information is introduced, helping prevent the working memory overload that can occur when the teacher, rather than the learner, sets the instructional pace (Mayer, 2019). Third, the immediate, game-based feedback in the guessing and quiz features narrows the gap between a student's response and the corrective information, reducing the demand on working memory to retain unresolved

errors until the next opportunity for correction (Hwang et al., 2020). Taken together, these mechanisms suggest that the reduction of extraneous cognitive load in this study was achieved primarily through multimodal presentation, learner-controlled pacing, and immediate feedback, rather than through changes to the intrinsic difficulty of the content. However, this study did not measure cognitive load directly; future research should use validated cognitive load instruments (e.g., subjective mental effort rating scales) to empirically verify these proposed mechanisms among slow learners and students with special needs in inclusive classrooms.

The findings indicate that mobile technology can be a powerful tool for reducing inequality in learning opportunities, particularly for students in inclusive schools with diverse learning needs (Navas-Bonilla et al., 2025). User-friendly, content-rich Android applications can serve as personal tutors, supporting individualized learning pathways.

These findings have several practical implications. Teachers in inclusive elementary schools can use Android-based learning media as a supplementary tool for differentiated instruction, allowing students to review content repeatedly and learn at their own pace both at school and at home. Schools should ensure equitable access by providing shared devices for students without compatible smartphones, as was done in this study. For curriculum developers and local education authorities, the results provide an evidence-based rationale for supporting the development of local-content digital learning media, such as ocean literacy materials, that are aligned with the Merdeka Curriculum.

This study has several limitations. First, it was conducted in a single inclusive school with a relatively small sample (N = 60) and a quasi-experimental design without random assignment; the two classes also differed significantly in initial ability, which was addressed through N-Gain analysis but would be better controlled in future studies using random assignment or analysis of covariance (ANCOVA) with pre-test scores as a covariate. These factors limit the generalizability of the findings. Second, the intervention lasted only nine weeks and covered a single DBR cycle, so the long-term retention of learning gains and the effects of the refined design principles could not be examined. Third, the number of PDBK students in each class was small (n = 2), which precluded separate analysis of the effects on students with different categories of special needs. Fourth, cognitive ability was measured only through a learning achievement test, and cognitive load was not measured directly. Future research should therefore involve multiple schools and larger samples, conduct longitudinal studies with additional DBR cycles, analyze differential effects across categories of special needs, and use validated instruments to measure cognitive load and other cognitive outcomes.

CONCLUSION

This study confirms the effectiveness of Android-based learning media in improving the cognitive abilities of students in an inclusive elementary school, as demonstrated by three main findings: (1) a very high level of product feasibility (M = 4.92 out of 5); (2) a significant difference in post-test learning achievement between the experimental class (M = 66.03) and the control class (M = 45.10), with a large effect size (Cohen's d = 1.68, $p < 0.001$); and (3) a medium normalized gain in the experimental class (N-Gain = 0.45; a 72.85% increase in the mean score) compared with a low normalized gain in the control class (N-Gain = 0.20). These findings suggest that pedagogically designed Android applications can facilitate differentiated instruction, increase student engagement, and reduce gaps in learning opportunities in inclusive schools. In practical terms, teachers can adopt such applications as a learning strategy that supports the implementation of the Merdeka Curriculum, and the findings provide an evidence base for policies on investment in educational technology. Despite these promising results, the short duration of the intervention (nine weeks) and the limited scope of the study (one school) mean that further research is needed, including longitudinal studies, larger samples, and analysis of differential effects across categories of special needs, to improve the generalizability of the findings and to evaluate the sustainability of learning gains in broader inclusive education contexts.

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