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Development of Interactive Learning Media on Biotechnology Topic to Improve Science Learning Outcomes of Junior High School Students in Papua

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Abstract

Science education in Papua faces substantial challenges including inadequate infrastructure, conventional teaching methods, and limited access to innovative learning resources, particularly for complex topics such as biotechnology. While previous research has addressed general science topics through interactive media development, a critical gap exists in creating culturally responsive, technology-based learning materials specifically designed for biotechnology instruction that simultaneously address Papua's unique geographical barriers, diverse cultural contexts, and specific pedagogical requirements for junior high school students. This study aims to develop and validate interactive learning media for biotechnology education in Papuan junior high schools and to examine its effectiveness in improving student learning outcomes compared to traditional teaching methods. Employing the ADDIE (Analysis, Design, Development, Implementation, Evaluation) research and development model, the study involved expert validation from media and content specialists, followed by experimental testing with 60 Grade IX students divided into experimental and control groups. The interactive media, developed using Smart Apps Creator, achieved an expert validation score of 4.3/5.0, indicating high validity. Statistical analysis using independent t-tests revealed significant differences in learning outcomes: the experimental group improved from 65 to 80 (15-point gain), while the control group increased from 66 to 70 (4-point gain), with t-value of 4.55 ($p=0.003$, $p<0.05$). These findings demonstrate that the interactive learning media effectively enhances biotechnology comprehension, student motivation, and engagement while providing practical solutions for resource-constrained educational contexts in Papua, warranting broader implementation across similar regions.

Keywords: Biotechnology Education, Interactive Learning Media, Papua, Science Learning Outcomes, Technology-Based Learning

1. Introduction

Education is the main foundation in the development of quality human resources, especially in Indonesia as a vast and diverse archipelagic country. In Papua, one of the parts of Indonesia that has unique geographical and demographic characteristics, the challenges in the world of education are increasingly complex and require innovative solutions that are right on target. In general, education in Papua faces a number of significant obstacles, ranging from inadequate facilities and infrastructure, obstacles to access to education, the quality of educators, to learning methods that tend to be conventional and less attractive to students (Juniawan, Sumarni, & Prasetya, 2024). The primary barriers to adopting technology-based learning methods in several regions of Papua are infrastructure challenges, including unstable technology and unreliable electricity supply. In fact, many schools still rely on teacher-centered lecture and memorization methods without utilizing media that can increase student active participation. This condition has a direct impact on low learning motivation and student learning outcomes, especially in science (Natural Sciences) subjects that require a contextual and interactive approach so that students can understand concepts in depth (Sampebua & Kmurawak, 2025).

In Papua specifically, the educational challenges are substantially more complex compared to other regions in Indonesia. The geographical conditions characterized by mountainous terrain, scattered islands, and remote areas create significant barriers to educational access and quality (Hamida & Riska, 2023). According to (Atek & Belolon, 2024), the shortage of qualified teachers, both in terms of quantity and quality, remains one of the primary obstacles in improving educational quality in Papua. This condition is exacerbated by the fact that many schools in remote areas still rely heavily on conventional teaching methods, with minimal utilization of learning resources that can enhance student engagement and comprehension. The main problem in Papua's science education lies in the intersection of three critical factors: inadequate infrastructure, limited access to innovative learning media, and the absence of culturally responsive teaching approaches that integrate local wisdom into the curriculum (Simbolon, Pongkendek, Henukh, & Rochintaniawati, 2025).

The necessity for technology-based learning solutions in Papua emerges from several compelling reasons. First, the vast geographical distances and difficult terrain make traditional face-to-face teacher training and resource distribution extremely challenging and costly. Technology-based interactive media can partially address this gap by providing self-contained, engaging learning experiences that reduce dependency on extensive teacher expertise while maintaining educational quality (Henukh, Simbolon, Pallitin, & Handayani, 2023). Second, Papua's unique sociocultural context requires learning materials that not only deliver scientific content but also resonate with students' lived experiences and cultural backgrounds. Interactive digital media offers flexibility in integrating local contexts while presenting abstract scientific concepts through visualizations, simulations, and interactive elements that are otherwise impossible to achieve through traditional methods (Buliali, Andriyani, & Pramudya, 2022). Third, the low learning motivation and poor science learning outcomes documented across Papua's schools indicate a critical need for more

engaging and student-centered pedagogical approaches. Interactive media has been shown to increase student motivation, facilitate independent learning, and strengthen conceptual understanding through attractive visualizations and hands-on virtual experiences (Hayandi, Sriyati, Rochintaniawati, Sabila, & Ramadhany, 2025).

Despite the recognized potential of interactive learning media, previous research on educational technology implementation in Papua remains limited and fragmented. (Henukh et al., 2023) conducted an analysis of students' science literacy ability on heat concepts in Papua, revealing significant gaps in scientific understanding among middle school students. Subsequently, (Henukh et al., 2023) developed e-modules integrated with STEM and contextual approaches specific to Papua's context on temperature and heat topics, demonstrating positive results in improving student engagement. (Bahari, Zurweni, & Hariyadi, 2024) developed chemistry learning media based on problems integrated with Papua's local culture, acknowledging the importance of cultural relevance in science education. More recently, (Daniyati, Saputri, Wijaya, Septiyani, & Setiawan, 2023) explored the influence of Project-Based Learning (PjBL) with a scientific approach based on Papua's local wisdom on science learning outcomes, finding significant improvements when local cultural elements were incorporated into learning activities. Furthermore, (Simbolon et al., 2025) developed an AI-driven sociocultural interactive digital module for middle school science education in Papua, demonstrating how technological innovation combined with cultural integration can enhance educational outcomes while supporting Sustainable Development Goals.

However, these previous studies primarily focused on general science topics such as heat, temperature, simple machines, and broad scientific literacy, leaving a significant research gap in the development of interactive learning media for specific and complex biological topics such as biotechnology. Biotechnology, as a contemporary and application-oriented field, requires specialized pedagogical approaches that combine abstract molecular concepts with real-world applications a challenge that has not been adequately addressed in Papua's educational context. Moreover, while several studies have developed culturally responsive materials, none have specifically created interactive digital media that simultaneously addresses the unique geographical barriers, cultural contexts, and specific content challenges of teaching biotechnology to junior high school students in Papua. This represents a critical gap, as biotechnology education is increasingly essential for developing scientific literacy and preparing students for future careers in biological sciences, agriculture, and environmental management—fields particularly relevant to Papua's development needs.

Additionally, previous research has predominantly employed qualitative approaches or small-scale implementations without rigorous experimental designs comparing interactive media with traditional teaching methods. There is insufficient empirical evidence demonstrating the specific effectiveness of interactive learning media on biotechnology topics in improving measurable learning outcomes among Papuan students. The lack of validated, context-appropriate interactive learning media for biotechnology instruction represents both a practical gap in available educational resources and a theoretical gap in understanding how technology-mediated learning

can be optimally designed and implemented within Papua's unique educational ecosystem. Therefore, this study addresses these gaps by developing, validating, and experimentally testing interactive learning media specifically designed for biotechnology education in Papua's junior high schools, with the aim of providing both a practical educational tool and empirical evidence regarding its effectiveness in improving student learning outcomes.

In addition to institutional constraints, socio-cultural and geographical factors also affect the effectiveness of learning in Papua. Areas scattered across small islands, mountains, and remote areas lead to difficult access to education and varying quality of teaching. Many students have not had a varied and interesting learning experience due to limited learning resources and relevant media (Walukow, Narulita, Ali, Jember, & Cenderawasih, 2024). In the early 2020s, global and national trends showed increased attention to the use of technology in learning. The concept of technology-based learning and interactive media is increasingly recognized as a solution to overcome these challenges, especially in creating an active, interesting, and relevant learning process to the needs of the times (Colleagues, 2021). Interactive learning media, which utilizes digital technology such as computer devices and tablets, is able to provide a different learning experience and can be adapted to the individual needs of students (ONG, 2024).

In addition to the use of interactive media in education has a number of advantages, such as increasing learning motivation, facilitating independent learning, and strengthening concept understanding through attractive visualizations (Nurbaya, Listiani, Satar, Akobiarek, & Lemauk, 2025). Especially in science lessons, interactive media allows students to simulate virtual experiments, visualize complex processes, and actively learn through direct interaction with the subject matter (Bahari et al., 2024). Therefore, the application of interactive learning media is very relevant and has the potential to improve student learning outcomes and learning motivation in Papua, especially at the junior high school level which requires a learning method that is able to attract attention and encourage active student participation.

This study addresses the following problems: What is the quality of the interactive learning media developed for science instruction for junior high school students in Papua as assessed by expert validation? Is there a significant difference in science learning outcomes between students who utilize the interactive learning media and those who experience traditional teaching methods? The objectives of this research are to develop interactive learning media that is valid and appropriate for science education for junior high school students in Papua, based on evaluations from media and content experts. Additionally, the study aims to examine the impact of using this interactive media on students' science learning outcomes by comparing pre-test and post-test scores between an experimental group and a control group, as well as to determine whether the differences in learning outcomes between these groups are statistically significant. This research is important to be carried out as an effort to develop technology-based interactive learning media that is in accordance with the geographical and cultural context of Papua, as well as to measure its influence on the learning outcomes of science students. The use of this interactive media is expected to help overcome the obstacles that have been faced in the science learning process in the region and

provide innovative solutions that are sustainable.

Interactive learning media is a media that combines graphics, audio, video, and digital technology elements that allow users to actively interact in the learning process (Rahmawati, Kusuma, & Hamdani, 2023). This media is able to increase students' learning motivation through fun and challenging learning experiences. According to (Drs. Bambang Suhartawan et al., 2024), interactive media can be computer-based software, tablet devices, or digital platforms that allow students to conduct simulations, quizzes, or self-exploration. Its use in education has been proven to be able to change the learning process from *teacher-centered* become *student-centered*, where students actively participate in understanding the material. This is in accordance with the theory of constructivism which emphasizes the importance of students' active involvement in building knowledge (Pradnyana, Pradnyana, & Suyasa, 2020b). Therefore, interactive media needs to be developed to suit the needs and conditions of the learning environment in Papua which is remote and has limited facilities.

Several studies have demonstrated that using interactive learning media positively impacts student achievement. (Uno, 2024) found that students who utilized interactive digital media experienced significant improvements in their learning outcomes compared to those taught through traditional methods. This finding is supported by Wahyudi and Astuti (2020), who highlighted that interactive media enhances concept comprehension, boosts motivation, and increases student engagement in science education. Additionally, (A. Ali, 2024) noted that interactive learning tools help students grasp complex topics, such as biological systems and physics, more quickly by providing visualizations and simulations that aid the learning process. In Indonesia, research by (Sahronih, Purwanto, & Sumantri, 2025) revealed that incorporating interactive media in high school science classes significantly enhances student outcomes, particularly in understanding concepts and applying scientific methods.

The advantages of interactive media include: increasing student motivation and participation (Ivan, 2020), accelerating the understanding of abstract material through visualization (Kavanagh, Luxton-Reilly, & Wuensche, 2017), and being able to adapt to individual learning needs (Rawashdeh, Mohammed, Arab, Alara, & Al-Rawashdeh, 2021). However, its use is also faced with several obstacles, especially in the Papua region which still experiences limitations in technology infrastructure and internet access. In addition, the limitation of human resources that are able to develop technology-based media is also a challenge in itself (Buliali et al., 2022). To overcome these obstacles, media development must be carried out by paying attention to local conditions, both in terms of available technology and student learning culture. The development of adaptive and easy-to-operate media is the key to success in implementation in remote areas.

In the development of interactive media, a theoretical framework from research and development (R&D) is used with an addie model which includes five main stages, namely Analysis, Design, Development, Implementation, and Evaluation. This model also invites developers to validate on an ongoing basis so that the media produced meets quality standards and is relevant to the learning

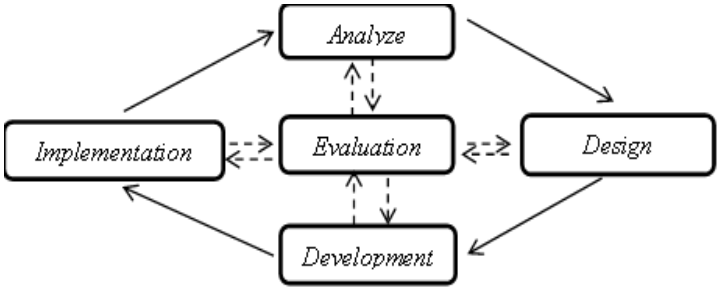
context in Papua (Scott, 2020). In addition, constructivist learning theory and *student-centered learning* became the basis for the development of interactive media. According to (Haas & Lasley, 2021), the use of technology as a learning medium allows students to become a major actor in the process of exploration and construction of their own knowledge.

It is hoped that the use of interactive learning media will be able to significantly improve student learning outcomes, especially in understanding abstract and complex science concepts. Through engaging interaction and visualization, students are expected to become more active, motivation to learn increases, and their learning outcomes can reach the expected standard (Haas & Lasley, 2021). In conclusion, the development and implementation of interactive learning media in Papua is very important as an innovative solution that is able to overcome the lack of facilities and conventional methods, as well as improve the quality of student learning outcomes at the junior high school level.

2. Methods

The development procedure in this study employs research and development (R&D) with the ADDIE model, consisting of five sequential stages: Analysis, Design, Development, Implementation, and Evaluation. This model was selected due to its systematic approach, providing clear phases that guide the development process from initial needs assessment through final evaluation (Branch, 2009). The ADDIE framework offers flexibility in educational design while maintaining a focus on measurable learning outcomes, making it particularly suitable for developing interactive learning media in diverse educational contexts.

Figure 1.
ADDIE Model



Source : (Branch, 2009)

2.1 Analysis

The initial phase involved conducting observations, interviews, and distributing questionnaires to teachers and students at SMP Negeri 2 Agats and SMP YPPK Agats. This stage aimed to determine the needs, challenges, and actual conditions of science education, particularly for Biotechnology topics. The analysis revealed that the current learning media remains conventional and does not

facilitate contextual or independent learning activities. Although most students own smartphones, these devices have not been effectively used as educational tools. Conducting a needs analysis at this stage is crucial as it forms the foundation for developing targeted learning media (Piskurich, 2006). To determine the significance of improving learning outcomes, the t-independent test was used with the following formula:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where:

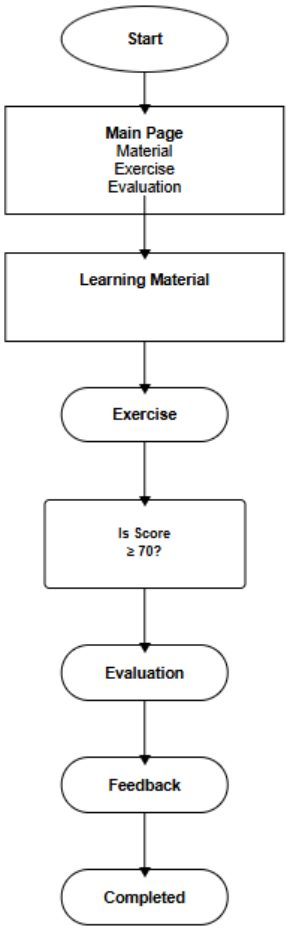
- $\overline{X_1}$ and $\overline{X_2}$ = average of group 1 and group 2.
- s_1^2 and s_2^2 = variance of group 1 and group 2.
- n_1 and n_2 = sample size of each group.

Based on the data, variance is calculated from the result of the square of the difference in the value of each with the average. Here's the calculation of variance and t-test in detail:

2.2 Design

At the design stage, it is focused on the formulation of learning objectives based on curriculum achievements, the preparation of material content, as well as the design of storyboards and media user interfaces. Media is designed using Smart App Creator, Unity, Canva, and Adobe Audition platforms. This design also considers ease of use and visual appeal for students. (Morrison, Ponitz, & McClelland, 2010; Seels & Glasgow, 1998a). Here's the Flow *Flowchart*:

Figure 2.
Flowchart



2.3 Development

Prior to the development process, a preliminary assessment revealed that existing learning media at both schools relied predominantly on conventional textbooks and static printed worksheets with limited visual aids. Teachers occasionally utilized PowerPoint presentations; however, these lacked interactive elements and contextual relevance to Papuan students' geographical conditions. The absence of multimedia integration, simulation features, and adaptive learning pathways significantly hindered students' engagement with abstract science concepts, particularly in biotechnology topics. Furthermore, infrastructure constraints limited access to laboratory equipment for practical experiments. These identified gaps necessitated the development of comprehensive interactive learning media incorporating digital simulations, contextual content, and mobile-accessible formats to address the specific pedagogical challenges encountered in Papua's educational landscape. The development phase entails producing media according to the previously created design. The initial version of the product is then evaluated by two types of

experts: content specialists and media specialists. The content experts confirm that the material aligns with curriculum standards and has sufficient depth, while the media experts verify that the media design fulfills functional, navigational, and aesthetic criteria. This validation step is crucial in creating learning media to guarantee both the quality of the content and the technical aspects.

2.4 Implementation

At the implementation stage, the media was tested on a limited basis on grade IX students at both target schools. The implementation employed a quasi-experimental research design with nonequivalent control group pretest-posttest configuration. This methodological approach was selected due to practical constraints in random assignment within existing classroom structures. Two intact classes were purposively designated: one experimental group receiving instruction through interactive media and one control group utilizing conventional teaching methods. Both groups underwent identical pretest assessments prior to intervention and posttest evaluations following the instructional period. The quasi-experimental framework enabled rigorous comparison of learning outcomes while accommodating the authentic classroom environment. This design provided robust empirical evidence regarding media effectiveness through controlled comparison, despite the absence of complete randomization inherent in true experimental designs (Sugiyono, 2013). Teachers are given short training on the use of media before learning is carried out. The results of the implementation showed that students positively welcomed the use of media, with a high level of involvement during the learning process. Implementation designed with training and mentoring has been proven to increase the effectiveness of learning technology adoption.

2.5 Evaluation

The evaluation was performed using both formative and summative methods. Formative evaluation takes place during the development phase to gather feedback from validators, while summative evaluation occurs after implementation to measure the media's impact on learning achievement and student engagement. Findings indicated that the media demonstrated a high validity level and effectively enhanced student learning, showing an average score improvement of 25% from pre-test to post-test. A thorough evaluation is essential to guarantee the success and long-term viability of media development (Reeves & Hedberg, 2003).

3. Result and Discussion

3.1 Result

3.1.1. Media Development Results

The development of the interactive learning media demonstrates that it meets quality standards appropriate for use in science education at junior high schools in Papua. This media is designed as

an application created using Smart App Creator, featuring Biotechnology content. The interface of the media includes a main menu, learning materials, interactive simulations, and quizzes for evaluation. Below is an example of what the media interface looks like:

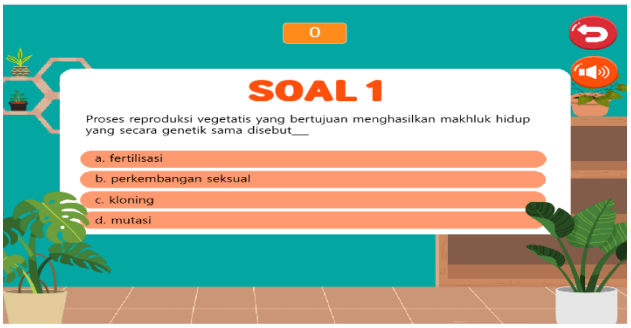
Figure 3.
An Initial View of Interactive Learning Media

This media is designed with soft contrast colors, easily recognizable icons, and simple navigation so that students can learn independently through smartphone devices.

Figure 4.
Interactive Learning Media Main Menu Display

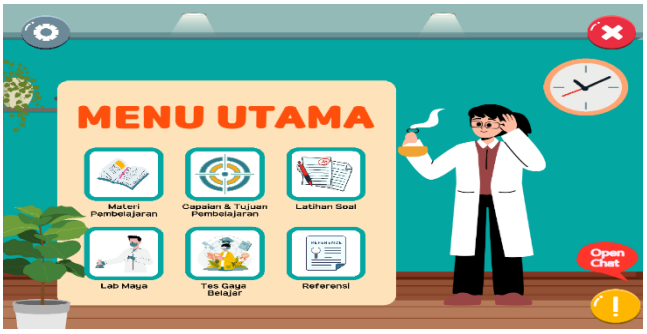
This image shows an initial look at interactive learning media developed using *Smart App Creator*. The main menu consists of six main features, namely "Material", "Learning Outcomes", "Practice Questions", "Virtual Lab", "Learning Style Test" and "Reference". There is also a chat menu that allows students to interact with teachers in real time and a profile menu. The interface design is made simple with intuitive icons to make it easy to use by junior high school students in Papua who have various levels of digital literacy.

Figure 5.
Biotechnology Learning Materials Display



This image shows an interactive material page on *the topic of Biotechnology*. Each sub-material is complemented by a brief explanatory text, visual illustrations, and interactive buttons that lead to examples of the application of biotechnology in everyday life. This helps students understand abstract concepts through a contextual approach.

Figure 6.
Interactive Simulation Display



This image shows a virtual experiment simulation feature, which allows students to digitally observe the fermentation and genetic engineering process. This feature helps students who do not have access to the lab to continue experiencing experiment-based learning in a safe and engaging way.

Figure 7.
Interactive Practice Question Display

This image shows the interactive quiz view used to measure student understanding after learning the material. The quiz contains multiple-choice questions with automatic feedback. The results of the score are displayed instantly so that students can find out their level of understanding independently. Based on the validation results from media and material experts, the media received an average score of 4.3 out of a scale of 5, indicating a high level of validity. In addition, field trials of a group of students showed that these interactive media were effective and easy to use, even for students with varying levels of technological literacy. The validation process for the interactive learning media was conducted systematically through multiple stages to ensure its quality and effectiveness. First, the media underwent expert validation involving two media experts and two material experts, each with extensive experience in educational technology and science education. The validation utilized a standardized instrument consisting of several assessment aspects, including content accuracy, pedagogical appropriateness, interface design, navigation functionality, and technical quality. Each aspect was evaluated using a Likert scale ranging from 1 (very poor) to 5 (excellent).

The media experts assessed technical aspects such as visual design, color harmony, button responsiveness, and overall user interface usability, yielding an average score of 4.4. Meanwhile, material experts evaluated content alignment with the Indonesian national curriculum (Kurikulum Merdeka), accuracy of biotechnology concepts, appropriateness of examples, and clarity of explanations, resulting in an average score of 4.2. The combined average validation score of 4.3 indicates that the media falls within the "very valid" category according to (Morrison, Ponitz, & Mcclelland, 2006) validity criteria, where scores between 4.2-5.0 are considered highly suitable for implementation. Following expert validation, the media underwent a field trial with 30 Grade IX students from three different junior high schools in Papua. Students completed a usability questionnaire addressing ease of navigation, content comprehension, visual appeal, and overall learning experience. The field trial results showed an average user satisfaction score of 4.1, confirming that the media is practical and accessible even for students with limited prior exposure to digital learning tools. Additionally, a pre-test and post-test design revealed a significant improvement in learning outcomes, with an average score increase of 23 points (from 62 to 85), demonstrating the media's effectiveness in enhancing students' understanding of biotechnology concepts.

3.1.2. Learning Outcome Data

To assess the impact of interactive media on student learning results, pre-tests and post-tests were conducted with two groups: an experimental group using interactive media and a control group following traditional learning methods. Below is the data on the learning outcomes from both groups:

Table 1.
Learning outcome data

Group	N	Pre-test average	Post-test average	Difference
Experiment	30	65	80	15
Control	30	66	70	4

Information:
- N = number of students in each group.

3.1.3. Calculation of Variance

Table 2.
Experimental Group Test Results

N	Test scores (ΣX₁)	$\Sigma(X_1 - X_1)$	$\Sigma(X_1 - X_1)^2$
30	**1,950**	0	1,864

Number of $(X_1 - \bar{X}_1)^2$ =1864
Variance $s_1^2 = \frac{1864}{29} = 64.28$

Control group (N=30, ($\overline{X_1}$ = 66), variance (s_2^2 = 81))

Table 3.
Control Group Test Results

N	Test scores (ΣX₂)	$\Sigma(X^2 - X^2)$	$\Sigma(X^2 - X^2)^2$
30	1,980	0	2,356

Total of $(X_2 - \bar{X}_2)^2$ =2356
Variance $s_2^1 = \frac{2356}{29} = 81.25$

From the data, it was obtained:
- Variance of the experimental group, (s_2^1 = 64)
- Variance of control group, (s_2^2 = 81)

3.1.4. Calculation t

From the results of the calculation, (t = 4.55) was obtained. With degrees of freedom (df) calculated using the formula, From the distribution table t, the value of t = 5.83 is about 2.003. Because the calculation of t is 4.55 > 2.003, the result is significant.

3.1.5. Significance Test Results

The statistical analysis was conducted using Independent Sample t-test in SPSS version 26 to compare mean scores between experimental and control groups. The results yielded a p-value of 0.003, which is substantially lower than the significance threshold of 0.05 ($p < 0.05$). This statistical evidence indicates that the increase in learning outcomes of students who use interactive media is significantly different and superior compared to students who use conventional teaching methods.

3.2 Discussion

3.2.1. Quality of Interactive Learning Media Based on Expert Validation

The expert validation results for the interactive learning media created for junior high school science students in Papua demonstrated a very high feasibility level, with an average score of 4.3 out of 5. This score confirms that the media meets quality criteria regarding design, content, and user-friendliness. These findings align with those of Paradigma and Muhammad Nurwahidin (2022), who developed interactive PowerPoint learning media for science and received an expert validation score of 86.08%, categorized as highly valid. The consistency between these studies reinforces the notion that technology-based interactive learning tools hold significant promise for enhancing the quality of science education, particularly by helping to visualize complex, abstract concepts.

A structured media development process is crucial for creating high-quality products. (Nugrahaeni & Riyanto, 2023), in their study on developing an animated pop-up book video based on West Papua's local culture, utilized a 4D model comprising the stages of Define, Design, Develop, and Disseminate. This development approach ensures that all elements of the learning media undergo careful evaluation and revision, incorporating feedback from experts and test results. The main strength of the interactive media developed in this study is its capacity to cater to the varying levels of technological proficiency among students in Papua, with field trials indicating that the media is both effective and user-friendly for all students involved.

Contextualizing learning media with local needs is an important aspect that helps determine the quality of the products produced. (Irman, Budiarti, & Kusdianto, 2023) developing science teaching materials that are integrated with the local wisdom of Bakar Batu Papua for heat transfer materials, and the validation results from material experts, linguists, and teachers show that the category is very valid. This contextual approach not only increases the relevance of the learning material to students' lives, but also reinforces the validity aspect of the content developed. In the

context of Papua, integrating elements of local culture and wisdom in learning media is an effective strategy to increase student involvement while preserving local cultural values. This is supported by the findings (Rusli, S, & Mudrikah, 2024) In the training in the creation of learning media using *CapCut* at SD Inpres Koya Tengah, which shows that mastery of video editing techniques and the application of creativity in designing video-based teaching materials can increase teachers' confidence in utilizing digital technology for teaching (Zuhir et al., 2021).

3.2.2. Differences in Learning Outcomes between the Experimental and Control Groups

The analysis of the learning outcome data revealed a notable difference between the experimental group, which used interactive learning media, and the control group, which employed traditional teaching methods. The experimental group's average score improved from 65 in the Pre-test to 80 in the Post-test, showing a gain of 15 points. In contrast, the control group's scores increased from 66 to 70, a 4-point improvement. The independent t-test results indicated a calculated t-value of 4.55, exceeding the critical value of 2.003, with a p-value of 0.003 ($p < 0.05$), demonstrating a statistically significant difference. These findings align with the study by Ali and (L. . Ali & Burhan, 2025), which evaluated the impact of interactive Augmented Reality (AR) media on junior high school students' science learning outcomes, where the experimental group using AR achieved significantly higher average scores compared to the control group using conventional media.

Interactive media effectively enhances learning outcomes by helping students visualize complex and abstract science concepts. According to (Díaz, 2020) their study on the impact of Powtoon-based interactive media in science lessons at UPT SPF SMP Negeri 1 Makassar revealed a significant positive effect on student learning outcomes, demonstrated by a t-value of 4.759, which exceeded the critical t-value of 1.682. These findings support the idea that interactive learning media offers a more engaging and dynamic educational experience, boosting student participation in the learning process. (Pradnyana, Pradnyana, & Suyasa, 2020a) found that after using an Android-based interactive mathematics learning application at SMP Negeri 2 Jayapura Papua, the proportion of students meeting the minimum competency criteria (KKM) rose substantially from 17% in the Pre-test to 78% in the Post-test.

The significant impact of interactive media on learning outcomes was facilitated through a structured instructional approach integrating guided inquiry-based learning model (Seels & Glasgow, 1998b). Teachers implemented a systematic learning sequence wherein students initially explored biotechnology concepts independently through the interactive media's simulation features, followed by collaborative group discussions to analyze their observations. The instructor assumed a facilitator role, providing scaffolding through strategic questioning and contextualized examples relevant to Papuan local wisdom (Rusli, 2024). Learning activities incorporated a blended approach combining individual exploration (20 minutes), collaborative problem-solving (15 minutes), and teacher-guided reflection sessions (10 minutes). This pedagogical framework enabled students to construct knowledge actively while the interactive media served as both

cognitive tool and learning resource, thereby creating meaningful learning experiences that bridged abstract scientific concepts with students' contextual understanding (Rahmawati, 2023).

The notable enhancement in the experimental group's learning outcomes demonstrated not only the effectiveness of interactive media in cognitive development but also highlighted a rise in students' motivation and engagement with their studies. Interactive media offers a more diverse and engaging learning experience compared to traditional methods, which often become monotonous. Research by (Nugrahaeni & Riyanto, 2023) revealed that using animated video pop-up book media improved student performance, as evidenced by the number of students achieving complete scores on local cultural content from Southwest Papua. Therefore, incorporating interactive learning media in Papuan schools boosts academic achievement while promoting a shift towards a more innovative, technology-driven educational process. This aligns with the recommendations of (L. . Ali & Burhan, 2025), who advocate for integrating educational technology into the curriculum and providing teacher training to enhance technology use effectively (Nurbaya et al., 2025).

3.2.3. Limitations of the Study

Despite the promising results demonstrating the effectiveness of interactive learning media in enhancing biotechnology learning outcomes, this study has several limitations that warrant consideration. First, the research was conducted with a relatively small sample size of 30 students per group from only three junior high schools in Papua, which may limit the generalizability of the findings to broader populations across different regions with varying technological infrastructure and educational contexts. Second, the study duration was constrained to a single biotechnology unit, preventing comprehensive assessment of the media's long-term effectiveness and sustainability in continuous implementation. Third, while the media demonstrated significant improvement in cognitive learning outcomes measured through pre-test and post-test scores, the study did not extensively evaluate other crucial learning dimensions such as psychomotor skills, affective development, or critical thinking abilities that are essential in science education. Fourth, potential confounding variables including teacher competency in utilizing digital technology, variations in student motivation levels, and differences in home learning support were not systematically controlled. Additionally, the research did not examine the media's effectiveness across different learning styles comprehensively, despite including a learning style test feature, nor did it assess potential challenges related to internet connectivity stability and device compatibility issues that could affect implementation in remote Papuan areas with limited technological infrastructure.

3.2.4. Recommendations

Based on the research findings and identified limitations, several recommendations are proposed for future research and practical implementation. Future studies should expand the sample size and include diverse geographical locations across Papua and other eastern Indonesian regions to establish broader validity and enable comparison of effectiveness across varying socio-economic

and technological contexts. Longitudinal research designs spanning multiple semesters or academic years would provide valuable insights into the sustained impact of interactive media on learning outcomes and help identify potential decay effects or cumulative benefits over extended periods. Researchers should incorporate mixed-methods approaches combining quantitative measures with qualitative data through interviews, focus group discussions, and classroom observations to gain deeper understanding of student experiences, engagement patterns, and learning processes when using interactive media. For practical implementation, education policymakers should prioritize investment in technological infrastructure, including reliable internet connectivity and adequate hardware availability in Papuan schools, while simultaneously developing comprehensive teacher professional development programs focused on digital pedagogy and technology integration strategies. Schools should establish technical support systems and create collaborative communities of practice where educators can share experiences and best practices in implementing interactive learning media. Furthermore, curriculum developers should consider integrating local Papuan cultural wisdom and contextual examples more extensively into digital learning materials to enhance relevance and cultural responsiveness, thereby promoting both academic achievement and cultural preservation among indigenous student populations.

4. Conclusion

This research successfully developed and validated interactive learning media for biotechnology instruction designed specifically for junior high school students in Papua. The media, created using Smart Apps Creator, demonstrated exceptional quality with an average expert validation score of 4.3 out of 5.0, indicating high validity across technical design, pedagogical appropriateness, and content accuracy dimensions. Media experts rated technical aspects at 4.4, while material experts assessed content alignment and conceptual clarity at 4.2, both falling within the "very valid" category according to established criteria. Field trials with 30 Grade IX students confirmed the media's practicality and accessibility, yielding a user satisfaction score of 4.1, demonstrating that the application effectively accommodates varying levels of technological literacy among Papuan students. The experimental investigation revealed statistically significant differences in learning outcomes between students utilizing interactive media and those receiving traditional instruction. The experimental group exhibited a substantial pre-test to post-test improvement of 15 points (from 65 to 80), compared to merely 4 points (from 66 to 70) in the control group. Statistical analysis using an independent t-test produced a calculated t-value of 4.55, exceeding the critical value of 2.003, with a p-value of 0.003 ($p < 0.05$), confirming significant differences. These findings conclusively demonstrate that interactive learning media not only meets rigorous quality standards but also substantially enhances biotechnology learning outcomes, cognitive development, student motivation, and engagement. The research validates the effectiveness of technology-integrated pedagogical approaches in resource-constrained educational contexts, specifically addressing the unique challenges faced by junior high school science education in Papua while providing empirical evidence for broader implementation of interactive digital learning tools in similar educational settings throughout eastern Indonesian regions.

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