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META-ANALYSIS: THE EFFECTIVENESS OF DIGITAL TECHNOLOGY IN BIOLOGY LEARNING IN INDONESIA

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ABSTRACT

The development of digital technology has made a significant contribution to the transformation of biology learning in Indonesia. This study aims to analyze the effectiveness of using digital technology on learning outcomes of senior high school students. The method used is a meta-analysis of 20 relevant research articles published between 2020 and 2025. The data analyzed consists of average learning outcomes of experimental and control classes, which were then calculated using effect size. The results indicate that digital technology is generally effective in improving biology learning outcomes across all senior high school levels, with a higher tendency of effectiveness in upper-level classes. Furthermore, the type of digital technology-based media also influences the level of effectiveness, where interactive, visual, and immersive media such as artificial intelligence, audiovisuals, and virtual laboratories have a greater impact compared to less interactive media. Therefore, the utilization of digital technology in biology learning needs to be adjusted to the characteristics of the material and students, and supported by teacher competence to ensure optimal learning.

Keywords: Learning Outcomes; Digital Technology; Biology Learning; Meta-Analysis; Effect Size.

INTRODUCTION

The development and advancement of global technology have influenced various aspects of life, including politics, economy, culture, arts, and even education. Rapid technological progress in line with the times demands the integration of technology into learning processes in the era of Industry 4.0 and Society 5.0 to enhance the quality of education (Wulandari, 2023). Education in the 4.0 revolution era responds to industrial developments that require curriculum adjustments to current conditions, aiming to broaden global perspectives through the use of digital technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) (Yoan & Siahaan, 2023). These changes have shifted learning from teacher-centered learning to student-centered learning, aligning with the demands of the 21st century that position students as active subjects. Moreover, 21st-century education emphasizes critical thinking, collaboration, communication, and creativity (Firmansyah & Jiwandono, 2022).

In Indonesia, digital transformation in education is realized through various government policies related to school digitalization and the utilization of educational technologies. The use of Learning Management Systems (LMS), e-learning, instructional videos, and virtual laboratories has increasingly developed, particularly since the COVID-19 pandemic, which accelerated the widespread implementation of online learning (Siti Rokhmah, 2025). However, the implementation of educational digitalization in Indonesia still faces several challenges, such as technological access gaps across regions, limited infrastructure, and uneven teacher readiness and digital literacy. This indicates that although digital transformation has occurred, efforts to improve quality and equity still need to be continuously pursued (Noor Ginanjar Jaelani & Prapantja, 2026).

Biology learning has specific characteristics involving many abstract and complex concepts, which are often difficult for students to understand without visual aids (Zahren et al., 2025). Materials involving microscopic processes or extensive systems require visualization, such as simulations and animations, to prevent misconceptions (Indah & Fadilah, 2024). The use of digital technologies, such as virtual laboratories and interactive media, has been shown to present biological phenomena more concretely and dynamically (Mahdingin, 2025). This technology integration not only improves conceptual understanding but also equips students with relevant digital literacy skills (Ifadah & Prastiwi, 2022).

Previous studies have shown that the implementation of digital technology and artificial intelligence is effective in significantly improving student learning outcomes and motivation (Purwanti & Suwardi, 2025). Nevertheless, meta-analysis results indicate variations in effectiveness, where some media have a very strong impact, while others provide only moderate effects (Wijayanto, 2023). This inconsistency is often caused by differences in research design, educational levels, and technical constraints, such as infrastructure limitations and teacher competence in the field (Afriyanty et al., 2024).

The variation in research results shows that the effectiveness of digital technology in biology learning cannot yet be concluded comprehensively. Therefore, a quantitative synthesis is required to provide a more comprehensive overview in the context of Indonesia. This study aims to analyze the effectiveness of digital technology in biology learning in Indonesia through meta-analysis by calculating effect sizes from various studies and examining the influence of educational level and technology type as moderator variables, thereby obtaining a more objective picture of the contribution of digital technology to improving biology learning outcomes.

RESEARCH METHODS

The research method used is a meta-analysis utilizing secondary data obtained from relevant research articles. The data consist of posttest scores from experimental and control classes in studies on the use of digital technology in biology learning at the senior high school level in Indonesia. The articles used were sourced from national journals published between 2016 and 2025, totaling 20 articles that met the research criteria.

The research stages consisted of preparation, implementation, and data analysis. The preparation stage involved collecting articles from various educational journals using keywords such as “digital technology in biology learning,” “digital biology learning media,” and “ICT-based learning technology,” adjusted to the senior high school level. Articles were then selected based on topic relevance and completeness of data.

The implementation stage involved collecting and summarizing data, including the researcher’s name, year of study, type of research, type of digital technology-based media, class level, and the

average posttest scores of experimental and control classes. This data was organized in tabular form to facilitate analysis.

The distribution of the 20 research article subjects can be seen in the groups presented in Table 1.

Table 1. Article Sample Distribution

Author	Year	Type of Research	Type of Digital Technology-Based Media	Senior High School Class Level
Fajri & Ningsih	2022	Experimental	Google Classroom	X
Kresnandya	2020	Experimental	Video	X
Darmawan	2020	Experimental	KAHOOT	X
Rihi *et al.*	2022	Experimental	Laboratorium Virtual	XI
Nirva	2018	Experimental	Video	XI
Nasution	2022	Experimental	Canva	X
Saputra	2021	Experimental	*Audio Visual*	XI
Mispa *et al.*	2022	Experimental	E-LKPD	X
Maryam *et al.*	2025	Experimental	*Virtual Reality* (VR)	X
Rezeki et al	2022	Experimental	E-LKPD	X
Setiawati *et al.*	2025	Experimental	*Flipbook*	XI
Syafitri et al	2025	Experimental	Infografis	XI
Siagian & Abdullah	2025	Experimental	Kahoot	XI
Hadarmawandi *et al.*	2025	Experimental	*ChatGPT*	X
Astuti	2022	Experimental	*Power Point*	X
Sari	2021	Experimental	*Leaflet*	X
Jauhariningsih	2023	Experimental	*Google classroom*	XI
Petriana *et al.*	2024	Experimental	Laboratorium Virtual	XII
Shafira & Suratsih	2025	Experimental	E-LKPD	XI
Azis *et al.*	2017	Experimental	Video	X

The analysis stage was conducted by calculating the effect size (ES) using Cohen's formula (Cohen et al., 2018):

$$ES = \frac{M_e - M_C}{SD}$$

Note:

ES = Effect size value;
Me = Mean score of the experimental class;
Mc = Mean score of the control class;
SD = Pooled standard deviation.

The pooled standard deviation value is calculated using the formula:

$$SD_{pooled} = \sqrt{\frac{(N_e - 1)SD_e^2 + (N_c - 1)SD_c^2}{N_e + N_c - 2}}$$

Note:

SD pooled = Pooled standard deviation value;
Ne = Number of students in the experimental class;
Nc = Number of students in the control class;
Sde = Standard deviation value of the experimental class;
SDc = Standard deviation value of the control class.

The calculation results will yield the effect size (ES) value, which is then interpreted using a table of ES value categories. Based on the interpretation of these effect categories, the effect or impact of using digital technology in biology learning on senior high school students' learning outcomes in Indonesia can be determined. The ES criteria can be seen in Table 2 (Cohen et al., 2018) below.

Table 2. Effect Size (ES) Value Criteria

Effect Size	Description
0,00 - 0,20	Has a weak impact
0,21 - 0,50	Has a low impac
0,51 - 1,00	Has a moderate impact
> 1,00	Has a high impact

RESULTS AND DISCUSSION

The distribution of research on the use of digital technology based on senior high school grade levels is presented in Table 3.

Table 3. Distribution of Class Levels in Senior High School

Class Level	Frequency	Relative Frequency (%)	Δ
X	11	55	1,14
XI	8	40	1,23
XII	1	5	1,28

The results of the meta-analysis indicate that the implementation of digital technology in biology learning was predominantly carried out in grades X and XI, while in grade XII it remains relatively limited. This suggests that the use of digital media tends to be focused on the early to intermediate stages of learning, which plays an important role in establishing an understanding of basic biology concepts.

However, the effect size values show a tendency to increase in higher grade levels. This finding indicates that students' cognitive maturity affects the optimization of digital technology use, particularly in understanding complex and abstract biology material. This aligns with Firmansyah and Jiwandono (2022), who stated that critical thinking skills develop alongside higher educational levels. Moreover, students' digital literacy also influences the effectiveness of technology-based learning. Students in higher grades generally have better experience in using technology, enabling them to optimize the use of digital media in the learning process. This finding is supported by Ifadah and Prastiwi (2022), who noted that digital literacy contributes to the increased effectiveness of technology-based learning.

The distribution of ICT-based media types and their effect sizes is presented in Table 4 below.

Table 4. Distribution of Digital Technology-Based Media Types

Type of Digital Technology-Based Media	Frequency	Relative Frequency (%)	Effect Size
Google Classroom	2	10	1,04
ChatGPT	1	5	2,57
KAHOOT	2	10	0,80
Laboratorium Virtual	2	10	1,32
Video	3	15	0,95
Canva	1	5	0,56
Audio Visual	1	5	2,34
E-LKPD	3	15	0,77
Virtual Reality (VR)	1	5	1,02
Flipbook	1	5	1,56
Infografis	1	5	1,40
Power Point	1	5	1,68
Leaflet	1	5	1,24

The results of the meta-analysis indicate that different types of digital technology-based media show considerable variation in effectiveness on biology learning outcomes. Highly interactive media, such as ChatGPT and audiovisual tools, demonstrated very high effect size values. This suggests that media capable of providing immediate feedback and integrating multiple representations of information are more effective in enhancing student understanding. The use of artificial intelligence in learning enables adaptive and contextual interaction, which increases student engagement and motivation (Zahren et al., 2025). Additionally, audiovisual media reinforce comprehension through the integration of visual and auditory elements, supporting more optimal information processing (Wicaksono & Wiratama, 2024).

Visual-based media such as PowerPoint, flipbooks, and infographics also showed high-effect categories. This indicates that structured and visual information presentation helps students understand abstract biology concepts. Visual media have been proven effective in reducing misconceptions by simplifying complex concepts into more easily understandable forms (Indah & Fadilah, 2024). Furthermore, media such as virtual laboratories and virtual reality (VR) provide more immersive and contextual learning experiences, enhancing conceptual understanding. Virtual laboratories allow students to explore without equipment limitations or risk, ultimately improving scientific literacy (Agushesa & Prastiwi, 2024).

Meanwhile, media such as Google Classroom function as supportive learning platforms and still show high effectiveness in improving learning outcomes. This is related to its ability to organize materials, assignments, and learning interactions systematically. The use of Learning Management Systems (LMS) has been shown to improve students' cognitive achievements through more structured learning (Fajri & Ningsih, 2022). On the other hand, media such as videos, E-LKPD, and Kahoot show moderate-effect categories. This indicates that while these media are fairly effective, the level of student interactivity and engagement still needs optimization through appropriate learning strategies. Videos, for example, tend to be one-way if not combined with activities that encourage active student participation (Kresnandya, 2020).

Media with relatively lower effect size values, such as Canva, suggest that the effectiveness of digital media is also influenced by its design and usage in learning. Canva, as a visual design-based tool, has potential to enhance conceptual understanding but requires teacher creativity to ensure it serves not just as an aesthetic tool but also as a meaningful learning medium (Cahyani & Bahri, 2024). Therefore, the successful use of digital media is determined not only by the type of media but also by the teacher's ability to integrate it pedagogically.

Overall, these findings indicate that interactive, visual, and immersive digital learning media tend to have a greater impact on biology learning outcomes. This aligns with Sugiarto et al. (2023), who state that the effectiveness of ICT-based media is highly influenced by the level of active student engagement in the learning process. Consequently, the selection of digital media should consider the suitability with the material characteristics and student capabilities to achieve optimal results.

CONCLUSION

Based on the results of the meta-analysis, the use of digital technology in biology learning in Indonesia has been proven effective in improving learning outcomes for senior high school students, with a tendency for higher effectiveness in upper-grade levels. Additionally, the type of media also influences learning outcomes, where interactive, visual, and immersive media such as artificial intelligence, audiovisual tools, and virtual laboratories demonstrate a greater impact compared to less interactive media. Therefore, the utilization of digital technology should be tailored to the characteristics of the material and students, and supported by teacher competence to ensure optimal biology learning.

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