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Building students' scientific literacy in biology learning through digital technology innovation

Uus Toharudin[1*], Nia Nurdiani[2], Cita Tresnawati[3], Cartono[4], Mia Nurkanti[5]
[1, 2, 3, 4, 5] Department of Biology Education, Universitas Pasundan, Tamansari Street No.6–8, Bandung, West Java, Indonesia
[*]Corresponding author: UusToharudin.Unpas.ac.id

ABSTRACT

This study aims to analyze the effectiveness of utilizing digital technology to enhance students' scientific literacy in biology learning at the secondary school level. Scientific literacy is recognized as a key 21st-century competency, encompassing mastery of scientific concepts, critical thinking, problem-solving, and the ability to construct evidence-based arguments. The research employed quantitative methods with quasi-experimental and pre-experimental designs, involving Grade X and XI science students as participants. Data were collected using pre-test-post-test assessments and questionnaires to measure learning outcomes, motivation, reading interest, and digital literacy. The results indicate that integrating various digital media with active learning strategies positively influenced students' engagement and academic performance. Specifically, Wordwall interactive games enhanced motivation and learning outcomes; Wattpad combined with the SQ3R method effectively improved reading interest and conceptual understanding; Powtoon facilitated digital literacy development and collaborative skills; ChatGPT supported the development of scientific literacy within a Problem-Based Learning framework; and YouTube, when applied through the Creative Problem Solving (CPS) model, significantly fostered analytical and creative thinking abilities. These findings suggest that digital technology not only strengthens students' mastery of biology concepts but also supports the development of essential 21st-century skills. Overall, the study demonstrates that digital technology-based biology learning can provide meaningful and contextually relevant experiences that bridge classroom learning with real-world applications, preparing students to actively participate in scientific discourse and problem-solving in their daily lives.

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Keywords
ChatGPT, Digital literacy, Learning motivation, Reading Interest, Scientific literacy.

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INTRODUCTION

Scientific literacy is one of the essential competencies in 21st-century education, enabling students to understand and apply scientific concepts in their daily lives. In biology learning, scientific literacy is not limited to the mastery of factual knowledge but also includes the ability to think critically and solve problems related to biological phenomena (Pratiwi, 2024; Panigrahi et al., 2018). Therefore, biology education needs to be directed toward comprehensively building students' scientific literacy so they are better prepared to face global challenges. Several studies indicate that students frequently experience misconceptions and struggle to grasp abstract concepts in biology, especially in topics such as the excretory system, which are often viewed as monotonous and difficult (Azizah & Alberida, 2021; Simorangkir & Napitupulu, 2020). These difficulties tend to increase when

learning relies heavily on teacher-centered methods like lecturing, as such approaches provide minimal opportunities for students to engage in reading or exploratory activities actively (Amini et al., 2018).

The development of digital technology offers broad opportunities to improve the quality of biology learning. The use of digital media, online learning platforms, and interactive applications has proven effective in strengthening conceptual understanding while also sharpening students' digital literacy skills. This is consistent with Asikin's (2024) study, which emphasizes that interactive multimedia is effective in helping students understand abstract or microscopic material that is difficult to explain through conventional methods.

Furthermore, integrating digital technology into learning provides students with opportunities to actively engage in the learning process (Opre et al., 2024). With the support of interactive applications, they can improve their skills in searching and exploring information, conducting data analysis, and presenting ideas scientifically (Uzorka et al., 2025). This shows that technology-based learning innovations can shift students' roles from passive recipients of information to active and reflective participants in the learning process.

Learning media play a crucial role in enhancing students' enthusiasm during the learning process (Saleh et al., 2023). Simbolon et al., as cited in Putri & Sutama 2023), state that strong digital literacy skills and the use of interactive learning media significantly contribute to improving learning effectiveness and achieving students' learning objectives. In addition, educational games and digital-based platforms can present engaging challenges and tasks for students (Try, 2023). The use of digital learning media enables students to participate in learning actively. Furthermore, beyond the use of supportive media, Rohim and Rahmawati (2020) emphasize that reading and comprehension habits can foster better conceptual mastery among students.

Therefore, this study selected five digital technology innovations to implement with students: Wordwall, Wattpad, Powtoon, YouTube, and ChatGPT. The use of the Wordwall platform has been shown to increase student motivation and learning achievement (Savira et al., 2022). Moreover, Merawati (2000), as cited in Syafi'i and Zahro (2022), explains that using Wattpad in biology learning can be implemented by integrating science fiction narratives that depict biological processes, thereby enabling students to enhance their understanding through literacy-based learning media. Toharudin and Kurniawan (2023) also report that learning with Powtoon videos can enhance students' learning outcomes through interactive visualization.

Using YouTube is considered effective for supporting biology learning because it can present concrete, contextually relevant, and easily understandable audiovisual content. As reported by Liu et al. (2025), the use of YouTube-based learning videos positively improves students' conceptual understanding and learning interest, particularly in abstract science topics. Finally, the selection of ChatGPT as an instructional medium in this study is based on its relevance to the demands of 21st-century literacy. The use of generative AI in educational contexts has been shown to enhance cognitive engagement, clarify misconceptions, and facilitate personalized, adaptive learning. This aligns with Zhai's (2022) findings, which reported that the use of AI conversational agents can improve the quality of learning interactions and support the development of students' critical thinking skills in science learning.

Nevertheless, the implementation of digital technology in biology learning still faces several challenges. Common obstacles include limited facilities, teachers' lack of readiness in integrating technology, and low levels of digital literacy (Anggraeni et al., 2024). A study conducted at SMA Negeri 1 Singaparna found that students' average digital literacy was only at a moderate level, indicating a need for improvement from both teachers and students (Hendrawan et al., 2024).

Based on the explanation above, it can be concluded that the use of digital technology has a positive impact on improving scientific literacy. Learning innovations that integrate digital content and interactive multimedia can provide students with more in-depth learning experiences. Therefore, building scientific literacy through biology learning integrated with digital technology is a strategic step in strengthening 21st-century competencies, especially for Grade X and XI science students.

METHOD

This study employed a quantitative research method focusing on the collection of numerical data and the use of objective statistical analysis to address the research problems (Sugiyono, 2024). Two research approaches were applied: a Quasi-Experimental Design using a Non-Equivalent Control Group Design for ChatGPT and Powtoon learning media, and a Pre-Experimental Design using a One-Group Pre-test–Post-test Design for the Wordwall, Wattpad, and YouTube learning media. The research subjects were Grade X and XI science students at a senior high school, with samples selected through purposive sampling based on their relevance to the research objectives and the availability of digital devices at the school. The instruments used in this study included a multiple-choice concept test and statistical analysis software (SPSS 25) for data processing. The design of a one-group pre-test and post-test is illustrated in Figure 1, and the design for the Non-Equivalent Control Group is illustrated in Table 1.

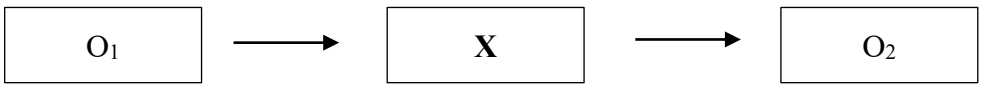


Figure 1. One-group pre-test and post-test design research model
Source: (Creswell & Creswell, 2018)

In this research design, O1 refers to the pre-test administered to participants prior to the implementation of the treatment, aiming to measure their initial level of knowledge or ability. X represents the intervention or treatment applied during the study to influence the participants' learning outcomes. O2 denotes the post-test conducted after the intervention, which is intended to assess participants' level of knowledge or ability following the treatment and to determine the effect of the intervention.

Table 1. Non-equivalent control group design research model

Group	Pre-test	Treatment	Post-test
Experiment	O1	X1	O2
Control	O1	X2	O2

Source: (Sugiyono, 2024)

In this research design, O1 refers to the pre-test administered before the treatment to measure students' initial level of knowledge or ability. X1 represents the intervention in the form of a Problem-

Based Learning (PBL) strategy integrated with ChatGPT, which is implemented to enhance students' learning outcomes through technology-supported instruction. X2 denotes the normal intervention using a Problem-Based Learning (PBL) strategy without the assistance of ChatGPT. Meanwhile, O2 refers to the post-test conducted after the implementation of the respective interventions to evaluate students' learning outcomes and to determine the effect of each treatment.

To measure the increase in concept mastery, the normalized gain (N-Gain) was calculated based on pre-test and post-test scores. The formula for normalized gain is:

$$N\text{-}Gain\ (g) = \frac{Posttest\ score - pretest\ score}{maximum\ score - pretest\ score}$$

Source: (Sugiyono, 2024)

The post-test score refers to the value obtained by students after the learning process has been completed, indicating their level of achievement following instruction. The pre-test score represents the value obtained by students before the learning process begins, serving as a measure of their initial knowledge or baseline competence. Meanwhile, the maximum score denotes the highest possible value that can be achieved on the test, functioning as the upper limit for evaluating students' performance.

The object of this study was to improve students' learning outcomes in biology by fostering scientific literacy habits through digital technology innovations across five learning media platforms: Wordwall, Wattpad, Powtoon, YouTube, and ChatGPT. The data were collected using test instruments developed specifically for this study. Before being administered to students, all test items underwent validity, reliability, and difficulty analyses, with the results presented as follows.

Table 2 Instrument test results

Type of Digital Technology Innovation	Validity			Realiability		Difficulty Index	
	Average Index	Status	Criteria	Index	Status	Average Index	Status
Wordwall	0,497	Valid	moderate	0,733	High	0,586	Moderate
Wattpad	0,463	Valid	moderate	0,736	High	0,607	Moderate
Youtub	0,463	Valid	moderate	0,736	High	0,607	Moderate
Powtoon	0,577	Valid	moderate	0,704	High	0,566	Moderate
Chat GPT	0,678	Valid	High	0,850	High	0,655	Moderate

RESULTS AND DISCUSSION

Consistent with the pre-experimental research approach employing a One-Group Pre-test–Post-test Design and the quasi-experimental approach using a Non-Equivalent Control Group Design, students were required to complete a pre-test before the learning intervention and a post-test after the learning session concluded (Sugiyono, 2024). The pre-test was administered to measure students' initial knowledge and baseline level of scientific literacy before the integration of digital technology innovations in biology learning, while the post-test aimed to assess the extent of learning gains and improvements in conceptual understanding after the instructional treatment. This pre–test–post–test comparison enabled the researchers to identify changes in students' learning outcomes attributable to the use of different digital learning media. The data presented below illustrate a comparative analysis of students' pre-test and post-test scores across the five types of digital technology innovations applied

in this study, providing empirical evidence regarding the effectiveness of each medium in supporting students' learning performance and scientific literacy development.

Table 3 N-gain test results

Type of Digital Technology Innovation	Description	Pre-test	Post-test	N-Gain	Category
Wordwall	Total Score	2136.00	3172.00	0.6833	Moderate
Wattpad	Total Score	2043.33	3110.00	0.6781	Moderate
Youtube	Total Score	60.80	83.31	0.5600	Moderate
Powtoon	Total Score X1	36.56	84.12	0.7483	High
	Total Score X2	20.41	62.90	0.5353	Moderate
Chat GPT	Total Score X1	56.41	83.06	0.6052	Moderate
	Total Score X2	59.52	77.19	0.7861	High

In the first discussion based on Table 2, it can be observed that students' learning outcomes in the pre-test and post-test showed a significant improvement, with the average score increasing from 59 to 88. This indicates that the use of the Wordwall digital platform can enhance students' learning outcomes. This improvement is attributed to the use of digital platforms that not only clarify learning materials but also increase learning motivation and promote learning outcomes across cognitive, affective, and psychomotor domains (Wardhana et al., 2024). Constructivist theory explains how learners adapt and develop knowledge through active and independent learning. According to Piaget (1971, as cited in Sugrah, 2019), through this process, students can discover new understanding through exploration and meaningful experiences. In this context, using Wordwall provides an active learning experience in which students do not merely receive information but also interact directly with the material, respond to questions, and receive immediate feedback.

In addition, other factors influence learning outcomes. Psychological and physiological aspects can contribute to variations in post-test results. Differences in intelligence levels, attitudes, talents, interests, and learning motivation among students also affect learning outcomes (Siregar, 2024). Beyond individual factors, teamwork and engagement in collaborative activities (Panigrahi et al., 2018) also play an important role in helping students solve problems presented in the Student Worksheets (LKPD), thereby enhancing overall learning outcomes.

The study's results show that using various media and innovative methods in biology learning positively affects students' motivation, reading interest, learning outcomes, digital literacy, and science literacy. The use of the Wordwall digital platform in teaching the excretory system, for example, has been proven to increase motivation and learning outcomes. Students are more actively involved in learning activities because the questions are presented as interactive games, creating a fun and challenging atmosphere. This condition aligns with the view that game-based learning can foster intrinsic motivation when students feel challenged yet still able to master the material. Research by Hamidah and Lestari (2022) also found that digital educational games are effective in improving biology learning outcomes by increasing student engagement.

Increased student engagement was also evident in learning about the excretory system using the SQ3R method combined with the Wattpad platform. The SQ3R active reading strategy helps students understand texts systematically, while Wattpad, as a popular reading platform, makes the learning experience closer to their everyday world. As a result, reading interest increases, followed by

mastery of concepts. These findings are consistent with active reading theory, which emphasizes the importance of the survey, question, read, recite, and review stages in improving reading comprehension. Research by Fitriani and Nurlaila (2020) also shows that applying SQ3R can improve students' reading comprehension by helping them focus on the content of the text.

In addition, the use of Powtoon in collaborative learning on ecosystem material significantly improves students' digital literacy. Students not only practiced technical skills in creating animations, but were also trained to work together, communicate ideas, and express creativity. The questionnaire results showed that digital literacy indicators, ranging from functional skills and creativity to effective communication and digital security, were in the very high category. This aligns with Ng's (2012) concept of digital literacy, which encompasses technical, cognitive, and socio-emotional skills in the use of technology. Novianti and Sari (2021) also reinforce that project-based learning with digital media can improve students' digital literacy and collaborative skills.

The integration of ChatGPT into the Problem-Based Learning (PBL) model for the immune system material also led to a significant increase in science literacy. The average N-Gain score in the experimental class was in the high category and better than that of the control class. Students were assisted in developing their science literacy skills in terms of content, context, process, and scientific attitude. ChatGPT served as scaffolding, providing information, explanations, and examples that helped students solve problems before they could think independently. The OECD (2019) emphasized that 21st-century science literacy requires the ability to evaluate information and think critically. Research by Dawson et al. (2023) and Lund & Wang (2023) also shows that the use of artificial intelligence, such as ChatGPT, can support science learning by improving students' conceptual understanding and critical thinking skills. In addition, the study by Hui et al. (2025) showed similar results, with PBL–ChatGPT improving theoretical scores and clinical skills compared with traditional methods; students were highly satisfied and reported better conceptual understanding.

Ecosystem learning with the YouTube-assisted Creative Problem Solving (CPS) model has shown a positive impact on science literacy. The visual and audio learning resources on YouTube make abstract concepts easier to understand, while the CPS model trains students to think divergently and find creative solutions to problems. The study's results show an increase in students' science literacy skills, with many students achieving high levels. Multimedia learning theory holds that combining text, images, and sound can improve understanding and retention. Research by Mulyaningsih (2021) also reinforces that the use of YouTube-based learning videos can improve understanding of biological concepts while building creative thinking skills.

Overall, the five studies included in this umbrella study reveal a common thread: integrating digital technology and active learning methods significantly improves the quality of biology learning in secondary schools. Wordwall and Wattpad have been proven to increase motivation and reading literacy skills; Powtoon develops digital literacy and collaboration skills; ChatGPT encourages science literacy through problem-based learning; while YouTube, in the CPS model, strengthens concept understanding and creative thinking skills. These findings are consistent with the theoretical framework that emphasizes the importance of implementing technology-based active learning to equip students with 21st-century skills, including critical thinking, creativity, communication, collaboration, and digital and science literacy. Thus, this umbrella study makes an important

contribution to innovation in biology education: the combination of digital technologies relevant to students' lives and active learning strategies can significantly improve learning outcomes, motivation, and the various literacy competencies needed in today's digital age.

In the second discussion, based on Table 2, it can be seen that students' learning outcomes on the pre-test and post-test using Wattpad improved, as students were guided to review chapter titles in science fiction stories and to note key terms from each chapter. They were then asked to connect these keywords with their prior knowledge. This activity aligns with constructivist theory, which emphasizes the importance of schema activation in strengthening initial understanding (Siregar et al., 2020). This strategy has been proven to enhance both short- and long-term memory. According to Piaget (Dewi & Sari., 2022) and (Schunk, 2012), learning occurs when new information is processed and linked to pre-existing schemas in long-term memory, which serve as frameworks for understanding and storing knowledge.

Furthermore, implementing the SQ3R method in reading activities on Wattpad helped students focus, particularly during the Question and Read stages. Students formulated questions based on the keywords they had recorded, then searched for answers in the science fiction narratives. This process stimulated critical thinking and deeper comprehension of the text while integrating new information into their cognitive structures. The increase in scores to the high category indicates the effectiveness of this stage in facilitating active meaning-making of the text.

The Recite stage was implemented through group discussions and worksheet completion based on the texts read. Students were asked to restate the information in their own words and apply the concepts to real-life situations. This stage trains logical thinking skills and knowledge transfer from text to real-life contexts, such as relating kidney structure to its function. The greatest improvement was achieved after implementing the Recite and Review stages. In group discussions, students were asked to analyze disorders of the excretory system and determine appropriate medical diagnoses based on stories such as "The Healer from the Future" and "The Trauma Code of Dialysis." Subsequently, they prepared summaries and presented their analyses, followed by feedback from other groups. This process sharpened higher-order thinking skills and the ability to construct logical and in-depth arguments.

The improvement in scores across all cognitive levels indicates that the use of digital science fiction narratives on Wattpad, combined with the SQ3R reading strategy, is effective in fostering students' reading interest and enhancing their conceptual understanding. This strategy works by activating schemata, encouraging metacognitive reflection, strengthening information retention, and enabling the integration of knowledge into real-life contexts.

In the third discussion, which focuses on learning media using YouTube (as shown in Table 2), the research results indicate a significant improvement in students' science literacy skills after implementing CPS learning assisted by YouTube. Based on pre-test and post-test results, students' average score increased from 60.80 (pre-test) to 83.31 (post-test). Furthermore, the N-Gain analysis yielded a value of 0.56, placing it in the medium category. All students experienced score improvements, with no declines observed. Questionnaire results further support these findings, as the majority of students responded positively to instructional videos, stating that the visual presentations on YouTube helped them understand the material more clearly and engagingly. This finding is

consistent with Nuriyah et al. (2023), the use of YouTube videos on ecosystems in Grade VII created a conducive and engaging learning environment and made it easier for students to understand the material; the majority of students achieved the Minimum Mastery Criteria (KKM).

This improvement occurred because digital technology, through YouTube, can present abstract material in a concrete, contextual manner. The visual presentations allow students to observe ecosystem phenomena directly, even in video format, making it easier for them to identify problems, analyze cause-and-effect relationships, and develop scientifically-based solutions. This finding is consistent with Masruroh et al. (2025), who demonstrated that the use of animated videos/YouTube facilitates a clearer, more concrete understanding of scientific concepts, while also enhancing scientific literacy and cognitive learning outcomes in problem-based learning (PBL).

In the fourth discussion, which examines student learning outcomes using Powtoon as a learning medium (as shown in Table 2), the results indicate a significant improvement in students' cognitive abilities in the experimental class. The average pre-test score of the experimental class was 62.4, which increased to 83.7 in the post-test, whereas the control class only increased from 61.9 to 72.5. Meanwhile, the digital literacy questionnaire results showed that students' average response score for their ability to access, evaluate, and produce digital content rose from 3.1 (fair) to 4.2 (good).

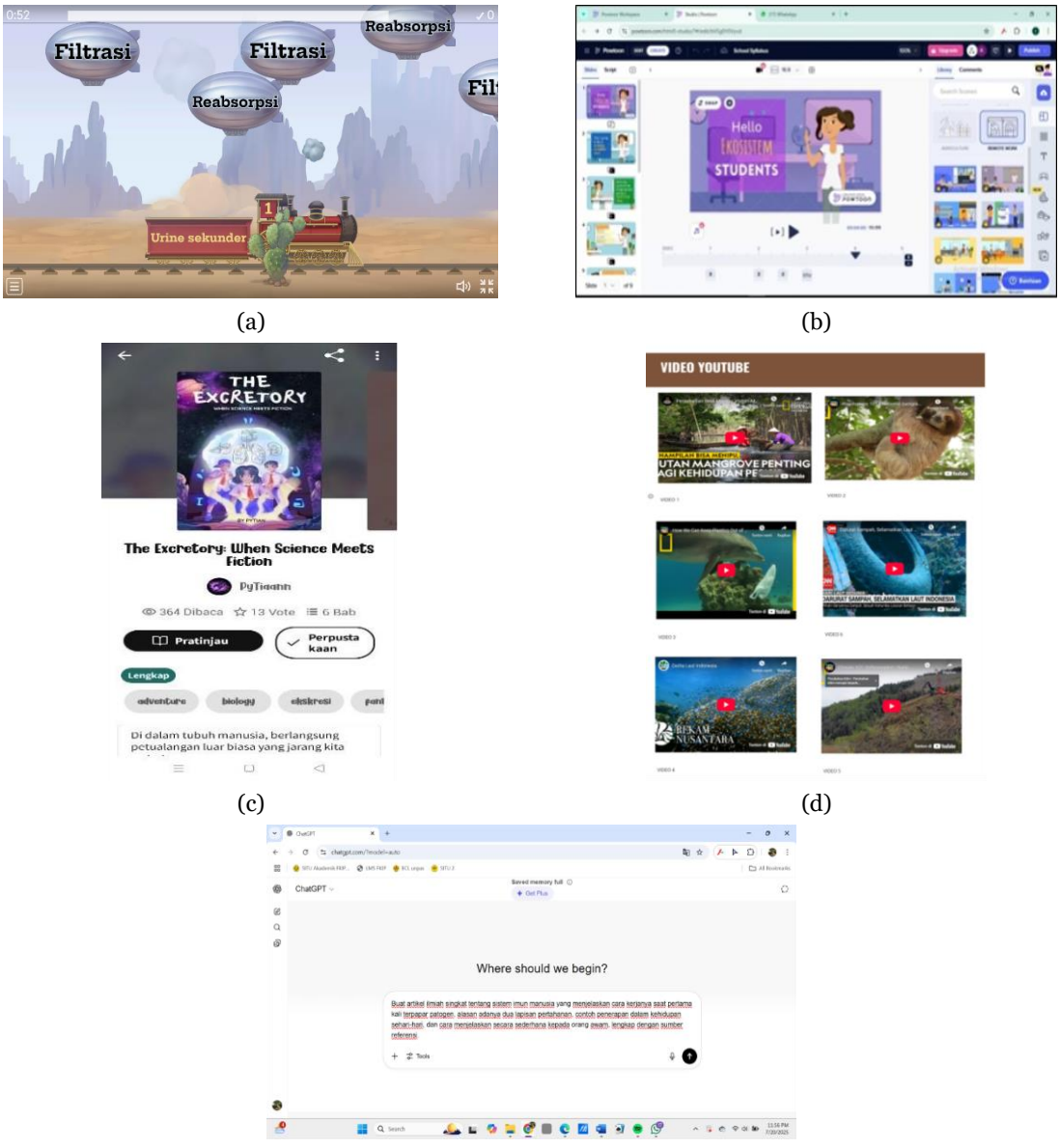
This improvement demonstrates that using Powtoon not only enhances mastery of Biology material but also strengthens digital literacy skills relevant to 21st-century learning needs. The increase occurred because Powtoon provides a visual, interactive, and collaborative learning experience. Students became more active in exploring information, presenting their ideas creatively, and collaborating in teams. This aligns with social constructivist theory, which emphasizes the importance of social interaction in the learning process. Additionally, project-based learning using digital technology motivates students to think critically and take responsibility for their work outcomes.

In the fifth discussion, which focuses on student learning outcomes using ChatGPT as a learning medium, Table 3 shows that science literacy tests, both before (pre-test) and after (post-test) the activities, demonstrated significant improvement in both classes, with the experimental class showing a higher increase. The average N-Gain obtained by the experimental class was 0.7861, categorized as high, while the control class had an N-Gain of 0.6052, falling into the medium category. This indicates that using ChatGPT in PBL learning helps students better access, understand, and communicate scientific concepts.

These research findings are consistent with theories proposed by Dawson et al. (2023) and OECD (2015), which state that science literacy encompasses the ability to access, evaluate, and apply scientific information in real-life contexts. Furthermore, the study by Tong et al. (2025) reported that the PBL–ChatGPT group achieved significantly higher theoretical and clinical practice scores, with increased learning motivation and satisfaction, without increasing total instructional time. In this context, ChatGPT is not merely an information retrieval tool but serves as a reflective partner that stimulates students to think critically, evaluate, and communicate scientific information more effectively.

Figure 2 presents a visual illustration of the biology learning media used in this study, representing digital technology innovations integrated into the learning process. These media were

designed and selected to support students' scientific literacy by providing interactive, multimodal, and technology-enhanced learning experiences. The visualization highlights how each digital platform was implemented within the instructional strategy to facilitate students' engagement, conceptual understanding, and active participation in biology learning activities.



(a) (b) (c) (d) (e)

Figure 2. Digital technology–based biology learning media used in this study: (a) Wordwall, (b) Powtoon, (c) Wattpad, (d) YouTube, and (e) ChatGPT.

CONCLUSION

Based on the findings, it can be concluded that the use of digital technology in biology learning has proven effective in enhancing various aspects of students' competencies, particularly scientific literacy. The integration of Wordwall, Wattpad, Powtoon, ChatGPT, and YouTube with active learning models significantly contributed to students' motivation, reading interest, digital literacy, conceptual understanding, and critical and creative thinking skills. The application of the CPS model supported by YouTube, for example, demonstrated a significant improvement from pre-test to post-test scores while also developing students' abilities to understand, analyze, and evaluate scientific

information. These results strengthen the view that technology-based learning innovation is a relevant and strategic approach in equipping students with 21st-century skills. Therefore, teachers are encouraged to continually develop and integrate digital media and active learning methods to create more interactive, collaborative, and contextually relevant biology learning experiences.

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