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Mapping digital literacy profiles of biology education students for technology-based learning

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ABSTRACT

Purpose: to analyze the level of digital literacy among students of the Biology Education Study Program and to examine its implications for technology-based learning.
Method: this research employed a descriptive quantitative approach with purposively selected participants. Data were collected using a Likert-scale questionnaire covering five dimensions of digital literacy: information, communication, content creation, social-emotional, and problem solving. The data were analyzed using descriptive statistics by calculating mean scores and categorizing literacy levels.
Findings: the results indicate that students' overall digital literacy was at a moderate level, with high proficiency in the information and social-emotional dimensions, moderate communication and content-creation skills, and very high problem-solving ability, highlighting the need to strengthen academic digital communication and content creation for learning.
Implications: this study implies the need for comprehensive digital literacy development of Biology Education students, including communication skills, content creation, and digital information evaluation, as a basis for strengthening the curriculum and technology-based learning to improve the readiness of prospective biology teachers.
Originality: lies in the analysis of digital literacy among Biology Education students based on five DigComp dimensions, which are directly linked to the needs of technology-based biology learning, thereby revealing gaps between technical skills, communication abilities, and academic content creation.

Introduction

The development of digital technology has changed almost every facet of society, including education. As a result, educators must have digital literacy skills that go

beyond mere technology use. Additionally, they must be able to critically, ethically, and creatively comprehend, evaluate, and use information (Limilia & Aristi, 2019; Ririen & Daryanes, 2022). Designing and executing technology-based learning requires strong digital competence (Falloon, 2020; Utami et al., 2019). In the educational setting, digital literacy not only enhances the efficiency of the teaching and learning process but also serves as a vital foundation for creating creative, cooperative, and relevant instruction that meets students' needs in the digital age (Gruszczynska & Pountney, 2013).

However, the reality is that the digital literacy level of prospective student-teachers remains varied and uneven across all aspects (Rosalina et al., 2021). According to several studies, these students are adept at using social media and communication apps, but they still struggle with selecting scientific information, creating digital learning materials, and understanding digital ethics (Borthwick & Hansen, 2017; Isrokatun et al., 2022; Spante et al., 2018). Students in the Biology Education study program also face this situation; in reality, they often use technology only as a supplementary tool rather than to innovate the teaching and learning process. According to Syah et al. (2019), this discrepancy indicates a difference between the intended ideal state and the reality observed in the field.

There are multiple contributing variables to this problem. First off, the curriculum for prospective teacher education does not fully incorporate digital literacy as a primary focus (Audrin & Audrin, 2022). Instead of fostering the development of critical, creative, and collaborative thinking skills in a digital context, technology-integrated learning often emphasizes the practical use of applications (Borthwick & Hansen, 2017). Second, not every student has the background or practice of using technology for learning, especially when it comes to producing biology-based course materials (Marci-Boehncke & Vogel, 2018). Thirdly, the development of thorough digital competency may be hampered by the scant advice given on digital ethics and security. Together, these elements limit students' ability to successfully handle the difficulties of upcoming technology-based learning (Hidayatullah et al., 2024).

The intrinsic features of the biological sciences, which are abundant in digital learning resources such as interactive media, experimental videos, simulations, and open educational resources (OERs), are also linked to the importance of digital literacy for Biology Education students (Kahar, 2018). Improving students' digital literacy helps them understand biological topics more deeply and inspires them to create innovative, contextual, and adaptive learning strategies (Selegi & Aryaningrum, 2022). As a result, mapping and analyzing students' digital literacy levels is a strategic first step in deciding how to enhance digital competence inside the study program. This procedure simultaneously ensures that aspiring biology instructors possess the skills required by 21st-century education.

The significance of digital literacy in preparing future teachers has been emphasized in numerous earlier studies. For example, research by Amelia & Ulumu (2019) and Taheri & Pennington (2024) confirms that digital literacy includes the interconnected technical, cognitive, and socio-emotional skills needed to access and use technology. According to this study, most students have a medium level of digital literacy, with significant gaps in their ability to create content and solve problems. Despite the field's great potential for incorporating context- and science-based, technology-driven learning, there are still few studies that specifically examine the digital literacy of biology education students.

According to the definition above, this study identifies a research gap that has not yet been thoroughly investigated in the evaluation of prospective biology teachers'

digital literacy. The results of this study are anticipated to offer empirical insights into students' digital literacy and to serve as a basis for creating curricula and learning methodologies better suited to the demands of the digital age. Thus, this study's primary goal is to assess the degree of digital literacy among students enrolled in the Biology Education study program and consider the implications for technology-based learning.

This study focuses on the primary concerns of how students in the Biology Education program's digital literacy levels are profiled and how these profiles affect technology-based learning, to clarify the research path. Targeting students who have finished the ICT in Biology Learning course, the study's scope is restricted to five aspects of digital literacy based on the DigComp framework: information, communication, content production, social-emotional, and problem-solving. These limitations were established to maintain the analysis's focus, relevance to the biology education environment, and the ability to produce an accurate empirical picture of students' preparedness to meet the demands of digital competency in 21st-century education.

Method

This study used a quantitative descriptive research design to objectively describe students' digital literacy levels across five principal dimensions. The research population comprised all students of the Biological Study Program, Faculty of Teacher Training and Education, Jambi University, from 2024 to 2025. The sample was a purposive selection of students who had passed an ICT in Biology Learning course, comprising 73 respondents. The data were gathered using the digital literacy questionnaire on a five-point Likert scale and modeled based on the Digital Competence Framework for Citizens (DigComp). The instrument comprised five dimensions: (1) Information (the ability to search, evaluate, and manage digital information), (2) Communication (the ability to interact and collaborate in digital environments), (3) Content Creation (the ability to create and produce digital content ethically), (4) Social-Emotional (understanding ethics, responsibility, and digital safety), and (5) Problem Solving (the ability to use technology to solve problems). This instrument had been tested for validity and reliability. First, the mean and percentage for each digital literacy dimension were computed to obtain descriptive statistics. The calculated values were then classified into five ordered categories: 1.00–1.79 (very low), 1.80–2.59 (low), 2.60–3.39 (moderate), 3.40–4.19 (high), and 4.20–5.00 (very high). After that, the interpretation of the findings was used to portray Biology Education students' digital literacy profile, and it served as an instrument to analyze digital literacy in relation to technology-based learning.

Results and discussion

These findings are based on an analysis of questionnaires completed by 73 respondents. Figure 1 shows the distribution of respondents by gender. Of the 73 respondents, 69 were female, and 4 were male. This indicates that the respondents in this study were predominantly female, reflecting the gender composition of the Biology Education Study Program where the study was conducted. This distribution is important as initial demographic information and can be taken into consideration in interpreting the research results, although this study did not specifically compare digital literacy by gender. Meanwhile, an overview of students' digital literacy achievements based on the mapping is shown in Table 1.

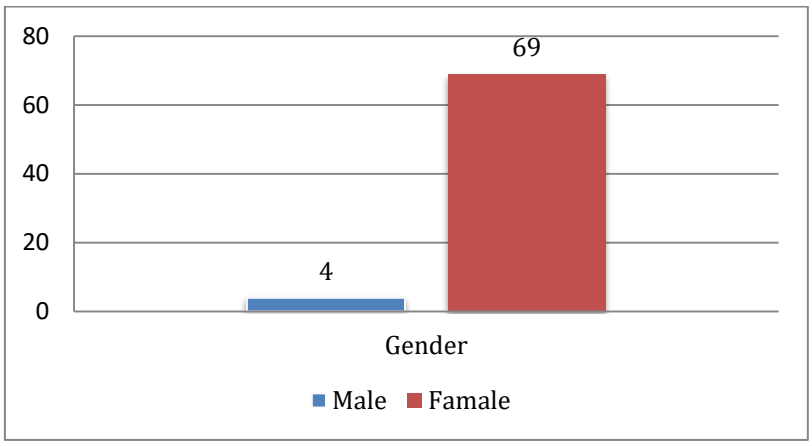

Figure 1 number of respondents by gender
Source: primary data, processed

Table 1 mean scores and categories for each digital literacy dimension

Nu.	Dimension(s)	Mean	Category
1.	Information	3.49	High
2.	Communication	3.27	Moderate
3.	Content creation	3.06	Moderate
4.	Social emotional	3.74	High
5.	Problem solving	3.60	High

Source: primary data, processed

The research results in Table 1 show that students demonstrate high levels of digital literacy in the information, social-emotional, and problem-solving dimensions, while communication and content creation remain at a moderate level. High proficiency in the information dimension (M = 3.49) indicates that students can effectively search for, select, and use digital information to support academic activities. This ability is essential in technology-based learning environments, where students must navigate vast amounts of digital information critically. As highlighted by Johnston (2020), the competence to locate and evaluate information is a core component of digital literacy, particularly in higher education contexts that demand independent and inquiry-based learning.

Furthermore, the high score in the social-emotional dimension (M = 3.74) reflects students' strong awareness of digital ethics, empathy, and responsible behavior in online interactions. This indicates that students are not only technically competent but also socially and ethically prepared to participate in digital learning environments. Budiman and Syafrony (2023) emphasize that ethical awareness, respect for others, and responsible digital participation are fundamental elements of digital citizenship and essential skills for the 21st century. Such competencies are particularly important for prospective teachers, as they are expected to model positive digital behavior and foster safe and respectful learning environments for their future students.

In addition, students' high performance in problem-solving (M = 3.60) suggests a strong ability to utilize digital tools and online resources to overcome technical challenges. This finding implies that students possess adaptive learning skills and can engage in self-directed problem-solving, which is crucial in rapidly evolving technological contexts. According to Falloon (2020), digital problem-solving skills enable learners to respond flexibly to technological changes and support lifelong learning, a key expectation for future educators in technology-rich classrooms.

Despite these strengths, the moderate levels observed in communication (M = 3.27) and content creation (M = 3.06) indicate that students have not yet fully developed their capacity to express ideas effectively and produce original digital learning materials. This gap suggests that students tend to use digital technology more as a consumption and support tool rather than as a medium for creative and pedagogical expression. Siregar (2024) similarly argue that digital communication and content creation skills require structured pedagogical support through collaborative learning, authentic tasks, and real-world projects in order to develop optimally.

In the context of Biology Education, this limitation is particularly significant, as effective technology-based biology learning requires the ability to communicate complex and abstract biological concepts through digital media such as videos, simulations, infographics, and virtual experiments. Without sufficient competence in digital communication and content creation, students may struggle to design engaging and meaningful biology learning resources. Therefore, these findings highlight the need for instructional strategies that emphasize project-based learning, collaborative content development, and reflective digital practices to strengthen students' creative and communicative digital competencies.

Overall, the results suggest that while students are relatively well-prepared to access information, behave ethically, and solve digital problems, targeted interventions are still required to enhance their ability to communicate academically and create digital learning content. Strengthening these dimensions will not only improve students' overall digital literacy but also better prepare them to become future biology teachers capable of implementing innovative, technology-based learning in the classroom.

Table 2 indicators of the information dimension

Nu.	Statement	Mean	Category
1.	I can simply discover the most recent information on web-based digital content creation applications via the internet.	4	High
2.	It's tough for me to remember when information about digital content creation applications was last updated on the Internet.	2.93	Moderate
3.	I have difficulty distinguishing between vital and unimportant information about digital content production programs that I come across on the internet.	2.93	Moderate
4.	I utilize the internet to get and exchange tutorial files and directions for digital content creation programs.	4.44	Very high
5.	I find it challenging to determine the veracity of tutorials or information about digital content creation programs that I encounter on the internet.	2.78	Moderate
6.	I use web resources to research the evolution of AI use in education.	4.23	Very high
7.	I like to put my video tutorial project files on cloud services instead of a physical device.	3.11	Moderate

Source: primary data, processed

Table 2 presents students' responses to the information dimension of digital literacy. The findings indicate that students demonstrate a high ability to search for up-to-date information related to web-based digital content creation applications (M = 4.00) and a very high ability to use the internet to download and share tutorial files or instructional resources (M = 4.44). These results suggest that students are highly accustomed to accessing digital information and utilizing online resources as part of their daily learning practices. In the context of higher education, such competencies reflect functional information literacy, where students can efficiently locate and retrieve information to support academic tasks. As noted by Selegi & Aryaningrum (2022), the

ability to access and use relevant information is a fundamental component of digital literacy. It serves as the foundation for independent, technology-based learning.

Moreover, students' frequent engagement with online resources indicates a readiness to participate in technology-enhanced instruction, particularly in courses that require self-directed exploration and the use of digital learning materials. This aligns with contemporary perspectives on digital literacy, which emphasize not only operational skills but also cognitive competencies involved in searching, organizing, and applying information in meaningful ways. In this regard, students' active use of digital platforms reflects their potential to function effectively in learning environments that integrate web-based tools, multimedia resources, and emerging technologies such as artificial intelligence in education.

Nevertheless, the moderate scores on several evaluative indicators reveal important limitations in students' information literacy skills. The ability to recognize the currency of information (M = 2.93), distinguish between essential and non-essential information (M = 2.93), and evaluate the credibility and accuracy of digital sources (M = 2.78) remains insufficiently developed. According to Georgopoulou et al. (2025) Digital Competence Framework, critical evaluation of information quality, reliability, and relevance is a core dimension of digital literacy and a key safeguard against misinformation and disinformation in digital environments. The presence of these gaps suggests that while students are proficient in accessing information, they are less confident in engaging in higher-order cognitive processes such as analysis, evaluation, and judgment.

This pattern is consistent with the findings of Djarwo et al. (2025), who reported that students often excel at the technical aspects of information retrieval but struggle to assess the validity and credibility of digital content critically. In the context of biology education, this limitation is particularly concerning, as students are frequently exposed to complex scientific information, online simulations, and AI-generated content that may vary in accuracy and reliability. Without strong evaluative skills, students may be vulnerable to accepting unverified or misleading information, which can negatively affect their conceptual understanding and instructional decision-making as future teachers.

Therefore, digital learning practices in higher education should place greater emphasis on fostering critical and reflective information literacy skills. Instructional strategies such as guided evaluation of digital sources, comparative analysis of scientific information, and reflective discussion of the reliability of AI-assisted content can help students move beyond surface-level use of information. Strengthening these competencies will enable students not only to access information efficiently but also to assess its quality, relevance, and ethical implications, thereby enhancing their preparedness for technology-based learning and professional practice in the digital era.

Table 3 indicators of communication

Nu.	Statement	Mean	Category
1.	I find it hard to use digital communication apps to discuss the video tutorial project.	2.55	Moderate
2.	I use social media to discuss or share ideas about creating digital content with lecturers or friends.	4	Very high
3.	I find it difficult to send the video-tutorial assignment file through the app recommended by the lecturer.	2.6	Low
4.	I'm reluctant to use social media to share the educational content from my video-tutorial project.	2	Low

Nu.	Statement	Mean	Category
5.	I actively use social networks to look for references or inspiration for educational video content from other students or professionals.	4.1	Very high

Source: primary data, processed

The research findings in Table 3 reveal a wide range of students' digital communication competence, highlighting both strengths and areas for improvement. On the positive side, students scored high in using social media platforms to discuss and share ideas with lecturers and peers (M=4.00) and in seeking inspiration for educational video content through social networks (M=4.10). These results suggest that many students have reached a certain level of digital maturity, where they can leverage technology not just for casual interaction but as a tool for meaningful academic collaboration and creative idea exchange. This aligns with Meyers et al. (2013) conceptualization of digital literacy, which extends beyond mere technical proficiency to encompass the ability to communicate effectively and collaborate in digital environments.

Furthermore, the students' active use of social media for academic purposes supports Rakuasa et al. (2024) assertion that digital communication competency facilitates productive collaboration and community-based learning online. These behaviors indicate that students recognize the value of digital networks as spaces for knowledge sharing and peer support, which are essential in modern educational contexts, especially in project-based and technology-integrated learning models. This tendency to transform social media into academic platforms reflects an encouraging shift toward embracing digital tools as integral components of learning and professional development.

However, the data also reveal significant challenges. Lower scores on indicators related to difficulties using digital communication apps (M=2.55), challenges in submitting assignments through lecturer-recommended applications (M=2.6), and reluctance to share educational content publicly (M=2.00) point to persistent barriers that inhibit students from fully utilizing digital communication tools for academic purposes. These issues could stem from a combination of technical hurdles, lack of familiarity with specific platforms, or even psychological factors such as fear of negative evaluation or privacy concerns. Amelia & Ulumu (2019) study similarly highlights that technical difficulties and motivational barriers remain common among some students, limiting their engagement in digital communication.

Moreover, according to the digital competence framework, digital communication skills encompass not only the technical ability to operate digital tools but also the willingness and confidence to actively participate, contribute constructively, and cultivate a positive digital identity. This suggests that digital communication competence is inherently socio-emotional, requiring students to develop a sense of digital citizenship, including responsibility, ethical behavior, and the courage to express their ideas publicly. The reluctance to share educational content may reflect underlying issues related to self-confidence, fear of criticism, or uncertainty about intellectual property rights, all of which are critical factors influencing active participation in digital spaces.

Therefore, addressing these gaps requires a multifaceted approach. Educational institutions should implement targeted digital literacy training programs that focus on building technical proficiency alongside ethical awareness and confidence-building strategies. For instance, workshops on navigating communication platforms, managing digital identities, and understanding digital etiquette can empower students to

overcome both practical and affective barriers. In addition, creating safe and supportive online environments where students can share their work with constructive feedback can foster a culture of collaboration and innovation. While students demonstrate encouraging competence in using digital communication tools for academic collaboration, the existing barriers highlight the need for pedagogical interventions that integrate technical training with socio-emotional support. Such comprehensive development of digital communication skills will enable students to harness the full potential of technology-based learning, fostering collaboration, creativity, and active engagement in the digital academic community.

Table 4 indicators of content creation

Nu.	Statement	Mean	Category
1.	I find it difficult to use web-based digital content creation apps to make a video tutorial.	2.5	Low
2.	I can create supporting documents for a video tutorial, such as a script or storyboard, using a word-processing app.	3.5	High
3.	I use digital content creation apps to make posters, images, or videos as part of my ICT course project.	4.1	High
4.	I find it difficult to make a video tutorial using the web-based apps learned in class.	2.7	Moderate
5.	I have trouble creating educational video content that is engaging and easy to understand.	2.6	Low
6.	I always include online sources in the video tutorials or digital materials I create.	3.8	High
7.	I'm reluctant to share my video-tutorial work on public platforms like YouTube or social media.	2.1	Low

Source: primary data, processed

Table 4 shows the research findings on the content creation dimension reveal that students generally possess a satisfactory level of skill in using digital tools to support academic communication through creative outputs. The high mean scores on indicators such as the use of digital content creation applications for making posters, images, or videos (M=4.1), the preparation of supporting documents like scripts and storyboards (M=3.5), and the inclusion of online references (M=3.8) demonstrate students' functional proficiency in producing digital content that effectively conveys ideas visually and textually. This aligns well with Kanyika et al. (2024) perspective, which underscores that digital literacy encompasses not only technical skills but also collaborative and creative competencies necessary for generating and sharing knowledge across diverse digital formats. These skills are especially critical in an academic context where multimodal communication, combining text, images, and videos, plays an increasingly prominent role in enriching the learning experience.

Additionally, Shopova's (2014) research highlights that strong digital communication skills are fundamental for the success of project-based learning (PBL), which relies heavily on students' active participation and their ability to create and share digital artifacts. By developing multimedia content, students can better engage with subject matter, demonstrate understanding, and collaborate more meaningfully with peers and instructors. This ability is particularly relevant in fields such as biology education, where abstract or complex concepts often benefit from visual and interactive representations.

However, despite these promising capabilities, the data also indicate notable challenges and limitations in students' digital content creation skills. Lower scores in

areas such as difficulty using web-based video creation applications (M=2.5), struggles to produce engaging educational content (M=2.6), and reluctance to share work publicly on platforms like YouTube or social media (M=2.1) reveal an underlying lack of confidence and hesitation toward open digital communication. These issues suggest that technical proficiency alone is insufficient to ensure complete competence in digital content creation. As Utami et al. (2019) argue, digital communication competence also depends heavily on affective factors, including self-confidence, a sense of responsibility, and adherence to digital ethics.

The reluctance to share work publicly may stem from concerns about digital privacy, fear of criticism, or uncertainty about intellectual property rights, all of which can undermine students' willingness to participate openly in digital academic communities. This is consistent with Audrin & Audrin's (2022) findings, which emphasize that developing online communication competency is not merely a technical challenge but also an emotional and ethical one. Without sufficient experience and positive reinforcement, students may hesitate to expose their creative efforts to public scrutiny, thereby limiting their opportunities for feedback, improvement, and collaboration.

Given these challenges, learning environments must foster not only the technical skills but also the affective and ethical dimensions of digital literacy. Pedagogical approaches should incorporate collaborative learning activities that encourage shared creation and peer feedback, thereby building students' confidence and digital identity in a supportive setting. Supervised opportunities to post and present digital work, coupled with constructive feedback, can gradually reduce anxiety and cultivate a culture of open sharing and responsible digital citizenship. Incorporating training sessions on digital ethics, copyright laws, and privacy protection can further empower students to navigate the digital landscape responsibly and confidently. This holistic approach to digital literacy development will better prepare students to harness digital content creation tools effectively, enabling them to produce innovative and engaging educational materials that align with 21st-century learning goals.

Table 5 indicators of social emotional

Nu.	Statement	Mean	Category
1.	I value differing opinions when discussing digital content creation online.	4.3	Very high
2.	I pay attention to ethics when giving comments on my friends' video-tutorial work.	4.3	Very high
3.	I ignore my peers' feelings when criticizing their digital content work.	1.7	Very low
4.	I respect my friends' privacy when communicating and sharing files during the video-tutorial project.	4.2	High
5.	I understand the legal risks of using copyrighted material for creating video tutorials.	4	High
6.	I am careful about sharing personal data when using digital platforms for ICT projects.	4.2	High
7.	I regularly check and adjust privacy settings on the apps or platforms used in the content-creation process.	3.6	High

Source: primary data, processed

Table 5 shows the research findings on the social-emotional dimension indicate that students possess a high level of awareness and competence in social and digital ethics when interacting in online environments. Very high mean scores on indicators

such as appreciating differences of opinion (M=4.3) and paying attention to ethics when commenting on peers' work (M=4.3) reflect students' strong capacity for empathy, respect, and constructive engagement in digital communication. These results suggest that students not only recognize the importance of ethical behavior but also consistently apply these principles in their interactions, demonstrating maturity in navigating complex social dynamics online. This aligns with Rosalina et al. (2021), who emphasize that social-emotional digital literacy encompasses ethical behavior, respect for digital rights, and safeguarding personal and others' digital safety.

The study also shows students' high awareness of privacy and personal data protection, with strong scores on indicators such as respecting others' privacy (M=4.2) and exercising caution when sharing personal information (M=4.2). This demonstrates that students are not only aware of ethical norms but also actively implement measures to protect themselves and their peers in the digital space. Such competencies are critical, particularly amid increasing exposure to online risks such as identity theft, cyber bullying, and the misuse of personal data. By demonstrating responsible digital behavior, students contribute to a safer, more respectful academic digital community.

The very low score on the negative indicator, "I ignore colleagues' feelings when criticizing their digital content work" (M=1.7), further confirms the high level of digital empathy among students. This suggests that students can manage their emotions constructively during online interactions and provide feedback respectfully. According to the social and emotional learning (SEL) framework proposed by CASEL, competencies such as emotion regulation, empathy, and the maintenance of positive social relationships are foundational to responsible digital literacy. The ability to manage emotions effectively in online communication allows students to participate in collaborative learning without causing conflict or disengagement, fostering a supportive digital academic environment.

In addition, students demonstrate knowledge and practice of digital responsibility, including copyright awareness (M=4.0) and routine checking of privacy settings (M=3.6). These findings indicate that students not only understand legal and ethical standards online but also integrate this knowledge into their daily digital behavior. This corresponds to the digital competence framework, which emphasizes responsibility as a key pillar alongside technical, cognitive, and creative competencies.

Taken together, these findings suggest that students' digital literacy extends beyond mere technical proficiency. They exhibit strong social-emotional skills that enable them to navigate digital spaces ethically, responsibly, and empathetically. Such competencies are essential for fostering a healthy digital culture in academic contexts, where collaboration, mutual respect, and safety are critical. Furthermore, the high social-emotional literacy among students provides a solid foundation for future professional practice, as educators in the 21st century must model ethical, empathetic, and responsible behavior in technology-mediated teaching and learning environments.

To further strengthen these competencies, educational interventions could include structured activities on digital citizenship, peer feedback exercises, and discussions of ethical dilemmas in digital contexts. These strategies would not only reinforce students' existing social-emotional skills but also prepare them to handle increasingly complex and diverse online environments as future professionals.

Table 6 indicators of problem solving

Nu.	Statement	Mean	Category
1.	I take additional training to improve my skills in creating digital content using web-based applications.	2.5	Low
2.	I look for solutions on the internet when I face technical problems in the digital content creation process.	4.3	Very high
3.	I can identify gaps in digital skills among my friends in the video-tutorial project group.	3.5	High

Source: primary data, processed

Table 6 presents the research findings on the problem-solving component, indicating that students demonstrate a strong ability to address digital challenges both independently and collaboratively. The very high score on the indicator "I search for solutions on the internet when experiencing technical difficulties" (M=4.3) suggests that students are accustomed to using online resources to overcome technical difficulties when creating digital content. This demonstrates not only technical competence but also adaptive problem-solving strategies, where students actively seek knowledge and solutions rather than relying solely on instruction. Such behaviors reflect a core element of digital literacy: the ability to engage in self-directed problem-solving using available technological resources.

Additionally, the data reveal that students have awareness of collaborative problem-solving. The score on identifying skill gaps within a project group (M=3.5) indicates that students can recognize their own limitations and those of their peers, enabling them to work effectively together to tackle complex digital tasks. This aligns with Vygotsky's (1978) concept of the zone of proximal development, which posits that learning and problem-solving are enhanced through social interaction and peer support. Students' engagement in collaborative problem-solving highlights the importance of social learning in developing digital competence, particularly when managing multifaceted projects or unfamiliar technological tools.

However, the findings also show variability in students' responsiveness to further instruction and guidance. While some students display high participation and engagement in structured learning or problem-solving activities (M=4.0), others exhibit lower participation (M=2.5). This discrepancy may stem from differences in intrinsic motivation, confidence in using digital tools, or perceptions of the relevance and applicability of instructional content to their academic needs. This observation is consistent with Ismuwardani et al. (2024), who emphasize that motivational factors and self-efficacy are crucial for enhancing digital literacy, particularly in problem-solving. Students who are less motivated or less confident may be slower to adopt new technologies or less willing to experiment with innovative solutions, limiting their ability to benefit from digital learning opportunities fully.

Problem-solving competence in the digital era encompasses not only technical skills but also initiative, creativity, critical thinking, and the capacity for lifelong learning. Rapid technological changes require students to continuously adapt and develop flexible strategies for overcoming challenges. Therefore, higher education programs aiming to strengthen digital literacy should adopt a holistic approach that combines technical skill-building with the cultivation of proactive, collaborative, and reflective attitudes. Strategies such as project-based learning, peer mentoring, guided troubleshooting exercises, and reflective digital journals can help students develop both individual and collective problem-solving skills. This approach ensures that students are not only competent in handling immediate technical problems but also equipped to navigate the

evolving demands of technology-mediated learning and professional contexts. The findings suggest that students' digital problem-solving abilities are strong overall, particularly in self-directed solution seeking and collaborative awareness. However, fostering consistent engagement and motivation across all learners remains critical. By integrating technical, cognitive, and social-emotional strategies into digital literacy education, institutions can produce graduates who are confident, innovative, and capable of thriving in dynamic digital environments.

The findings of this study are closely related to the features of technology-based biology education, which require students to manage, communicate, and create scientific content digitally, in addition to having access to information. The Information and problem-solving skills, which are already in the high group, show that students are reasonably ready to use biology simulations, experimental footage, or interactive learning platforms as teaching tools. On the other hand, students may not yet be at their best when it comes to creating technology-based biology content, such as virtual practicum videos, info graphics of biological processes, or other digital learning materials, according to the Communication and Content Creation skills, which are still in the moderate category. This is important because students must be able to visually, collaboratively, and artistically communicate abstract biological concepts in order to participate in technology-based biology instruction. These findings thus show a disconnect between students' preparedness in digital communication and scientific content production skills and the expectations of technology-based biology education.

It is clear from the debate above that students need to be digitally literate in the age of technology-driven educational change. They will succeed in the learning process and in overcoming future professional challenges if they have a solid grasp of the many facets of digital literacy, such as the ability to access and manage information, communicate and collaborate online, uphold ethical standards and social-emotional balance, and solve digital problems independently. To develop digital competency improvement techniques pertinent to the demands of 21st-century education, this study assessed students' levels of digital literacy within the framework of web application-based learning.

The Biology Education Study Program's curriculum creation and instructional strategies will be significantly impacted by the research's conclusions. Curriculum strengthening is necessary to address the identified skill gaps. This calls for reinforcing digital literacy integration by aligning course learning outcomes, particularly in the ICT in Biology Learning course, to emphasize not only application use but also evaluative, creative, and collaborative skills in the digital context. As a result, the ICT course's Semester Learning Plan (SLP) should be revised to incorporate elements that specifically foster communication and content-creation skills. Examples of these include assignments that call for students to produce multimedia biology content, apply digital ethics, and collaborate in online communities. Additionally, it is advised that the ICT course assignments for Project-Based Learning Design focus on creating technology-based biology learning materials, such as scientific infographics, biological concept animations, experimental videos, or fundamental augmented reality, to boost students' creative self-efficacy and familiarize them with digital literacy standards relevant to future biology instructors. Therefore, the study's findings offer helpful guidance for enhancing students' digital competency and streamlining the educational process.

Conclusions

The findings show that students' digital literacy levels fall into the good category, although some aspects still vary. Students demonstrate strong abilities in searching for and using digital information, communicating and collaborating through online platforms, and maintaining ethical conduct and empathy in digital interactions. They can also solve technical problems independently by using online resources. However, evaluative aspects such as assessing the credibility of information and building confidence in sharing digital work still need strengthening. Overall, these results highlight the importance of developing comprehensive digital literacy, not only in technical skills but also in critical, ethical, and social dimensions, so that students can adapt and participate productively in digital learning environments and the broader digital society.

The findings of this study have implications for the need for educational interventions that emphasize the development of academic communication skills and the creative and collaborative production of digital learning materials. Educational institutions need to design curricula and learning strategies that encourage students to actively produce digital content, critically evaluate information, and participate ethically and confidently in digital environments. Therefore, strengthening the communication and creative content dimensions will ensure students' readiness as future biology teachers capable of utilizing technology innovatively in learning, while fostering balanced and professional digital literacy.

This study has several limitations, including its limited scope to students in the Biology Education Study Program at the University of Jambi, so the results may not be generalizable to other study programs or institutions. Furthermore, this study used a descriptive quantitative design with a self-report questionnaire, thus only describing students' perceptions of their digital skills without exploring the causes, strategies, or actual practices in developing digital literacy. The research focus is also limited to the five dimensions of digital literacy outlined in the DigComp framework. In contrast, other aspects, such as AI, interactive content, and digital innovation, have not been analyzed. Given these limitations, further research is recommended using mixed methods to provide a more in-depth picture, expand the study population and context, analyze factors influencing digital literacy, and assess students' abilities through practical assessments or digital projects to yield more objective and comprehensive data.

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