



Digital Literacy Profile of Biology Education Students for 21st-Century Learning

Ummi Kalsum^{1*}, Iffa Ichwani Putri¹, Tri Yuliawan², Sepita Ferazona¹

¹Biology Education Study Program, ²Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Islam Riau, Jalan Kaharuddin Nasution No. 113, Perhentian Marpoyan, Pekanbaru, Riau, Indonesia 28284.

Email Correspondence: ummibio@edu.uir.ac.id

Abstract

Digital literacy is increasingly important for prospective biology teachers because biology learning requires the use of digital scientific resources, online journal databases, multimedia representations, virtual laboratories, and digital tools for interpreting evidence and communicating scientific knowledge. Yet, empirical profiles that examine multiple dimensions of digital literacy specifically among Biology Education students remain limited. This study aimed to describe the digital literacy profile of Biology Education students, identify relative strengths and weaknesses across seven dimensions, and derive curriculum implications for teacher preparation. A quantitative descriptive survey was conducted with 45 fourth-semester Biology Education students at Universitas Islam Riau during the even semester of the 2025/2026 academic year. Participants were selected purposively. Data were collected using the final 35-item self-assessment instrument developed and psychometrically established by Kantona and Munadi (2024), which covers information literacy, digital scholarship, learning skills, ICT literacy, career and identity management, communication and collaboration, and media literacy. The original instrument development involved expert review, confirmatory factor analysis, graded response model/item response theory analysis, and reliability testing; the present study additionally obtained a sample-specific Cronbach's alpha of 0.894. Data were analyzed using descriptive statistics, achievement percentages, category distributions, and dimension-level comparisons. The overall achievement was 70.36% (mean = 3.52/5) and was categorized as moderate. Career and identity management was the strongest dimension (76.83%), while media literacy was the weakest (62.40%). The findings indicate a functional but uneven digital literacy foundation. Biology Education programs should therefore integrate authentic digital practices, especially scientific source evaluation, media critique, digital data interpretation, and technology-supported instructional design, across biology and pedagogical courses.

Keywords: Digital Literacy; Biology Education Students; Prospective Teachers; Digital Competence; 21st-Century Learning.

How to Cite: Kalsum, U., Putri, I. I., Yuliawan, T., & Ferazona, S. (2026). Digital Literacy Profile of Biology Education Students for 21st-Century Learning. *Empiricism Journal*, 7(3), 2828-2837. <https://doi.org/10.36312/ej.v7i3.6601>



<https://doi.org/10.36312/ej.v7i3.6601>

Copyright© 2026, Kalsum et al.

This is an open-access article under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) License.



INTRODUCTION

The rapid expansion of digital technology has changed how university students search for information, communicate, construct knowledge, and participate in learning. In teacher education, this transformation has a direct implication: digital literacy is no longer adequately described as the ability to operate devices or access the internet. It increasingly involves locating and evaluating information, using digital resources strategically, communicating and collaborating in networked environments, creating and interpreting digital content, managing professional identity, and participating responsibly in digital spaces. Studies in higher education have shown that frequent exposure to technology does not automatically produce comprehensive digital competence because students may still experience gaps in critical evaluation, purposeful application, and responsible participation (Dolezal et al., 2025; Hidayat et al., 2025). Digital literacy therefore needs to be examined as a multidimensional competence rather than as a single technical skill.

The issue becomes more specific and consequential in Biology Education. Biology is a data- and evidence-rich discipline in which students routinely encounter scientific articles, genomic and biodiversity databases, interactive simulations, microscopic images, infographics, digital datasets, virtual laboratory environments, and online scientific communities. A prospective biology teacher is consequently expected to do more than find digital information. The teacher must judge whether a scientific claim is credible, compare

evidence from multiple sources, interpret biological representations, select a suitable digital tool for a particular learning objective, and transform scientific information into pedagogically meaningful learning resources. Recent research with prospective biology teachers confirms that digital competence remains a relevant preparation issue, although studies report different levels depending on the instrument, context, and learning experience (Nurbaya, 2023; Adhani & Nursia, 2024; Farid et al., 2024).

Digital technology also changes the nature of biology teaching practice. A pre-service teacher may need to combine content knowledge with technological and pedagogical decisions when designing a lesson, conducting a virtual laboratory, analyzing student data, or producing digital learning media. Aumann et al. (2024) showed that translating technology-related knowledge into actual biology teaching requires contextual decisions rather than simple technical familiarity. Similarly, Ramadan and Lestari (2024) reported the value of integrating digital and scientific literacy within biology learning, while Rosamsi and Nurdiani (2024) demonstrated that technology-integrated pedagogical approaches can strengthen the preparation of future biology teachers. These findings indicate that teacher education programs should understand students' existing digital strengths and weaknesses before designing more targeted learning experiences.

One difficulty in interpreting previous studies is the diversity of digital literacy frameworks and instruments. Different studies have emphasized information searching, content creation, communication, safety, critical thinking, or technology use, and therefore their results are not always directly comparable. For prospective teachers, Kantona and Munadi (2024) developed a multidimensional instrument specifically for higher education teacher candidates. The final psychometrically established instrument contains 35 items distributed across seven dimensions: information literacy, digital scholarship, learning skills, ICT literacy, career and identity management, communication and collaboration, and media literacy. Its development involved expert review, confirmatory factor analysis (CFA), graded response model/item response theory analysis, and reliability testing. The final items showed factor loadings above 0.40, providing a defensible measurement basis for profiling prospective teachers.

Evidence from Biology Education contexts also suggests that digital literacy profiles can vary substantially across settings and frameworks. Nurbaya (2023), for example, reported a high overall level among 71 prospective biology teachers at Cenderawasih University, with information skills particularly strong but safety and problem-solving comparatively weaker. Adhani and Nursia (2024) reported a moderate average level among prospective biology teachers using a different digital competence framework. Farid et al. (2024) likewise identified specific needs related to evaluating information and considering the effects of digital messages among Biology Education students. More recent mapping by Sudirgayasa et al. (2025) found an intermediate level of digital literacy among prospective biology teachers in Bali and recommended learning programs that integrate technology with authentic problems. These differences reinforce the importance of context-specific profiling and caution against assuming that a single digital literacy score represents all dimensions of competence.

The present study responds to this gap by profiling Biology Education students at Universitas Islam Riau using the final 35-item instrument of Kantona and Munadi (2024). The research gap is therefore twofold. First, existing Biology Education studies commonly use different indicator structures, making it difficult to see whether a cohort is strong in some dimensions but weak in others. Second, studies that report an overall digital-literacy score do not necessarily identify which competencies should become priorities for teacher-preparation curricula. The novelty of the present study lies in combining a biology-specific context with a psychometrically established seven-dimensional framework to produce an actionable competency profile. The study does not develop or revalidate the instrument; it uses the final established instrument to generate evidence for curriculum planning. This positioning differentiates the study from instrument-development studies and from intervention studies that focus on whether a particular learning model increases digital literacy.

METHOD

Research Design

This study employed a quantitative descriptive survey design. The design was selected because the research objective was to obtain an empirical profile of digital literacy in a defined

group without manipulating variables or introducing an experimental treatment. A descriptive survey is suitable when standardized responses are used to summarize the characteristics of a population or accessible group and to compare patterns across predefined dimensions (Creswell & Creswell, 2023). The study was conducted during the even semester of the 2025/2026 academic year in the Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Islam Riau, Pekanbaru, Indonesia.

The unit of analysis was the individual student response. The analysis was designed to answer profile-oriented questions rather than to estimate causal effects. Consequently, inferential claims about predictors of digital literacy, intervention effects, or institutional differences were outside the scope of the present design. This approach also aligns with the study's purpose of generating a baseline that can subsequently inform curriculum improvement and future comparative or intervention research.

Participants and Sampling

The participants were 45 fourth-semester undergraduate students enrolled in the Biology Education Study Program and taking the Innovative Educational Product Innovation in Biology Education course during the study period. Purposive sampling was used because the accessible participants met characteristics relevant to the research objective: they had received foundational biology and pedagogical coursework and were engaged in activities requiring the use of digital resources and the development of educational products. The dataset did not contain age, gender, device ownership, internet-access, or prior digital-learning-experience variables; therefore, the study did not conduct demographic subgroup comparisons.

Table 1. Participant Characteristics

Characteristic	Description
Number of participants	45 students
Study program	Biology Education
Semester	Fourth semester
Institution	Universitas Islam Riau
Sampling technique	Purposive sampling
Data collection period	Even semester, 2025/2026
Course context	Innovative Educational Product Innovation in Biology Education

Instrument and Data Collection

Data were collected using a self-assessment questionnaire based on the final instrument developed by Kantona and Munadi (2024) for prospective teacher students in higher education. The original development study established content and construct evidence through expert review, CFA, and graded response model/item response theory analysis, followed by reliability analysis. The published final instrument contains 35 items across seven dimensions, and the reported factor loadings of the final items range from 0.459 to 0.902 (Kantona & Munadi, 2024). The present study therefore did not conduct a new construct-validity test. The role of the present analysis was to apply the final established item set consistently to the available response data.

Each retained statement used a five-point Likert response scale. Positively worded statements were scored from 1 to 5, while negatively worded statements were reverse-scored before calculating dimension and total scores. The seven dimensions and their final item counts are shown in Table 2. The same scoring procedure was applied to all participants so that the dimension scores could be compared on a common five-point metric.

Table 2. Final 35-Item Instrument Structure Used in the Study

Dimension	Final item numbers used	No. of items
Information literacy	1, 2, 4, 6, 8, 9, 12	7
Digital scholarship	13, 14, 15, 16, 17, 18	6
Learning skills	19, 20, 21	3
ICT literacy	22, 26, 27	3
Career and identity management	28, 29, 30, 31, 32, 33, 35	7
Communication and collaboration	37, 38, 41, 42	4

Dimension	Final item numbers used	No. of items
Media literacy	43, 44, 46, 47, 48	5
Total	Final 35 items	35

Data Analysis

Data analysis comprised descriptive statistics, sample-specific internal consistency estimation, achievement percentage, category distribution, and dimension-level comparison. The total score was calculated after reverse-scoring the retained negatively worded items. With 35 items and a five-point response scale, the maximum ideal score was 175 per respondent. The achievement percentage was calculated as obtained score divided by the maximum ideal score and multiplied by 100. The category criteria adopted from the study framework were 81–100% for high, 61–80% for moderate, 41–60% for low, and $\leq 40\%$ for very low.

Cronbach's alpha was calculated to describe the internal consistency of responses in the present sample. It was not used as a substitute for the original construct-validation evidence. This distinction is important because reliability is sample-dependent, whereas the evidence for the instrument's structure and item functioning was established in the original development study. Dimension means were calculated by averaging the retained item scores within each dimension, allowing comparison despite differences in the number of items per dimension.

The analysis also considered the practical meaning of the confidence interval around the overall mean. A 95% confidence interval was calculated for the mean total score and converted to the corresponding achievement percentage. Because the design was descriptive and the sample was purposive, the interval is interpreted as a statistical summary of the observed cohort rather than as a population estimate for all Biology Education students.

Table 3. Achievement Category Criteria

Percentage range	Category
81–100%	High
61–80%	Moderate
41–60%	Low
$\leq 40\%$	Very low

RESULTS AND DISCUSSION

Overall Digital Literacy Profile

The overall digital literacy score had a mean of 3.52 on the five-point scale. The corresponding achievement was 70.36%, which falls within the moderate category. The mean total score was 123.13 out of a maximum possible 175, with a standard deviation of 10.40. The 95% confidence interval for the mean total score was 120.01–126.26, equivalent to approximately 68.58–72.15% of the maximum ideal score.

From a teacher-education perspective, a moderate score should not be interpreted as evidence of inadequate access to technology or inability to use digital devices. Digital competence includes evaluative, communicative, ethical, pedagogical, and content-specific practices. The observed result therefore suggests a functional base from which more sophisticated competence can be developed. The distinction is important because students may be familiar with common platforms while still needing structured opportunities to evaluate sources, interpret digital evidence, select technology for pedagogical purposes, and produce trustworthy digital learning resources.

Table 4. Overall Digital Literacy Results

Indicator	Result
Number of respondents	45 students
Number of items	35 items
Maximum ideal score	175
Mean total score	123.13
Standard deviation	10.40
Mean score per item	3.52
Achievement percentage	70.36%

Indicator	Result
95% CI of achievement Category	68.58–72.15% Moderate

Table 5. Distribution of Students by Digital Literacy Category

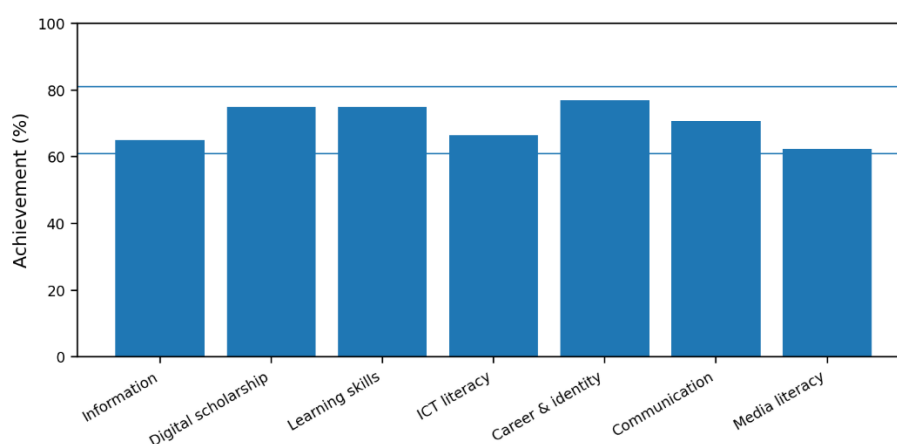
Category	Score range	Number	Percentage
Very low	≤40%	0	0.00%
Low	41–60%	2	4.44%
Moderate	61–80%	40	88.89%
High	81–100%	3	6.67%
Total	—	45	100.00%

The category distribution shows that 40 of the 45 students (88.89%) were in the moderate category, three students (6.67%) were in the high category, and two students (4.44%) were in the low category. No student was classified as very low. The strong concentration in the moderate range indicates that digital literacy is established at a functional level for most participants, but relatively few students demonstrate consistently high competence across all seven dimensions. This pattern supports the argument that familiarity with digital technology should not be equated with comprehensive digital competence (Adhani & Nursia, 2024).

Digital Literacy Profile by Dimension

Table 6. Digital Literacy Achievement by Dimension

No	Dimension	Items	Mean	Achievement	Category
1	Information literacy	7	3.25	65.08%	Moderate
2	Digital scholarship	6	3.75	75.04%	Moderate
3	Learning skills	3	3.75	74.96%	Moderate
4	ICT literacy	3	3.33	66.52%	Moderate
5	Career and identity management	7	3.84	76.83%	Moderate
6	Communication and collaboration	4	3.53	70.67%	Moderate
7	Media literacy	5	3.12	62.40%	Moderate

**Figure 1.** Seven-dimensional digital literacy profile of Biology Education students

All seven dimensions remained within the moderate category, but the profile was clearly uneven. Career and identity management was the highest dimension at 76.83%, followed by digital scholarship at 75.04% and learning skills at 74.96%. Communication and collaboration reached 70.67%. At the lower end, ICT literacy was 66.52%, information literacy was 65.08%, and media literacy was 62.40%. The pattern is important because it identifies specific competencies that may be masked by the overall mean.

Career and identity management as the strongest dimension may reflect students' routine participation in digital communication, academic platforms, social networking, and other online environments. Such experience can support awareness of digital presence and communication. However, the moderate rather than high category indicates that this strength should not be interpreted as full mastery of professional digital identity. For prospective

teachers, professional identity online includes ethical participation, privacy awareness, management of digital footprints, responsible communication, and the ability to distinguish personal from professional digital practices. The result is therefore best understood as a foundation that can be intentionally transformed into professional competence.

Digital scholarship (75.04%) and learning skills (74.96%) were also relatively strong. These dimensions are encouraging in Biology Education because academic biology increasingly depends on digital journal databases, electronic scientific resources, multimedia representations, and technology-supported learning environments. Students appear to have a reasonably functional basis for using digital environments to support academic learning. Nevertheless, successful digital scholarship should progress beyond access toward evidence comparison, source credibility evaluation, citation practices, interpretation of biological data, and construction of evidence-based explanations. In other words, the curriculum should move students from consuming digital information to interrogating and producing knowledge.

The Lowest Dimensions: Media, Information, and ICT Literacy

Media literacy was the weakest dimension, with an achievement of 62.40%, only slightly above the lower boundary of the moderate category. This result is particularly important in Biology Education because students are exposed to large quantities of scientific and pseudo-scientific information through social media, video platforms, news portals, and visually persuasive digital content. The difficulty is not simply finding information. Students need to recognize how the source, medium, visual design, framing, context, and presentation of evidence can influence interpretation. In a biology context, this includes distinguishing peer-reviewed evidence from unsupported health claims, recognizing misleading biological images or graphs, and checking whether a conclusion is warranted by the underlying data.

The finding is consistent with Farid et al. (2024), who identified information-source evaluation and consideration of the effects of digital messages as important areas for Biology Education students. The present result extends that concern by placing media literacy alongside six other dimensions and showing that it is the lowest relative component within this cohort. For future biology teachers, the implication is substantial: weak media literacy can be transferred into classroom practice if teachers select digital materials primarily because they are attractive, accessible, or popular rather than because they are scientifically and pedagogically credible.

Information literacy was also comparatively low at 65.08%. Information literacy is foundational to biology because scientific learning requires students to search, compare, evaluate, synthesize, and cite evidence. The moderate score suggests that students can work with information but may need more systematic practice in evaluating the quality and relevance of sources. A practical response is to embed source-comparison tasks into biology assignments. For example, students can be asked to compare a peer-reviewed research article, a science-news article, and a social-media post addressing the same biological issue; they then identify claims, evidence, authorship, publication context, and limitations before deciding which source is appropriate for classroom use.

ICT literacy reached 66.52%, making it the third-lowest dimension. The result should not be reduced to a question of whether students can operate computers or mobile devices. In teacher education, ICT literacy concerns selecting and using technologies appropriately for particular learning purposes. A student may be able to operate a platform but still be uncertain about when a simulation, virtual laboratory, spreadsheet, digital microscope, learning-management system, or interactive assessment is pedagogically justified. Falloon (2020) emphasized the movement from basic digital literacy toward teacher digital competence, while Feng and Sumettikoon (2024) highlighted the importance of meaningful digital competence in teacher practice.

Comparative Interpretation with Previous Biology Education Studies

The present profile should be interpreted in relation to empirical studies that use different conceptualizations of digital literacy. Nurbaya (2023), working with 71 prospective biology teachers, reported high overall competence and particularly strong information skills, while safety and problem-solving were the weakest areas. The current cohort showed the opposite pattern in one important respect: information literacy was among the lower dimensions, whereas career and identity management was the strongest. The difference may arise from

the instruments and learning contexts used in the two studies, but it also highlights that a high overall score can conceal particular competencies that need attention.

Adhani and Nursia (2024) reported a moderate digital competence profile among prospective biology teachers, which is closer to the present finding. Their study and the present study both suggest that future biology teachers often possess a workable technological foundation without necessarily demonstrating high-level competence across all areas. However, direct numerical comparison should be avoided because the instruments do not measure identical constructs. The value of comparison is therefore conceptual: across studies, digital competence emerges as a developmental target rather than a fixed characteristic of students entering teacher education.

Farid et al. (2024) provide a particularly relevant comparison because their participants were also Biology Education students and their study focused on digital literacy. Their findings emphasized evaluation of information and awareness of message effects. The current finding of relatively low media literacy provides convergent evidence that critical engagement with digital information deserves greater attention in biology teacher preparation. The convergence is more meaningful than a direct comparison of percentages because the studies used different item structures.

The present study also differs from intervention studies in its purpose. It does not claim that a particular model causes improvement. Instead, it identifies a baseline from which targeted interventions can be designed. This distinction is useful for program-level curriculum planning. If the strongest dimensions are already moderately developed, interventions can focus on the dimensions with the greatest developmental need rather than allocating equal instructional time to every digital competency.

Curriculum Implications for Biology Education

The seven-dimensional profile suggests that digital literacy should be treated as a distributed curriculum responsibility. A stand-alone digital-literacy course can introduce concepts, but students are more likely to develop durable competence when the same practices are repeatedly applied in authentic disciplinary and pedagogical settings. Biology courses can require digital evidence evaluation; research-methodology courses can develop scientific searching and data literacy; instructional-design courses can require technology-pedagogy alignment; and teaching-practicum courses can assess responsible digital communication and classroom technology use.

Media literacy should be prioritized because it is the lowest dimension. Students can be assigned to fact-check biological claims circulating online, compare visual representations of the same biological phenomenon, analyze the rhetorical features of short-form science videos, and identify misleading graphs or images. These activities would make media literacy observable and discipline-specific rather than treating it as a generic discussion of social media.

Information literacy should be strengthened through structured scientific-search tasks. Students can learn to formulate search strategies, identify primary literature, compare peer-reviewed and non-peer-reviewed sources, trace claims to original evidence, and synthesize multiple sources into a defensible explanation. Such tasks can be incorporated into laboratory reports, literature reviews, lesson plans, and project-based learning. The objective is to move from 'finding information' to 'constructing an evidence trail.'

ICT literacy can be strengthened through authentic design and analysis tasks. For example, students can select digital tools for a specific biology-learning objective, justify the choice using pedagogical criteria, develop a small digital learning product, and evaluate its usability and scientific accuracy. Virtual laboratory activities, digital microscopy, spreadsheet-based data analysis, interactive simulations, learning-management systems, and technology-enhanced assessment can all serve as contexts for this competence.

Career and identity management, the strongest dimension, can be linked more explicitly to professional teacher identity. Students can build professional digital portfolios, practice ethical online communication, reflect on digital footprints, and develop guidelines for responsible use of artificial intelligence and digital media in teaching. This would transform an already relatively strong dimension into a concrete professional competency that can be assessed during microteaching and field-experience activities.

Table 7. Suggested Curriculum Responses Based on the Digital Literacy Profile

Priority dimension	Observed profile	Suggested authentic learning response	Potential course context
Media literacy	Lowest (62.40%)	Fact-check biology claims; analyze misleading visuals; evaluate source and message effects	Biology content, media development, science communication
Information literacy	65.08%	Compare primary literature and secondary sources; build evidence trails; synthesize claims	Research methodology, literature review, biology seminars
ICT literacy	66.52%	Select and justify digital tools; virtual labs; digital assessment; data tools	Educational technology, instructional design, practicum
Communication & collaboration	70.67%	Digital peer review, collaborative scientific communication, group evidence synthesis	Project learning, research, microteaching
Learning skills	74.96%	Self-regulated digital learning, reflective e-portfolios, learning analytics	Independent learning, pedagogy
Digital scholarship	75.04%	Evidence-based digital products, research synthesis, scientific visualization	Research, biology seminars, product development
Career & identity management	Highest (76.83%)	Professional digital portfolio, ethics, privacy, digital footprint reflection	Microteaching, practicum, professional development

Table 8. Synthesis of Findings, Interpretation, and Curriculum Implications

Dimension	Finding	Interpretation	Curriculum implication
Media literacy	62.40% (lowest)	Critical evaluation of digital media needs the greatest strengthening.	Fact-check biological claims; analyze visualizations and source framing.
Information literacy	65.08%	Students can work with information, but evidence evaluation needs more structure.	Compare primary/secondary sources; build evidence trails and syntheses.
ICT literacy	66.52%	Technology use is functional but needs stronger pedagogical justification.	Select tools for biology objectives; use virtual labs and digital assessment.
Communication & collaboration	70.67%	Digital interaction is functional and can support scientific collaboration.	Use peer review, collaborative evidence synthesis, and science communication.
Learning skills	74.96%	Digital learning routines are relatively established.	Develop self-regulated digital learning and reflective portfolios.
Digital scholarship	75.04%	Students show a stronger base for academic digital use.	Extend toward research synthesis, scientific visualization, and evidence-based products.
Career & identity management	76.83% (highest)	Frequent digital participation may support professional identity, but mastery is not yet high.	Develop professional portfolios, ethics, privacy, and responsible digital footprints.

Table 8 translates the descriptive results into a curriculum-oriented interpretation. The key issue is not the absence of digital competence, but the mismatch between relatively

comfortable academic and social digital practices and weaker critical-evaluative practices. This supports a developmental curriculum in which students repeatedly encounter the same digital competencies at increasing levels of complexity as they move through Biology Education courses.

Reliability, Measurement Scope, and Study Limitations

The Cronbach's alpha obtained from the 35 retained items in the present sample was 0.894. This coefficient indicates strong internal consistency of the responses in this cohort. However, it should not be interpreted as a new validation of the instrument. The construct validity and item-level psychometric evidence were established by Kantona and Munadi (2024) through expert review, CFA, and GRM/IRT analysis. The present study's contribution is the application of that final instrument to a Biology Education context and the description of the resulting competency profile.

Several limitations should be considered when interpreting the findings. First, the sample consisted of only 45 fourth-semester students from one Biology Education program at one university, and purposive sampling limits statistical generalization. Second, the questionnaire was a self-assessment measure, so responses may not perfectly represent observed digital performance. Third, the dataset did not include demographic or technology-access variables, preventing analysis of possible differences associated with gender, age, device access, internet conditions, or previous digital-learning experience. Fourth, the descriptive design does not permit causal conclusions about why particular dimensions are stronger or weaker.

CONCLUSION

The participating Biology Education students demonstrate a functional but still developing level of multidimensional digital literacy. The most meaningful feature of the profile is not the overall moderate level by itself, but the uneven pattern across the seven dimensions. Career and identity management, digital scholarship, and learning skills provide relatively stronger foundations, whereas media literacy, information literacy, and ICT literacy represent more immediate areas for strengthening. This pattern indicates that students are not simply lacking digital exposure; rather, they need more systematic opportunities to use digital technology critically, strategically, and pedagogically within biology contexts.

RECOMMENDATION

Future research should replicate the assessment with larger and more diverse samples across Biology Education programs and include relevant participant characteristics and technology-use variables. Comparative studies across semesters or institutions could identify developmental patterns, while correlational studies could examine relationships between digital literacy and pedagogical knowledge, research experience, learning autonomy, or technology use. The use of performance-based tasks alongside self-assessment is also recommended to reduce the limitations associated with self-report.

ACKNOWLEDGMENT

The authors thank the Biology Education students who participated in the study and contributed their responses. The authors also acknowledge the Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Islam Riau, for supporting the implementation of the academic activities through which the data were collected. No specific external research funding was reported for this study.

REFERENCES

- Aumann, A., Schnebel, S., & Weitzel, H. (2024). Teaching biology lessons using digital technology: A contextualized mixed-methods study on pre-service biology teachers' enacted TPACK. *Education Sciences*, 14(5), 538. <https://doi.org/10.3390/educsci14050538>
- Adhani, A., & Nursia, N. (2024). Pre-service Biology Teachers' Digital Competences Profile. *Jurnal Pendidikan Indonesia Gemilang*, 4(1), 54–66. <https://doi.org/10.53889/jpig.v4i1.355>

- Dolezal, D., Motschnig, R., & Ambros, R. (2025). Pre-Service Teachers' Digital Competence: A Call for Action. *Education Sciences*, 15(2), 160. <https://doi.org/10.3390/educsci15020160>
- Falloon, G. (2020). From digital literacy to digital competence: The teacher digital competency framework. *Educational Technology Research and Development*, 68, 2449–2472. <https://doi.org/10.1007/s11423-020-09767-4>
- Farid, A. M. M., Zubaidah, S., & Munzil. (2024). Profile analysis of digital literacy skills of biology education students. *Edubiotik: Jurnal Pendidikan, Biologi dan Terapan*, 9(2), 71–80. <https://doi.org/10.33503/ebio.v9i02.1>
- Feng, L., & Sumettikoon, P. (2024). An empirical analysis of EFL teachers' digital literacy in Chinese higher education institutions. *International Journal of Educational Technology in Higher Education*, 21, 42. <https://doi.org/10.1186/s41239-024-00474-1>
- Hong, J. (2025). The impact and perception of digital media utilization teaching programs on the digital literacy of pre-service biology teachers. *Biology Education*, 53(1), 92–102. <https://doi.org/10.15717/bioedu.2025.53.1.92>
- Hidayat, M. L., Abdurahman, S. G., Astuti, D. S., Prabawati, R., Anif, S., Hariyatmi, H., & Zannah, F. (2025). Pilot Study of Digital Competency Mapping of Indonesian Preservice Teachers: Rasch Model Analysis. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 7(1), 100–116. <https://doi.org/10.23917/ijolae.v7i1.23935>
- Kantona, H., & Munadi, S. (2024). Development of digital literacy assessment instrument for prospective teacher students in higher education. *Jurnal Penelitian dan Evaluasi Pendidikan*, 28(2), 173–185. <https://doi.org/10.21831/pep.v28i2.72712>
- Momdjian, L., Manegre, M., & Gutiérrez-Colón, M. (2025). A study of preservice teachers' digital competence development: Exploring the role of direct instruction, integrated practice, and modeling. *Evaluation and Program Planning*, 109, 102538. <https://doi.org/10.1016/j.evalprogplan.2025.102538>
- Nurbaya, N. (2023). Identifying prospective biology teachers' digital literacy competence at Cenderawasih University. *Jurnal Penelitian Pendidikan IPA*, 9(11), 10051–10058. <https://doi.org/10.29303/jppipa.v9i11.4908>
- Ramadani, S. D., & Lestari, A. (2024). Empowering prospective teachers' scientific and digital literacy through exploring-resuming integrated criticizing (ERIC) in biology classroom. *Biosfer: Jurnal Pendidikan Biologi*, 17(1), 223–232. <https://doi.org/10.21009/biosferjpb.40886>
- Rifqiwati, I., Fitriana, D. E. N., Sari, I. J., Fadilah, Y., & Intakanok, C. (2025). Mapping the Digital Literacy of Pre-Service Biology Teachers as a Needs Analysis in Developing of STEM-Based Liveworksheets. *Jurnal IPA & Pembelajaran IPA*, 9(4), 1218–1228. <https://doi.org/10.24815/jipi.v9i4.49732>
- Rosamsi, S., & Nurdiani, N. (2024). Implementing the TPACK model to enhance learning outcomes of future biology teachers for the digital era. *JPBIO (Jurnal Pendidikan Biologi)*, 9(2), 294–302. <https://doi.org/10.31932/jpbio.v9i2.3940>
- Sumadi, S. W., Nurhayati, B., & Faisal, F. (2025). Digital literacy of biology education students: Trends and differences based on semester level. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan*, 7(3), 466–473. <https://doi.org/10.20527/bino.v7i3.22361>
- Sudirgayasa, I. G., Sulisetijono, Mahanal, S., Gofur, A., Dewi, N. P. S. R., Ratnani, D. A. S., Rai, I. G. A., & Sudiana, I. M. (2025). A profile of digital literacy, problem-solving skills, and socio-cultural awareness among pre-service biology teacher in Bali. *Journal of Science and Education Research*, 4(1), 95–102. <https://doi.org/10.62759/jser.v4i1.206>