

Designing Integrated Digital Tasks in Science-Specific Education: A Quasi-Experimental Study

Gaukhar Baitasheva¹, Aitzhamal Mussina², Galiya Medeuova¹, Ayaulym Umbettulla², Karlygash Zhamanbayeva¹

¹Department of Biology, Institute of Natural Sciences, Kazakh National Women's Teacher Training University, Almaty, Republic of Kazakhstan

²Department of Chemistry, Institute of Natural Sciences, Kazakh National Women's Teacher Training University, Almaty, Republic of Kazakhstan

Correspondence: Karlygash Zhamanbayeva, Department of Biology, Institute of Natural Sciences, Kazakh National Women's Teacher Training University, Almaty, 050000, 99 Aйтеке Би Str., Republic of Kazakhstan. Email: karlygash.zhamanbayeva@gmail.com

Received: February 7, 2026

Accepted: April 8, 2026

Online Published: April 12, 2026

doi:10.11114/jets.v14i3.8464

URL: <https://doi.org/10.11114/jets.v14i3.8464>

Abstract

The rapid digitalization of higher education has increased the need to develop students' digital competence in ways that are closely aligned with disciplinary learning. In natural science education, particularly in ecophysiology, digital tools should support inquiry, data interpretation, and systems thinking rather than serve as isolated technological additions. This study aims to examine how integrated, collaborative digital tasks influence undergraduate students' digital competence in a subject-specific context. A quasi-experimental design was employed in an ecophysiology course. Students were divided into experimental and control groups. The experimental group completed inquiry-based integrated tasks using collaborative visual platforms, while the control group engaged in comparable tasks through conventional instructional approaches. Digital competence was assessed via pre- and post-tests and qualitative analysis of students' task artefacts. Results showed that students using integrated digital tasks developed greater overall digital competence than the control group, with notable improvements in motivational, content-related, and operational components. The strongest effects were observed in students' ability to independently and purposefully use digital tools within collaborative scientific inquiry. Qualitative analysis revealed that collaborative platforms promoted deeper engagement, clearer conceptual representations, and more coherent reasoning processes. These findings demonstrate that digital competence develops most effectively when digital tools are embedded in discipline-specific, inquiry-oriented tasks. The study's novelty lies in its focus on ecophysiology and evidence that collaborative visual platforms can act as epistemic tools, supporting both digital and scientific competence. This contributes to a more situated understanding of digital skill development in higher science education.

Keywords: ecophysiological intervention, digital competence, digital skills, Miro Board, STEM education

1. Introduction

1.1 Introduce the Problem

Against the background of rapid digitalization, higher education institutions face an imperative to prepare students with disciplinary knowledge and digital competencies that enable effective participation in inquiry-based and data-rich academic and professional environments. Digital competence in higher education encompasses learners' ability to search, evaluate, process, and create information using digital tools, as well as cooperate to solve problems in digital contexts (Zhao et al., 2021). This construct integrates information literacy, communication, and research skills, which make it distinct from basic ICT literacy.

Kakogianni et al. (2025) identify digital tools, particularly those that afford collaborative visual interaction and real-time co-creation, as having substantial potential to enhance active and constructivist learning practices. Platforms such as Jamboard, Miro, Padlet, and other collaborative whiteboards enable group brainstorming, knowledge representation, and shared problem-solving (Beltrán-Martín, 2019; Srivastava, 2025). They align with socio-constructivist theories of learning, where knowledge emerges through social interaction and co-construction (Rath, 2025).

Within science and STEM education, digital technologies support interactive inquiry, collaborative experimentation, and visualization of complex phenomena, which are essential components of scientific reasoning and deep conceptual engagement. Recent research on technology integration suggests that when digital tools are purposefully embedded in curriculum design, they can improve student engagement, facilitate collaborative knowledge construction, and support formative feedback practices (Dyka et al., 2023; Pelaez-Sanchez et al., 2024).

Despite these positive indications, the evidence base remains disproportionately focused on broad measures of digital competence or general-purpose digital learning environments. Few studies investigate subject-specific contexts where the nature of disciplinary knowledge and task demands interact uniquely with digital tool use (Elías et al., 2022). For example, ecophysiology, an interdisciplinary field that examines physiological processes in relation to environmental variables, requires students not only to master content but to synthesize data, interpret complex causal systems, and engage with dynamic models of organismal responses. However, empirical research on how digital platforms enhance digital skill development specifically within such natural science courses is scarce.

Moving further, collaborative visual platforms like Jamboard and Miro are discussed in educational literature primarily in terms of their general collaborative affordances, with limited evidence on their didactic impact on subject-specific cognitive and digital skill outcomes (Ríos-Muñoz et al., 2025). While studies in project-oriented and engineering contexts show that structured use of digital tools can improve collaboration and assessment transparency, these have not been systematically examined in ecophysiological inquiry learning yet.

Thus, the considered literature reveals at least two key gaps. The first one concerns a lack of empirical evidence on the effectiveness of collaborative digital platforms in fostering integrated digital competences within science-specific courses. The second one comes from the need to clarify how integrated tasks designed to combine disciplinary reasoning, digital tool use, and collaborative processes contribute to measurable improvements in students' digital competence. Addressing these gaps, the present study aims to determine the effectiveness of collaborative visual platforms (Jamboard and Miro) in developing students' digital skills within an ecophysiology course. By focusing on a discipline-specific implementation of integrated digital tasks, this research contributes evidence on how such tools mediate the development of complex digital and cognitive competencies in natural science education, a context underrepresented in current research

According to the defined aim, the following objectives are determined in this study:

- to characterize the design and implementation of integrated tasks using Jamboard and Miro within an ecophysiology curriculum;
 - to assess changes in students' digital competences associated with engagement in these tasks;
- to analyze students' collaborative interactions and task artefacts to understand how digital platforms contribute to the formation of discipline-specific digital skills.

2. Materials and Methods

2.1 Research Design and Participants

This study employed a quasi-experimental research design with pre-test and post-test control to examine the effectiveness of integrated digital tasks in developing students' digital skills within an ecophysiology course. Since random assignment of participants was not feasible without disrupting the existing academic structure, a quasi-experimental approach was selected. Instead, the study was conducted in an authentic instructional environment using intact student groups. The study sample consisted of 58 second-year undergraduate students enrolled in a chemistry–biology teacher education curriculum at the Kazakh National Women's Teacher Training University.

Pre-existing (intact) student groups that had been formed prior to the study were divided into the experimental ($n = 29$) and control ($n = 29$) groups, allowing the intervention to be implemented under authentic instructional settings. This approach is typical for quasi-experimental research conducted in authentic educational settings and allows the intervention to be implemented without disrupting the existing academic structure.

The research design was structured to compare learning outcomes between two groups that followed the same curriculum content, duration, and assessment schedule but differed in the mode of task implementation. The experimental group completed integrated tasks using collaborative digital platforms (Jamboard and Miro), whereas the control group engaged in analogous tasks using conventional instructional approaches. This design helped to isolate the pedagogical effect of integrated digital tasks while controlling for content exposure and instructional time.

The study was conducted over a nine-week academic period during the second semester of the 2024–2025 academic year. The pre-test was administered to both groups in order to verify baseline equivalence before the intervention. Since random assignment was not possible, confirming that the groups had comparable initial levels of digital competence was an essential methodological requirement of the study. The first week was dedicated to orientation and the pre-test

administration. Pre-test results indicated comparable baseline levels of digital skills and subject understanding. No statistically significant differences were observed between groups at the outset, supporting the assumption of initial homogeneity. The intervention phase lasted seven weeks and involved systematic task-based learning activities aligned with the ecophysiology curriculum. The final week was devoted to post-test administration and data consolidation. Throughout the study, both quantitative and qualitative data were collected to provide a comprehensive evaluation of changes in students' digital skills.

Participation in the study was voluntary, and all students were informed about the purpose and procedures of the research. Ethical considerations were addressed by ensuring anonymity of responses, confidentiality of data, and the right to withdraw from the study at any stage without academic consequences.

The choice of a mixed-methods perspective within the quasi-experimental framework allowed for triangulation of findings. Quantitative data provided measurable evidence of skill development, while qualitative data offered insight into how students engaged with digital tools and integrated tasks. This combination helped to strengthen the validity of conclusions regarding the pedagogical effectiveness of the intervention.

2.2 Intervention and Integrated Task Design

The core pedagogical intervention involved implementing integrated tasks systematically in the experimental group. Integrated tasks were designed as learning activities that simultaneously required the application of subject knowledge, research-oriented reasoning, and purposeful use of digital tools. Each task was aligned with specific learning objectives of the ecophysiology course and structured to promote collaborative inquiry and digital competence.

In the experimental group, integrated tasks were implemented using Jamboard and Miro as collaborative visual platforms. These tools were selected because of their capacity to support real-time interaction, shared visualization, collective data organization, and iterative refinement of ideas. Tasks were completed in small groups, encouraging peer interaction and joint problem-solving. Students used the platforms to analyze datasets, construct visual models, compare environmental effects, and document their reasoning processes (Figure 1).

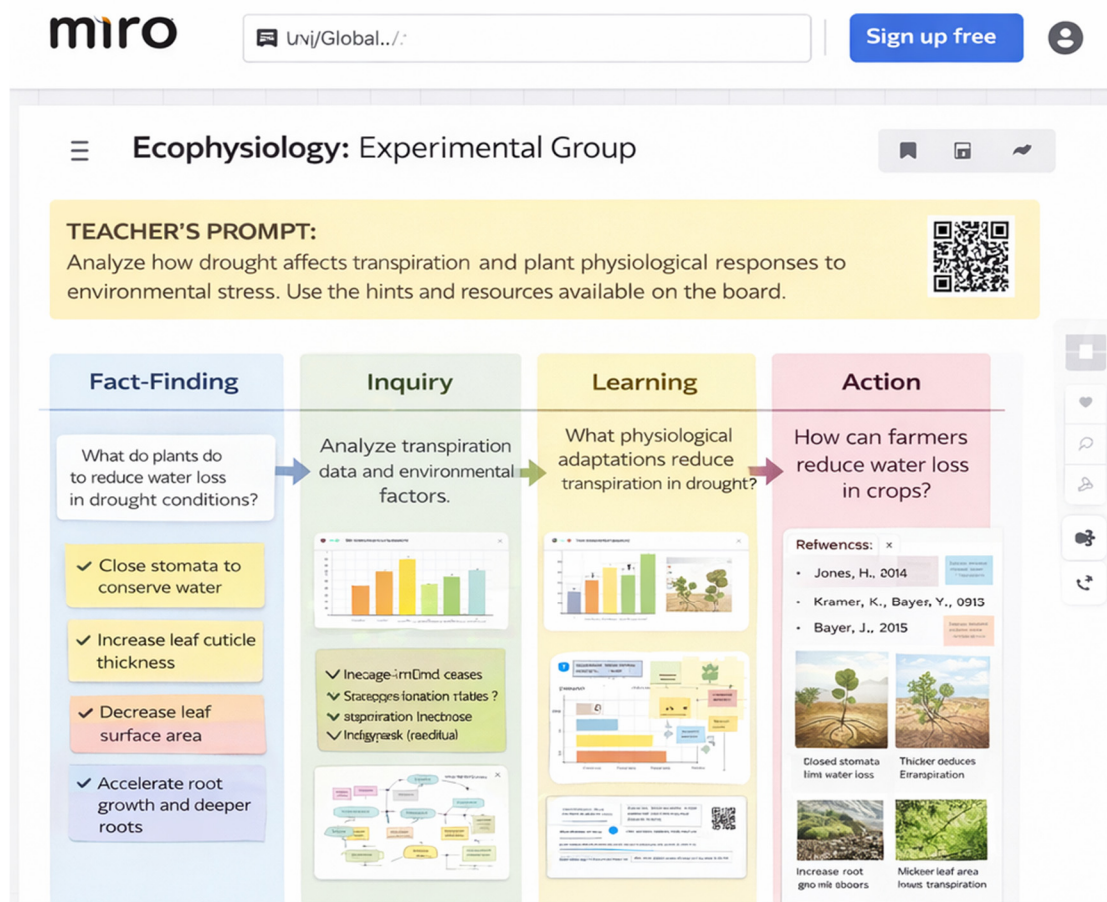


Figure 1. Integrated digital tasks using the Miro Board

Source: made by the authors

The control group followed the same course content and schedule but completed tasks using traditional instructional methods, such as written responses, slide presentations, tables, and individual explanations (Figure 2). While students in the control group were allowed to use basic digital resources (e.g., word processors or presentation software), they did not engage in structured collaborative work on Jamboard or Miro Board. This distinction ensured that differences in outcomes could be attributed to the integrated digital task approach rather than general exposure to digital technology.

TEACHER'S TASK:
Analyze how drought conditions affect plant transpiration and physiological responses using lecture materials and the textbook. Answer the questions individually and submit written responses.

TASK 1. Content Comprehension
What physiological mechanisms do plants use to reduce water loss under drought conditions? *

Expected answers:

- ✓ Stomatal closure
- ✓ Reduction of leaf surface
- ✓ Increased leaf cuticle thickness

Soil Moisture	
High	→
Moderate	→
Low	→

*Students were given a static table or printed graph.

Format and Tools

- Individual work
- Written answers
- Tables and static images
- No collaborative digital tools

Learning Focus

- Reproduction of theoretical knowledge
- Individual reasoning
- Content understanding without digital integration

TASK 2. Data Interpretation
Based on the provided table, **describe** how transpiration rates change under different soil moisture levels. *

Soil Moisture	Transpiration Rate
High	→ High
Moderate	→ Moderate
Low	→ Low

*Students were given a static table or printed graph.

Learning Focus

- Reproduction of theoretical knowledge
- Individual reasoning

TASK 3. Concept Explanation
Explain how environmental factors influence plant water balance during drought stress.

Student activity:

- Written explanation (150–200 words)
- Use of lecture notes and textbook only

TASK 4. Application Question

- Short written answer
- No collaborative discussion

*Submission required

Figure 2. Tasks designed for control group

Source: made by the authors

Task design was informed by the FILA method, which structures learning activities into four stages: Fact-finding, Inquiry, Learning, and Action (Abubakar & Arshad, 2015). During the fact-finding stage, students collected relevant information from textbooks, scientific sources, and provided datasets. The inquiry stage involved discussion and interpretation of data within groups. In the learning stage, students formulated guiding questions and clarified conceptual relationships. Finally, the action stage required applying acquired knowledge to solve ecophysiological problems or draw evidence-based conclusions.

2.3 Assessment Methods and Variables

The assessment of students' digital skills was grounded in established approaches to educational measurement and mixed-methods evaluation. A combination of pre-test and post-test assessments and qualitative task verification was employed to capture both measurable changes in skill levels and qualitative differences in students' use of digital tools, which is consistent with recommendations for evaluating complex educational interventions (Creswell & Plano Clark, 2018). Digital skills were operationalized as a multidimensional construct comprising motivational, content-related, and operational components. This operationalization follows widely used conceptualizations of digital competence as an

integrated set of cognitive, technical, and affective dimensions rather than a single technical skill (Ferrari, 2013; van Laar et al., 2017).

Quantitative data were collected using a criterion-referenced pre-test and post-test design, a method commonly applied to evaluate instructional effectiveness in quasi-experimental educational research (Shadish et al., 2002). The test instrument consisted of seven items aligned with the learning objectives of the ecophysiology course and the adopted digital competence framework. Each item was scored dichotomously (1 = correct or adequate response; 0 = incorrect or insufficient response), following standard pedagogical assessment practice when the focus is on mastery of predefined competencies rather than scale construction (Brookhart, 2018). Group-level frequencies of correct responses were then calculated. Based on aggregated test scores, students' digital skills were classified into high, medium, and low levels, an approach frequently used in competence-based educational studies to support interpretability of results (Ibrahim et al., 2022).

Besides the quantitative assessment, qualitative verification of integrated tasks was conducted. Verification involved a systematic evaluation of students' task artefacts to determine whether digital tools were used purposefully and in alignment with instructional objectives. This procedure corresponds to performance-based assessment, which is recommended for evaluating applied digital competencies that cannot be fully captured through test scores alone (Redecker, 2017).

Qualitative data included collaborative boards created on Jamboard and Miro, written task submissions, and records of group discussions. These data were analyzed using thematic analysis, following the procedures outlined by Braun and Clarke (2006). The analysis focused on three analytical criteria: correctness of subject content, coherence of reasoning, and appropriateness of digital tool use. Qualitative findings were used to contextualize and interpret the quantitative results rather than to generate numerical indicators, in line with mixed-methods validation strategies (Creswell & Plano Clark, 2018).

2.4 Data Collection and Analysis

Data collection and assessment procedures were designed to ensure coherence between the research design, the instructional intervention, and the quantitative results presented. Multiple data sources were used to strengthen the validity of the findings and to capture both measurable changes in students' digital skills and qualitative aspects of task performance.

The primary data collection instrument was a researcher-developed pre-test and post-test administered via Google Forms. The test consisted of seven items, including five open-ended questions and two dichotomous (Yes or No) items. Content validity of the test instrument was established through expert review by two university lecturers specializing in biology education and educational technologies. The experts evaluated the relevance, clarity, and alignment of the items with course objectives and the study's conceptualization of digital skills. Minor revisions were made based on their feedback prior to data collection.

To examine differences between groups and changes over time, inferential statistical analysis was conducted using analysis of variance (ANOVA). A mixed-design ANOVA was applied to assess the effects of group (experimental vs. control) and time (pre-test vs. post-test) on digital skill scores. This approach allowed evaluation of both within-group changes and between-group differences associated with the instructional intervention. Assumptions of normality and homogeneity of variance were examined prior to analysis. Given the educational context and moderate sample size ($N = 58$), results were interpreted cautiously and supported by descriptive statistics.

Nevertheless, certain limitations should be acknowledged. Limitations include the single-institution context, moderate sample size, and uncontrolled differences in students' prior digital experience, suggesting directions for future multi-institutional and longitudinal research.

3. Results

As it was stated, a pre-test was administered to determine the initial level of students' digital competence. The maximum possible score was 7 points. To ensure comparability of groups at baseline, descriptive statistical analysis was administered. For each group, mean scores (M) and standard deviations (SD) were calculated to determine the central tendency and dispersion of digital competence levels. Each correct or adequate response was assigned one point, and total individual scores were calculated by summing correct responses across all items. Furthermore, minimum and maximum values were examined to verify the distribution range and detect potential outliers. Descriptive statistics demonstrated comparable baseline levels between the experimental and control groups (Table 1).

Table 1. Pre-test descriptive statistics

Group	n	Mean (M)	SD	Min–Max
Experimental	29	2.48	0.91	1–4
Control	29	2.41	0.88	1–4

Source: calculated by the authors

An independent-samples t-test confirmed that the difference between the groups at pre-test was not statistically significant, $t(56) = 0.29$, $p = .77$. Thus, both groups were statistically homogeneous at the outset of the study; students' digital competence was generally at a low-to-moderate level across both groups. Most participants demonstrated limited operational mastery of digital platforms and required teacher guidance to complete inquiry-based tasks.

After seven weeks of intervention, during which the experimental group engaged in integrated digital tasks using Jamboard and Miro and the control group completed analogous tasks using traditional approaches, a post-test was administered to assess changes in students' digital competence. The structure of the post-test fully replicated the pre-test to ensure measurement consistency and comparability of results across time points (Table 2).

Table 2. Post-test descriptive statistics

Group	n	Mean (M)	SD	Min–Max
Experimental	29	5.52	0.83	4–7
Control	29	4.31	0.95	3–6

Source: calculated by the authors

The results demonstrate substantial improvement in both groups; however, the magnitude of growth was markedly greater in the experimental group. Students who participated in collaborative digital tasks achieved higher overall digital competence scores than those in the control condition.

To assess the statistical significance of these differences and the effectiveness of the intervention over time, a 2×2 mixed-design ANOVA was conducted with *Group* (Experimental vs. Control) as the between-subjects factor and *Time* (Pre-test vs. Post-test) as the within-subjects factor (Table 3).

Table 3. Mixed-design ANOVA results

Effect	F	df	p	Partial η^2
Time	412.68	(1,56)	< .001	.88
Group	16.94	(1,56)	< .001	.23
Group $\times$ Time	24.61	(1,56)	< .001	.31

Source: calculated by the authors

A statistically significant main effect of *Time* was observed, $F(1,56) = 412.68$, $p < .001$, partial $\eta^2 = .88$. This indicates that digital competence increased significantly across both groups over the seven-week intervention period. The very large effect size ($\eta^2 = .88$) suggests that instructional exposure in general contributed substantially to skill development. A statistically significant main effect of *group* was also found, $F(1,56) = 16.94$, $p < .001$, partial $\eta^2 = .23$, indicating that overall performance differed between the experimental and control groups.

Most importantly, the *Group $\times$ Time* interaction effect was statistically significant, $F(1,56) = 24.61$, $p < .001$, partial $\eta^2 = .31$. This interaction effect confirms that the magnitude of improvement differed significantly between groups and provides strong evidence that the integrated digital task intervention had a measurable and meaningful pedagogical impact. The effect size ($\eta^2 = .31$) can be interpreted as large within the context of educational research.

While the mixed-design ANOVA demonstrated statistically significant interaction effects, it was also important to examine the practical magnitude of improvement within each group. In educational intervention studies, evaluating absolute post-test differences alone may not fully capture the extent of instructional impact. Therefore, to provide a more direct indicator of individual progress, gain scores were calculated.

For each participant, a gain score was computed as the difference between the post-test and pre-test total scores. By aggregating these individual gain values, mean gain scores and standard deviations were calculated separately for the experimental and control groups. Analyzing gain scores provides a clearer representation of pedagogical effectiveness, as it directly measures growth rather than final performance alone. The comparative results of the gain score analysis are presented in Table 4.

Table 4. Gain score comparison

Group	Mean Gain	SD
Experimental	+3.04	0.89
Control	+1.90	0.92

Source: calculated by the authors

An independent-samples t-test revealed a statistically significant difference between groups in gain scores, $t(56) = 4.79$, $p < .001$. The calculated effect size (Cohen's $d = 1.25$) indicates a large effect according to conventional benchmarks. This result confirms that the experimental group not only improved but did so at a substantially greater rate than the control group, strengthening the causal interpretation of the intervention's effectiveness.

Since interventions may not only increase mean scores but also reduce the proportion of low-performing students and expand the high-achievement segment, it is equally important to examine how performance is distributed across achievement levels. Total digital competence scores were categorized into three performance levels based on predefined criteria: high (6–7 points), medium (4–5 points), and low (0–3 points). The distribution of students across these three levels at post-test was calculated for both groups. Absolute frequencies (n) and corresponding percentages (%) were computed to ensure transparent comparison of structural differences. To determine whether the observed differences in level distribution were statistically significant, a chi-square (χ^2) test of independence was conducted (Table 5).

Table 5. Post-test distribution of digital competence levels

Level	Experimental (n=29)	%	Control (n=29)	%
High	15	51.7%	8	27.6%
Medium	11	37.9%	14	48.3%
Low	3	10.4%	7	24.1%

Source: calculated by the authors

A chi-square test indicated a statistically significant difference in distribution between groups, $\chi^2(2) = 6.84$, $p = .033$. More than half of the students in the experimental group reached a high level of digital competence, compared to only 27.6% in the control group. Furthermore, the proportion of low-level students was considerably smaller in the experimental group (10.4%) compared to the control group (24.1%). These findings suggest that collaborative digital platforms not only increased average scores but also shifted the distribution toward higher competence categories.

As outlined in the methodological framework, digital competence in this study was conceptualized as comprising three interrelated components: motivational, content-related, and operational. Each component reflected a distinct dimension of competence development: motivational, content-related, and operational. The sole total score analysis could not ensure the identification of specific dimensions that were most influenced by the intervention. Therefore, a component-level analysis was administered.

For analytical consistency, categorical performance levels (III – high, II – medium, I – low) were transformed into numerical values (3, 2, and 1, respectively). This conversion enabled quantitative comparison of pre-test and post-test mean scores for each component and facilitated the application of repeated-measures analysis. Mean values (M) were calculated separately for each group at both measurement points, allowing examination of developmental dynamics within and between groups (Table 6).

Table 6. Component-level analysis of digital competence development

Component	Group	Pre-test M	Post-test M	F (1,56)	p	Partial η^2
Motivational	Experimental	1.94	2.63	7.94	.007	.12
	Control	1.91	2.28			
Content-related	Experimental	1.88	2.47	5.31	.025	.09
	Control	1.85	2.19			
Operational	Experimental	1.82	2.64	18.27	< .001	.25
	Control	1.79	2.21			

Source: calculated by the authors

The interaction effect for the operational component was significant, $F(1,56) = 18.27$, $p < .001$, partial $\eta^2 = .25$. This indicates that the intervention had its strongest influence on applied digital performance, including independent use of collaborative platforms and task execution. Table 6 shows that the motivational component also demonstrated a significant interaction effect, $F(1,56) = 7.94$, $p = .007$, partial $\eta^2 = .12$. Students in the experimental group exhibited greater growth in research interest, engagement, and autonomous problem-solving initiative. The content-related component showed a statistically significant interaction effect, $F(1,56) = 5.31$, $p = .025$, partial $\eta^2 = .09$. Although the effect size was smaller compared to the operational dimension, the results indicate that integrated tasks contributed to deeper understanding of ecophysiological concepts in digital contexts.

The results of the quasi-experimental study provide convergent quantitative evidence that the systematic implementation of integrated digital tasks within an ecophysiology course significantly enhanced students' digital competence. While both groups demonstrated improvement over time, the experimental group exhibited significantly greater gains, as confirmed by mixed-design ANOVA, gain score analysis, effect size calculations, and categorical distribution

comparisons. The strongest impact was observed in the operational dimension of digital competence, suggesting that structured collaborative engagement on Jamboard and Miro particularly supports the development of applied digital skills.

4. Discussion

The present study examined the pedagogical effects of integrating collaborative digital platforms into ecophysiology intervention. The findings permit suggesting that structured engagement with integrated digital tasks supported deeper and more differentiated development of digital competence compared to traditional task formats. These effects were not limited to general technological literacy but extended to motivational engagement, conceptual understanding, and applied operational use of digital tools within scientific inquiry.

The observed advantage of the intervention aligns with a growing body of research emphasizing the importance of task–tool alignment rather than mere exposure to technology. Prior studies demonstrate that digital tools produce meaningful learning gains primarily when embedded within inquiry-oriented activities (Smetana & Bell, 2012; de Jong et al., 2014; Trujillo-Juárez, et al., 2025). In this respect, the current findings reinforce the argument that digital competence develops most effectively when tools function as epistemic supports for disciplinary thinking rather than as neutral delivery mechanisms.

Unlike studies that conceptualize digital competence as a generic or transferable skill set, the present results support a more situated interpretation. Research in higher education emphasizes that digital skills are context-dependent and shaped by disciplinary norms, cognitive demands, and forms of collaboration (Henderson et al., 2017; Markauskaite & Goodyear, 2017). Ecophysiology, as an interdisciplinary field dealing with environmental data synthesis, causal reasoning, and systems thinking, demands context for digital engagement. The stronger outcomes observed in the experimental group suggest that collaborative visual platforms are well-suited to supporting these disciplinary requirements.

The findings concerning the differential development of competence components are specifically important. The strongest effects were observed in the operational dimension of digital competence, which includes independent navigation of digital environments, purposeful selection of tools, and execution of tasks without continuous instructor guidance. This pattern is consistent with research indicating that hands-on, collaborative use of open-ended digital platforms promotes procedural fluency and adaptive expertise more effectively than scripted or individually completed digital activities (Kirschner & Stoyanov, 2018; Blanc et al., 2025). In contrast to more constrained learning management systems, platforms such as collaborative whiteboards require learners to actively structure information, negotiate meaning, and make decisions about representation, thereby strengthening applied digital skills.

At the same time, the study also demonstrated meaningful growth in motivational and content-related dimensions of digital competence. Increased motivation and engagement can be interpreted through the lens of self-determination theory, which highlights autonomy, competence, and relatedness as key drivers of intrinsic motivation (Ryan & Deci, 2020). Integrated digital tasks afforded students a higher degree of autonomy in organizing their work, negotiating solutions with peers, and choosing representational strategies, while collaborative platforms supported social interaction and shared responsibility. Similar motivational effects have been reported in studies of collaborative digital inquiry in biology and environmental science education, suggesting that well-designed digital collaboration can enhance students' willingness to engage in cognitively demanding tasks (Scheel et al., 2022; Orlov, 2025).

The improvement in content-related digital competence indicates that digital platforms did not distract from disciplinary learning but instead supported conceptual understanding within digital contexts. This finding contrasts with concerns raised in earlier literature that technology use may lead to superficial engagement or cognitive overload in science learning (Mayer, 2017). The results of the present study suggest that when digital tasks are carefully structured and aligned with learning objectives, collaborative platforms can facilitate deeper processing by making relationships visible, supporting comparison of cases, and enabling iterative knowledge construction. This interpretation is consistent with research on external representations in science education, which shows that shared visual artifacts can scaffold reasoning and promote conceptual change when learners actively manipulate and discuss them (Nicholas et al., 2015).

An additional contribution of this study lies in its focus on ecophysiology as a subject-specific context. Much of the existing literature on digital competence development in higher education is based on generic courses, teacher education programs, or technology-focused curricula. Fewer studies address natural science courses where digital tools must support empirical reasoning, data interpretation, and system-level thinking simultaneously. The present findings suggest that integrated digital tasks are particularly valuable in such contexts because they mirror authentic scientific practices, including collaborative data analysis, model construction, and evidence-based argumentation. This aligns with broader calls to design digital learning environments that approximate professional scientific activity rather than simplified classroom simulations (National Research Council, 2012).

The comparison between experimental and control conditions also highlights the limitations of traditional task formats in fostering advanced digital competence. While students in both groups demonstrated improvement over time, conventional

approaches relying on individual work and static digital outputs appeared less effective in supporting autonomous and flexible digital skill use. This supports prior research suggesting that passive or minimally interactive uses of technology tend to reinforce existing skill levels rather than transform learners' digital practices (Selwyn, 2016; Basilotta-Gómez-Pablos et al., 2025). In contrast, integrated digital tasks required students to actively coordinate content knowledge, digital operations, and collaborative decision-making, leading to more substantial competence development.

Thus, the findings contribute to the growing evidence that digital competence in higher education is best understood and developed as a situated, practice-oriented construct. The use of integrated digital tasks in ecophysiology instruction not only enhanced students' operational digital skills but also supported motivational engagement and disciplinary understanding. By embedding digital tools within collaborative, inquiry-based learning activities, educators can move beyond superficial technology integration toward pedagogically meaningful digital transformation in science education.

5. Conclusion

This study confirms that the integration of collaborative digital platforms into ecophysiology instruction can substantially enhance students' digital competence when such tools are embedded within well-designed, inquiry-oriented tasks. Rather than treating digital skills as generic or auxiliary abilities, the findings support a situated perspective in which digital competence emerges through purposeful engagement with disciplinary content, collaborative problem-solving, and reflective use of digital environments.

The implementation of integrated digital tasks enabled students to coordinate subject knowledge, research-oriented reasoning, and digital tool use in a coherent learning process. Compared to traditional task formats, collaborative visual platforms supported greater learner autonomy, more active participation, and clearer externalization of reasoning. These features appear particularly important in ecophysiology, where understanding complex interactions between organisms and environmental factors requires visualization, comparison, and iterative refinement of ideas. Digital platforms facilitated these processes by allowing students to jointly construct representations, discuss interpretations, and negotiate meaning in real time.

The results also highlight that digital competence is multidimensional. Integrated digital tasks contributed not only to operational proficiency but also to increased motivation and deeper engagement with content. Students demonstrated greater initiative in organizing their work, selecting appropriate digital tools, and applying them to solve ecophysiological problems. This suggests that collaborative digital environments can foster both technical fluency and epistemic engagement, supporting students' transition from guided use of technology toward more independent and reflective digital practice.

From a pedagogical perspective, the findings emphasize the importance of intentional task design. The effectiveness of digital platforms depended on their alignment with learning objectives and their role in supporting inquiry processes rather than information transmission. Simply introducing digital tools without integrating them into the cognitive and collaborative structure of the course is unlikely to yield comparable outcomes. Integrated tasks that combine disciplinary reasoning, collaboration, and digital action appear to be a critical condition for meaningful digital competence development.

In conclusion, this study contributes to higher science education by demonstrating that collaborative digital platforms can serve as epistemic tools that support both digital and disciplinary learning. The results underscore the value of subject-specific approaches to digital competence development and provide practical implications for designing ecophysiology and other natural science courses in digitally enriched learning environments.

Acknowledgments

Thank you to all colleagues who have helped, so that this research can be carried out and completed.

Author contributions

GB and KZh were responsible for study design and revising. AM and GM were responsible for data collection. AU drafted the manuscript and revised it. Authors' contributions are equal.

Funding

No funds, grants, or other support was received.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Redfame Publishing.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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