EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2026, 11(1), 26
eISSN: 2468-4368

lectito

Research paper

Integrating Mobile Technology in Inquiry-Based Instruction for Sustainable and Innovative Learning in Higher Education

Winarto[1], Misbah[2], Ariyatun[3], Erwinsyah Satria[4], Evita Widiyati[5], Sri Jumini[6], Pradina Parameswari[7], Galih Albarra Shidiq[8*]

[1] *Universitas Negeri Yogyakarta*, INDONESIA
[2] *Universitas Lambung Mangkurat*, INDONESIA
[3] *Universitas Negeri Jakarta*, INDONESIA
[4] *Universitas Bung Hatta*, INDONESIA
[5] *Universitas Hasyim Asy'ari*, INDONESIA
[6] *Universitas Sains Al Qur'an*, INDONESIA
[7] *Universitas Negeri Surabaya*, INDONESIA
[8] *Universitas Bhayangkara Jakarta Raya*, INDONESIA

*__Corresponding Author:__ galih.as@dsn.ubharajaya.ac.id

Citation: Winarto, Misbah, Ariyatun, Satria, E., Widiyati, E., Jumini, S., Parameswari, P., & Shidiq, G. A. (2026). Integrating mobile technology in inquiry-based instruction for sustainable and innovative learning in higher education. *European Journal of STEM Education, 11*(1), article 26. https://doi.org/10.20897/ejsteme/18304

Published: April 27, 2026

ABSTRACT

Digital transformation in higher education offers new opportunities to promote sustainability-oriented innovation and equitable learning in developing countries. This study investigates how integrating mobile phone technology and applications into inquiry-based instruction can enhance students' innovative thinking skills while promoting sustainable learning environments in university classes. Thirty Indonesian University students participated in a mixed-method intervention involving pre- and post-tests and semi-structured interviews to investigate the effects of mobile-supported inquiry learning on four components of innovative thinking: questioning, observing, exploring, and networking ideas. Quantitative analysis revealed significant improvements in questioning and exploring (Cohen's d = 0.48 and 0.82), while qualitative findings highlighted improvements in motivation, engagement, and digital literacy. The integration of mobile applications facilitated the development of advanced cognitive processes and improved the ability of students to connect conceptual learning with the solution of genuine, real-world problems. This study enhances Education for Sustainable Development (ESD) by employing hands-on and questioning methods in mobile learning. It demonstrates how digital teaching can be made user-friendly, thereby fostering the development of sustainability-focused, creative, and thoughtful learners. The findings provide valuable advice to universities that aspire to establish inclusive, efficient, and innovative learning experiences that are aligned with SDG 4 and SDG 9, particularly by identifying specific strategies and best practices that can enhance sustainability education.

Keywords: sustainable education, mobile technology, inquiry-based instruction, innovative thinking skills, education for sustainable development (ESD).

The digital transformation of education is reshaping how universities prepare graduates to meet the demands of a rapidly changing, sustainability-oriented global economy. In this context, higher education institutions play a crucial role in achieving the United Nations Sustainable Development Goals (SDGs), particularly in SDG 4 (Quality Education) and SDG 9 (Industry, Innovation, and Infrastructure), which aim to prepare learners with the capacity for innovation, critical reflection, and adaptive problem-solving. The emergence of digital and mobile technologies has enabled new pedagogical models that support sustainability through inclusive access, resource efficiency, and lifelong learning (UNESCO, 2020; Leal Filho et al., 2021), which are essential for higher education institutions to effectively contribute to the United Nations Sustainable Development Goals (SDGs) by enhancing educational quality and fostering innovation.

Innovative thinking is a fundamental 21st-century skill necessary for tackling intricate sustainability issues that demand creativity, inquiry, and interdisciplinary collaboration (Dyer et al., 2011; OECD, 2016). However, evidence indicates that many college students still struggle with thinking creatively. This is often because of traditional teaching methods that focus too much on the teacher and do not afford students enough chances to learn by doing (Saracaloglu et al., 2020), which limits their ability to develop critical thinking and problem-solving skills necessary for addressing real-world sustainability problems. This can make it harder for them to confront real-world sustainability problems, such as effectively applying theoretical knowledge to practical situations or collaborating on projects that require innovative solutions. The integration of mobile phone technology and applications offers a promising strategy for enhancing both learning engagement and sustainability outcomes. Mobile technologies provide cost-effective, scalable, and environmentally conscious alternatives to traditional laboratory-based instruction by promoting virtual experimentation, reducing material use, and enabling flexible access to educational resources (Keengwe & Bhargava, 2014).

Inquiry-based instruction, grounded in constructivist learning theory, encourages learners to explore real-world phenomena through questioning, observing, and problem-solving (Fosnot, 2013). When combined with mobile technologies, this approach supports Education for Sustainable Development (ESD) by engaging students in active, self-directed learning that cultivates digital literacy, collaboration, and reflective inquiry skills for sustainable societies (Tilbury, 2011). However, empirical evidence remains limited regarding how mobile-assisted inquiry-based instruction enhances innovative thinking in sustainable higher education contexts, particularly in developing countries.

Recent studies showed the innovative thinking skills of students in higher education have not yet reached their optimal performance levels. For example, Saracaloglu et al. (2020) found that students' innovative thinking remains inadequate, which is linked to an educational framework in Turkey that lacks enough experiential learning opportunities. Likewise, Sáez-López et al. (2019) identified a lack of creativity in the lesson plans developed by university students in Spain. This outcome arises from the educational experiences of university students who use the conventional strategy of auditory and visual engagement during lectures, which may not foster innovative thinking or adaptability in lesson planning. However, research conducted in Indonesia by Haryanto & Arty (2019) indicates that university students have challenges in course planning, which can hinder their academic success and limit their ability to engage fully with the curriculum, particularly in areas such as time management and prioritization of tasks. Consequently, it is essential to implement educational activities that provide university students with the ability to cultivate innovative thinking skills, such as workshops, collaborative projects, and mentorship programs that encourage creative problem-solving and critical thinking.

Although implementing mobile phone technology and applications that address knowledge model strategies can enhance innovative thinking skills among students for sustainable higher education, obstacles such as limited access to technology, resistance from educators, and insufficient training for effective use are still encountered when developing digital devices in their learning environments. These challenges encompass a lack of cognitive abilities required for understanding, as well as learning limitations, the accessibility of technology resources, and concepts (Aminatun et al., 2022; Setuju et al., 2022). The difficulties of utilizing learning strategies through m-learning applications in Indonesian higher education are further complicated by insufficient digital literacy and skills, especially when applying information technology for learning purposes, which includes limited resources and engagement in technology-oriented courses and self-competency improvements (Santoso et al., 2018; Winoto, 2022). This study addresses that gap by examining how the integration of mobile tools in inquiry-based instruction influences university students' innovative thinking skills in Indonesia. It contributes to both educational technology and sustainability research by (1) providing empirical evidence of mobile-supported inquiry learning in fostering innovative thinking, (2) demonstrating how digital pedagogy can advance sustainability competencies aligned with SDG 4 and SDG 9, and (3) offering practical recommendations for universities seeking to implement sustainable and inclusive instructional models in higher education.

LITERATURE REVIEW AND THEORETICAL UNDERPINNINGS

Innovative thinking is proposed as a crucial concept in the educational context for developing higher-order thinking skills (Eurostat, 2005; OECD, 2016). Research suggests that innovative teaching skills could reflect the creativity and originality of producing action and thought, e.g., teaching approaches and learning new ideas and skills (Xu & Chen, 2010; Lu et al., 2013; Sultan et al., 2025). Promoting innovative thinking skills in education encountered many obstacles across the curriculum, including the requirement for creative ways to provide university students with learning assistance and implementing new technological methods (Kalyani & Rajasekaran, 2018; Grass, 2024). Cognitively reconsidering design problems and redefining essential parameters for design interaction and limitations using basic-element models promotes innovative thinking (Li et al., 2022; Halpern et al., 2025). The explanation of innovative thinking and understanding of pedagogical methods to engage innovative thinking skills in classroom environments is limited, which often leads to misinterpretation and negatively affects the cognitive skills of underexplored university students across various disciplines, such as the inability to apply critical thinking and problem-solving skills effectively (Xu & Chen, 2010; Dyer et al., 2011; Lu et al., 2013; Anderson et al., 2014; Deiri, 2025). M-learning apps could boost the ability of cloud technologies to change and improve education by offering a variety of new methods and tools for different subjects and education levels, showing the challenges of limited access to physical resources, the need for flexible learning spaces, and the increasing importance of developing soft skills (Papadakis et al., 2024; Tolmie, 2024). This mindset promotes creativity, experimentation, and a willingness to take calculated risks. It furthers standard problem-solving by encouraging individuals to investigate unusual possibilities and embrace complexity (Webb, 2026).

The present study involved university students integrating mobile phone technology and applications into inquiry-based instruction (Yıldırım et al., 2024). The instructor informed university students about the learning science topics using m-learning applications prior to the intervention course. This intends to enhance university students' knowledge prior to classroom introduction. During the implementation phase, university students were required to identify and solve a problem. Additionally, they participated in active learning activities. The instructor was unable to assist in this process; university students turned to the instructor at specific points for support and guidance. The instructor provided support and guidance in various ways and articulated relevant points. This study employed the constructivism theory to support university students in the development of their knowledge and the enhancement of their cognitive abilities, including the articulation of evidential, conceptual, and methodological concepts (Karagiorgi & Symeou, 2005; Fosnot, 2013). In this context, using constructivist learning approaches could serve as a feasible instructional design to facilitate the development of university students' knowledge construction in innovative ways through engaging and authentic learning experiences (Karagiorgi & Symeou, 2005). Furthermore, constructivism represents a conceptual framework that highlights the educational experience of university students by facilitating their understanding of concepts, fostering reflective learning, and encouraging dialogic engagement through various activities, in addition to offering guidance on structuring the learning process (Fosnot, 2013).

The literature studies indicated that using an effective learning model and mobile phone technology and applications could explore students' thinking skills and impact the outcomes of learning in many ways. For instance, Lee et al. (2021) found that integrating mobile tools in educational environments could improve reflective thinking, adaptability, peer collaboration, emergent learning, and intense learning. Strycker (2020) emphasized that promoting digital devices in education could improve pedagogical approaches while considering variables such as self-efficacy, comfort, and stress to facilitate the learning environments. This emphasizes the significance of adopting m-learning applications in educational contexts, particularly in classroom teaching and learning methodologies, and investigating cognitive abilities. In addition to the advantages of mobile learning in higher education, many countries in Asia, America, Australia, and Europe have looked into using m-learning apps as new ways to teach and learn by incorporating augmented reality (AR), gamification, and social media along with learning management systems (LMS) to improve education and get students more involved in encouraging interaction, ongoing learning, and student motivation. Therefore, this study could help university students gain enough teaching knowledge about mobile phone technology and apps that meet the needs of their college courses and important skills for the 21st century.

Advanced technology enables portable devices, such as mobile tools, to facilitate daily activities, including photography, videography, note-taking, and gaming for educational purposes (Hwang et al., 2018; Ürek, 2024; Satria et al., 2024). Introducing university students to the practical application of technology in the classroom can enhance their knowledge and proficiency in teaching. Using m-learning applications in education can offer numerous benefits, such as enhancing university students' engagement in digital literacy and their willingness to apply technology in the classroom (Ürek, 2024). Mobile phone technology and applications hold considerable promise for enhancing pedagogy, organization, strategy, and content by accommodating diverse learning styles and providing educational materials accessible to anyone, at any time, and in various flexible formats such as podcasts, videos, or audio recordings (Keengwe & Bhargava, 2014; Winarto et al., 2025). However, measuring university students during learning activities could provide numerous benefits for the development of educational research.

METHOD

Research design

This study employed a pre-experimental design to utilize a combination of both quantitative and qualitative research approaches. The quantitative method was employed to investigate how the integration of mobile phone technology and applications can support and enhance science courses that promote innovative thinking skills among university students (Creswell & Creswell, 2017). The qualitative method was used to explore students' perspectives after the intervention (Cohen, 2007). The questionnaire was initially distributed to students using pre- and post-tests to assess the effectiveness of mobile devices in developing inquiry-based instruction in university classes. Therefore, the semi-structured interviews were shown to uncover the details of the students' opinions, experiences, and understanding of the concepts.

Participants

The participants consisted of 19–21-year-old university students from Indonesia who enrolled in general science coursework located in Central Java, Indonesia. The participants were of multiple races, e.g., Javanese, Sundanese, Betawi, Dayak, and Batak, as well as Papuan from lower-middle-income backgrounds. This comprised 6 male and 24 female university students. A purposive sampling strategy was employed to select participants who met specific inclusion criteria relevant to the study objectives. Students were intentionally recruited because they were enrolled in the targeted general science course in which the mobile-supported inquiry-based intervention was implemented (Creswell & Creswell, 2017).

Procedure and instruments

The data collection of this study was carried out in three phases designed to examine the effectiveness of the mobile phone technology and applications in inquiry-based instruction from a mixed-methods viewpoint.

Initial preparation and implementation

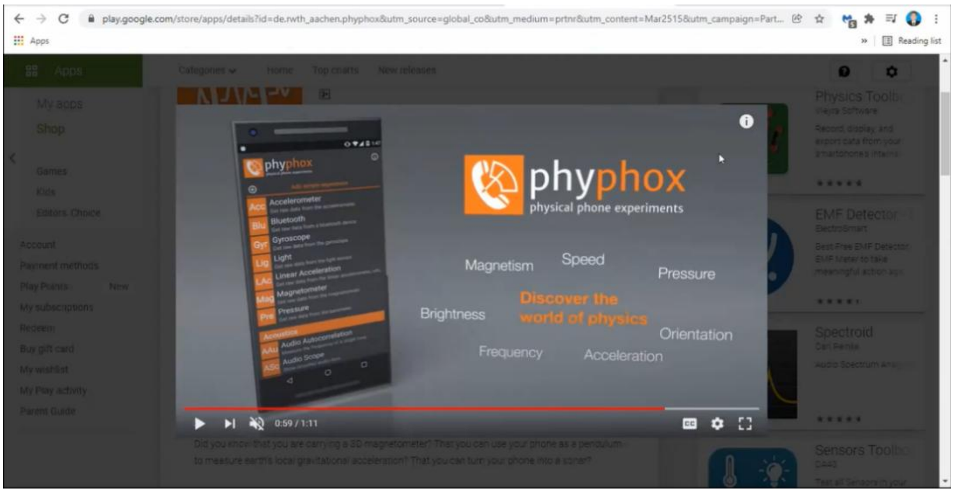
At the beginning of the preparation and implementation process, it started with giving a pre-test to participants before implementing coursework, and a post-test was at the end of the class. The authors conducted two-month-long courses consisting of one class per week. This class involved the participants in face-to-face participation and hands-on laboratory work using mobile phone technology and applications. The authors employed the inquiry-based instruction model to explore innovative thinking skills, encompassing step-by-step engagement, exploration, explanation, engineering, enrichment, and evaluation of impressions. This study examined the integration of m-learning applications in exploring university students' innovative thinking skills in elementary school teacher education based on the participants' responses in the learning activities. Consequently, we described the procedures as shown in **Figure 1**.

Figure 1
The implementation process of learning model activities

At the beginning of this implementation, University students were introduced to science topics: disaster concepts and house construction. Participants were asked for their opinions on listening to instructions, such as downloading the application on their mobile phones, reading the guidelines, and preparing equipment for learning activities. Additionally, the instructors explained the reason why university students are required to follow and clarify the information. In this situation, the role of instructors is important to encourage university students' understanding of science concepts, such as using digital devices and conducting experiments with the application. When faced with mobile tools in science lessons, university students' group work in the experiment step gained a thorough understanding of how to learn innovative thinking skills. At the same time, the instructors were given the worksheet for guiding university students' activities in the experiment using the Phyphox application. As shown in Figure 2, university students were asked to conduct a physics experiment using a building model to determine the measurements of raw sensors, such as the acceleration of ground movement during the disaster, by shaking the cardboard back. The results of this experiment are expressed in university students' respective building model units. At the end of this implementation, university students and their instructors evaluated what they had learned and reported and revealed the findings of their experiments. The data collection for this research was administered to participants as a post-test immediately following the learning implementation. Hence, comparing the pre- and post-test data made it possible to examine the effect of the implementation.

Figure 2

Screenshot of the phyphox app used in this study



Innovative thinking questionnaire

The quantitative data was employed by the innovative thinking questionnaire to gather data from participants. The innovative thinking questionnaire was adapted from existing instruments primarily linked to the assessment of individual innovative behavior (Kleysen & Street, 2001), innovation-related self-efficacy (Schar et al., 2017), entrepreneurial innovation (Dyer et al., 2008), and the innovative thinking in education questionnaire (Keinänen et al., 2018; Mirattanaphrai & Srikoon, 2025). It comprises four components: (1) questioning (four items), observing (four items), exploring (four items), and idea networking (three items). In more detail, Dyer et al. (2008) defined four key components of inquiry: (1) questioning, characterized by a tendency to pose challenging questions and contemplate future possibilities; (2) observing, which involves dedicating time to closely examine the surrounding environment and derive new insights from everyday experiences; (3) experimenting, defined by the frequency of engaging in hypothesis-driven exploration, including visiting new locations, trying novel activities, seeking information, and learning through experimentation; and (4) idea networking, which pertains to the active pursuit and evaluation of ideas within a diverse network of individuals with varying backgrounds and perspectives. The instrument was developed through four validation phases: planning, construction, evaluation, and validation. The objective was to obtain data from a sample of the target population and assess several variables (Creswell & Creswell, 2017). The authors have translated the instrument into Indonesian by creating new items. The instrument was used and changed based on what recent empirical studies have found to be standard and regular features of developing the skills needed for innovative thinking. This questionnaire comprises 19 items and is modified into a 5-point Likert format, which is a scale used to measure attitudes or opinions, starting from strongly disagree (1) to agree (5), with a response option of strongly. The authors calculated that the Cronbach's alpha coefficient score, which measures the internal consistency of a test, was 0.70 on the pre-test and 0.72 on the post-test. These values have proved reliable, as the results could be more than

0.70 (Taber, 2018). The participants should answer and complete the tests before and after the learning implementation. The authors collected the data based on the results of innovative thinking instruments. Therefore, this instrument was selected for several reasons, e.g., validity and reliability. Respondents were familiar with using questionnaire tests to evaluate their understanding and knowledge of science concepts. Additionally, the environment has used the instrument to assess its perspectives on comprehensive science classes.

Semi-structured interview

Following the innovative thinking questionnaire, semi-structured interviews were conducted to explore participants' perspectives on innovative thinking, learning achievements, and motivation. This qualitative data consists of the questions that were organized with the main categories, such as (1) the assessment and effectiveness of the integration learning methods, (2) improving innovative thinking in learning integration, (3) students' motivation and roles in learning, and (4) students' experience in university courses. See **Table 1**. These interviews were conducted in person for 45–60 minutes each and allowed for the collection of significant suggestions and insights from participants. All interviews were recorded with consent and transcribed verbatim. The authors created the descriptive notes of the events, activities, and dialogue among participants.

Table 1
List of questions of the interview

Category	Questions
The assessment and effectiveness of the integrated learning methods	What components of skills would you like to improve to be effective in learning the course?
Improving innovative thinking in learning integration	What skills or knowledge do you think are essential and need to be improved?
Students' motivation and roles in learning	How do you perceive learning using mobile phone technology and applications? What is your motivation for improving learning?
Students' experience in university courses	How was your experience when engaging in the learning?

DATA ANALYSIS

The quantitative results from the questionnaire were analyzed to investigate students' innovative thinking skills based on their learning achievements. The qualitative responses from the semi-structured interviews confirmed the learning experiences and motivation of students. Data were analyzed using Jeffreys's Amazing Statistics Program (JASP), which encoded and transferred the data into normality tests were conducted on the dataset. According to the experts, this JASP technique for data analysis could benefit authors as an alternative software that can provide more advanced statistical techniques (Love et al., 2019; Van Doorn et al., 2021). In addition, the normality analysis is crucial; it is equally important to consider other assumptions and potential biases in the data that could impact the overall results. The normality test was used to compare the values. Subsequently, we applied the Shapiro-Wilk test analysis to determine the skewness and kurtosis values. The results from the Shapiro-Wilk test revealed the normality of the data for the innovative thinking questionnaire (pre-test: 0.940 and post-test: 0.941). Additionally, the skewness results (pre-test: -0.529 and post-test: -0.837) and kurtosis values (pre-test: -0.529 and post-test: -0.837), which were determined in the normality results, are in the range of +2 to -2 (Tabachnick & Fidell, 2013). Additionally, the parametric t-test results for related samples were employed to compare the pre-test and post-test data sets, which exhibited a normal distribution, exposing a significance level of 0.05. After the data analysis, we used Cohen's d to determine the effect size by examining the significant difference between values. We found Cohen's d results (questioning: 0.48, observing: 0.34, exploring: 0.82, and networking: 0.2). The Cohen's d results were rated as small, medium, or large based on the values of 0.2, 0.5, and 1.0 (Cohen, 2013).

The qualitative analysis from the interviews was conducted using qualitative software (NVivo) and interpreted through a thematic analytical method to identify, analyze, and report patterns in the data set of all recordings and transcripts (Patton, 2014; Creswell & Creswell, 2017). NVivo facilitated the visualization of word frequencies, code co-occurrence, and the relationships of themes. Visual representations, such as word clouds and conceptual maps, were created to represent the patterns of meaning that developed in the narratives of university students. The analysis was conducted in five systematic steps: (1) familiarization involves reading and rereading all transcripts and field notes to achieve a comprehensive understanding of the data. Initial coding involves the generation of open codes that represent various concepts. Theme development involves the organization of related codes into broader categories that correspond with the research questions. Themes were collaboratively reviewed by the authors to ensure consistency and alignment with constructivist principles. The final themes were synthesized to clarify students' perspectives of the integration of mobile tools in inquiry-based instruction with the objective of enhancing innovative thinking skills. The authors utilized a constructivist framework to analyze data distribution and created a coding scheme. An inductive approach was employed to analyze the interview, thereby improving the reliability of the analysis. The interview protocol was examined, defined, and designated during an expert discussion. To ensure the credibility and confirmability of findings, this study implemented several qualitative validation strategies. These included member checking, where summaries of findings were shared with seven participants to verify interpretations and ensure contextual accuracy; peer debriefing, involving three external qualitative researchers reviewing the coding structure and theme definitions; triangulation, which entailed cross-verification among interview transcripts, observation notes, and institutional documents; and an audit trail, documenting all analytical decisions and coding revisions systematically in NVivo logs.

RESULTS

Analysis of integrated learning methods

The goal of this study is to examine the effectiveness of innovative thinking skills through the implementation of mobile phone technology and applications in inquiry-based instruction in the university classes. The quantitative analysis of integrated learning methods could be calculated by using the normality data analysis for pre- and post-tests **(Table 2)**, which showed the data is normally distributed for the quantitative analysis with the p-values from the Shapiro–Wilk normality test above. 05, skewness and kurtosis values between -2 and +2, as suggested by Tabachnick and Fidell (2013); these results indicated the normal distribution data analysis. Additionally, the results of the analysis of innovative thinking skills for each component in the learning implementation of m-learning applications to support science lessons in the university class are presented in **Table 3**.

Table 2

Normality data analysis from the innovative thinking questionnaire

Test	Distribution	Shapiro-Wilk	Skewness	Kurtosis
Pre-test	Normal	0.940	-0.529	0.49
Post-test	Normal	0.941	-0.837	1.5

Table 3

Comparison of the innovative thinking scale, subscale, and total scale

Test	M		SD		*T*	df	*p*	Cohen's *d*
	Pre	Post	Pre	Post				
Questioning	14.8	15.5	1.67	1.96	2.15	19	0.04	0.48
Observing	15.3	15.9	1.81	1.58	1.5	19	0.15	0.34
Exploring	15.4	16.7	1.63	1.29	3.65	19	0.02*	0.82
Networking	12.3	12.7	1.55	1.44	0.87	19	0.39	0.20

*Mean, SD standard deviation with *p < .05*

The results of the parametric t-test for related samples are provided in Table 3, which compares the innovative thinking skills that created a substantial impact in each component. It was found that university students' innovative thinking mean score at the beginning was questioning 14.8 (SD = 1.67), observing 15.3 (SD = 1.81), exploring 15.4 (SD = 1.63), and networking 12.3 (SD = 1.55) and developed to questioning 15.5 (SD = 1.96), observing 15.9 (SD = 1.58), exploring 16.7 (SD = 1.29), and networking 12.7 (SD = 1.44) at the end of the study. This finding examines the significant development of the innovative thinking scale, including its subscale and total scale, specifically for university students. At the same time, questioning ($t(19) = 2.15$, $p = 0.04$) and exploring ($t(19) = 3.65$, $p = 0.02$) demonstrated a substantial rise in the implementation process. Other components, such as observing ($t(19) = 1.5$, $p = 0.15$) and networking ($t(19) = 0.87$, $p = 0.39$), did not show a substantial increase. Cohen's d coefficients are examined to assess the substantial difference in innovative thinking, and the analysis reveals an important effect size ($\geqslant 0.8$) (Cohen, 2013). The results of Table 3 indicated the effects of mobile phone technology and applications in inquiry-based instruction for developing innovation thinking skills in university classes.

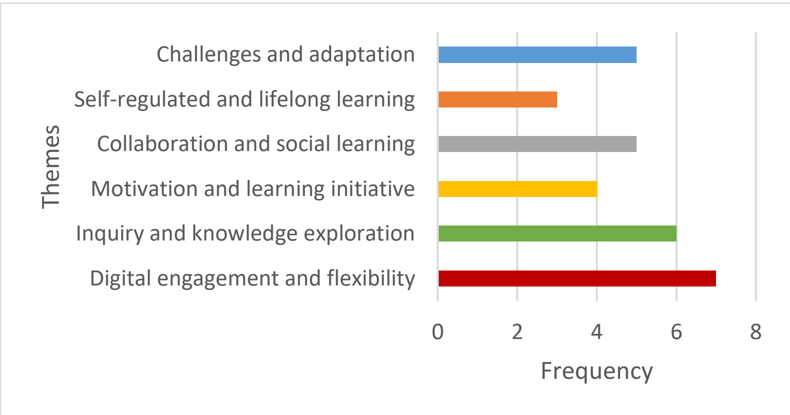
The results from analysis data indicated that students improved their questioning and exploring skills (Cohen's d = 0.48 and 0.82), while other skills such as observing and networking showed moderately large effects. On the other hand, students recognized that they need to process, question, and synthesize all information before the learning intervention, which focused on the essentials of m-learning applications in inquiry-based instruction. For example, S03 responds that "I need to be better at analyzing information critically before drawing conclusions." Similar to the argument, S07 argued that "I want to improve my ability to generate new and original ideas to solve problems." This indicates that students' awareness of higher-order thinking skills and creativity could be improved as core targets of study, and integrated learning methods can explore the value of connecting ideas from different fields and designing something original. However, in opposite opinions, other students described that digital literacy and mobile application skills are important knowledge. For instance, S08 defined that "mobile phones are not only about communication or entertainment, but they can also be used for academic purposes, such as learning applications, making content, and creating online collaboration with peers." Furthermore, S06 also argued that "improving digital literacy skills could be beneficial for evaluating the credibility of information, and using mobile phone tools is effective for learning skills and knowledge." Therefore, the findings from students' interviews highlighted the need for improving teaching and learning with mobile phone technology and applications in the interventions using various learning strategies for improving students' thinking skills, such as innovative thinking skills, which can enhance problem-solving abilities and foster creativity in educational settings. In addition, the university also needs to integrate the new ways for adopting digital devices into the curriculums. This would facilitate students' achievements, motivation, and experiences in educational settings.

Analysis of students' motivation and roles in learning

The results of this study explored the students' motivation and roles in m-learning applications in inquiry-based instruction for improving innovative thinking skills. According to **Figure 3**, there are some themes that have been explored in relation to students' perceptions of learning and their motivation, e.g., digital engagement and flexibility, inquiry and knowledge exploration, motivation and learning initiative, collaboration and social learning, self-regulated and lifelong learning, and challenges and adaptation. On the other hand, their motivation for learning has improved. For example, students are motivated when learning is engaging, meaningful, and self-directed. S04 claimed that she is motivated when she can explore and find things on her own.

Figure 3

Frequency of themes in relation to how students perceive their motivation



This study examined various perspectives on students' opinions and ideas regarding observation and motivation during the intervention. Students use mobile phones as tools for inquiry learning, data collection, and collaboration. They also perceived that mobile technology helps us locate information and work together with classmates. For example, S01 described, "I can access materials anytime and anywhere through my phone, and mobile technology and applications make learning more engaging due to their multimedia features." Students perceive learning as meaningful when it links class concepts with real-life applications. For instance, S05 argued that using mobile learning helps students connect what they learn to real-life problems. Additionally, students value the opportunity to communicate effectively through online platforms, and they believe that mobile learning helps improve communication and teamwork. They express the need for self-control to avoid distractions and stay focused. Some students, such as S08, explained that they need to discipline themselves because mobile phones can be distracting. The negative impact of using a mobile phone can affect my imagination. Therefore, students emphasize that they require guidance in choosing appropriate apps and managing technology effectively. It needs to elaborate on how to use apps effectively for studying.

Analysis of students' experience in university courses

This study highlighted students' experiences with mobile phone technologies and applications in inquiry-based instruction for enhancing innovative thinking skills. A word cloud emphasized the principal components of students' feedback during the educational intervention. The most important terms, including "information," "creativity," "apps," and "clarity," signify a desire for visually engaging design and feedback gathered from students' experiences.

Figure 4 showed the results of students' responses to studying mobile tools in inquiry-based instruction for improving innovative thinking, which related to fostering learning participation, collaboration, interactivity, connectivity, flexibility, creativity, confidence, and engagement apps as well as promoting the gaps of technology usefulness. For instance, S12 responded that "it took me to learn the app features before entering the class. After that, tasks were faster, but at first, it slowed me down." Similarly, S14 claimed that "I felt more confident proposing ideas due to creating prototypes quickly, such as sketching, recording, and iterating on our phones." This learning strategy exposed students' confidence and improved their skills. The mobile phone technology and applications are not primarily focused on helping effectiveness in learning, but inquiry-based instruction is also important for fostering students' engagement with skills development. For instance, some student, S5, argued that "using the phones to search, collect mini-data, and compare sources helped me investigate questions like a real researcher." In addition, S7 explained that working in groups was smoother than taking notes in a cloud document and discussing it on chat without waiting for lab time. Therefore, this learning strategy using digital devices in inquiry-based instruction could explore students' interactive learning with engaging multiple approaches to increase their experiences.

Figure 4

Word clouds from students' experience in university courses

DISCUSSION

This study examined how integrating mobile phone technology and applications into inquiry-based instruction can enhance innovative thinking skills of students for sustainable higher education within a framework of sustainable education. The findings discovered significant improvements in questioning and exploring components, while observing and networking demonstrated moderate yet meaningful development. Students' perspectives have positively impacted their innovative thinking experiences, motivation, and roles in learning, as well as students' experiences in university courses. These results suggest that mobile technology-supported inquiry learning can effectively encourage higher-order cognitive processes that underpin innovation, creativity, and sustainability-oriented problem-solving.

The integration of mobile technologies fosters active and resource-efficient learning environments that align with the principles of Education for Sustainable Development (ESD). Through promoting inquiry, collaboration, and digital participation, the instructional model employed in this study supports SDG 4 (Quality Education) through inclusive, equitable, and flexible access to learning opportunities. Furthermore, it advances SDG 9 (Industry, Innovation, and Infrastructure) in cultivating human capital capable of leveraging technology for innovation and sustainable transformation. From this study, students recognized that they need to process, question, and synthesize all information before the learning intervention, which focused on the essentials of mobile phone technology and applications in inquiry-based instruction. Ürek (2024) described that using technology and mobile phone applications for learning could positively impact university students' digital literacy skills. Similarly, Al-Qatawneh et al. (2022) argued that the effectiveness of m-learning applications in higher education could explore the positive attitudes and achievements of university students. Moreover, Samala et al. (2025) found the advantages of mobile learning in higher education. Many countries in Asia, America, Australia, and Europe have looked into using m-learning apps as new ways to teach and learn by incorporating augmented reality (AR), gamification, and social media along with learning management systems (LMS) to improve education and get students more involved in the interaction, ongoing learning, and student motivation. Hence, Criollo et al. (2025) concluded that mobile technology and applications could improve the understanding of technology to enhance learning outcomes and provide the global market competitiveness of university students. According to the results of this study, students perceived the need for digital devices for improving learning interventions and students' thinking skills, such as innovative thinking skills, for facilitating their achievements, motivation, and experiences in educational backgrounds.

This study argued that technology is important for gaining work experience by exploring university students' skills. At the same time, the inquiry-based instruction guidelines encourage university students to explore and gain new insights from concepts and application processes while participating in cooperative learning for fostering higher levels of knowledge (Friedman et al., 2010; Krainer & Zehetmeier, 2013; Luo et al., 2023). Another study from Friedman et al. (2010) reported that the feature in inquiry-based instruction provides active learning, and most of the research addressed in the class emphasizes questions, discussion, and logical reasoning among university students. Therefore, it can be said that teaching with inquiry-based instruction has become a growing trend in educational development for fostering higher-order thinking skills (McClune & Jarman, 2010; Krainer & Zehetmeier, 2013; Spector & Ma, 2019). Likewise, this study explored the students' motivation and roles in learning interventions. Students' perceptions further underscore the pedagogical value of mobile-assisted inquiry learning. They described heightened engagement, self-regulated learning, and improved motivation when digital tools were integrated into science lessons. These outcomes align with previous research suggesting that digital inclusion enhances both academic performance and sustainability literacy by enabling learners to interact, create, and reflect within connected, technology-driven environments (Keengwe & Bhargava, 2014; Ürek, 2024). Importantly, this pedagogical approach reduces dependency on physical resources, such as laboratory materials or printed worksheets, thereby contributing to the environmental dimension of sustainability.

In the implementation process, this study provides the most influential components of innovative thinking for university students, which are mentioned by several researchers, namely innovative questioning, observing, exploring, and networking for achieving the effectiveness of science lesson activities (Kleysen & Street, 2001; Dyer et al., 2008; Schar et al., 2017; Keinänen et al., 2018; Mirattanaphrai & Srikoon, 2025). A study from Baričević & Luić (2023) argued that implementing innovative thinking could allow university students to be more active in learning and practical application, allowing university students to interact with others to propose applicable solutions to real-life problems, such as developing projects that address community issues or collaborating on research initiatives that benefit society. Research conducted by Avcı and Yildiz Durak (2023) found that university students have high perspectives of pleasure and value in what they do and could be actively engaged in the learning implementation process. At the same time, university students who received a higher score in the innovative thinking skills can have higher engagement in understanding the science course. The results of this study, along with what has been reported in the literature, found that university students could be more attracted when learning with mobile applications, learning to engage their innovative thinking. This study found that the components of innovative thinking, e.g., innovative questioning, observing, exploring, and networking among university students, have been significantly improved in science lesson activities in the university class. The effectiveness has been established based on the significance of the parametric t-test and the magnitude of the effect sizes for each component of innovative thinking. The findings arise from the dynamic relationship between the implementation of mobile application learning and the innovative thinking skills of university students. This results in arguments that innovative teaching could reflect the creativity and novelty of producing action and thought, e.g., teaching approaches and learning new ideas and skills (Xu & Chen, 2010; Lu et al., 2013). Additionally, the findings expose how mobile technology serves as a sustainability enabler in higher education, such as expanding learning beyond physical and institutional boundaries. The combination of inquiry-based instruction and mobile applications promotes reflective, lifelong, and collaborative learning that aligns with the transformative competencies highlighted by UNESCO's ESD framework (UNESCO, 2020). Through experiential and digital learning, students engage with real-world contexts, practice problem-solving, and develop creativity and resilience, e.g., key attributes for sustainable citizenship.

The analysis of the innovative thinking scale, including its subscales and overall measure, revealed that university students excelled in questioning and exploring as part of the components of innovative thinking skills. On the other hand, other components, such as observation and networking, did not demonstrate a significant improvement in the context of mobile application learning to support science lessons regarding university students' innovative thinking skills, indicating that these methods may not be as effective as other strategies in enhancing students' creativity and problem-solving abilities. Yilmaz (2021) suggested that extensive interaction with technology is essential for university students to cultivate technology integration skills. It enables university students to keep engaged in discussing problem situations, exchanging information, and enhancing engagement, which could augment their academic performance based on innovative thinking. According to the results of this study, we also found that students' responses to studying mobile phone technology and applications in inquiry-based instruction could be related to fostering learning participation, collaboration, interactivity, connectivity, flexibility, creativity, and confidence, as well as promoting the usefulness of engagement apps and addressing gaps in technology. These findings, supported by Wang and Burdina (2024), believed that the incorporation of technology in education could influence technological interventions on innovative thinking skills, with an emphasis on the distant learning format. However, the findings of this study also highlighted the challenges associated with digital learning sustainability. Some participants expressed difficulties managing distractions and navigating new applications, indicating that digital literacy and self-regulation must be intentionally developed as part of sustainability pedagogy. This insight supports the need for capacity building among educators and learners to ensure equitable participation in technology-enhanced environments, particularly in resource-constrained environments between Indonesian universities and global perspectives, as this can help bridge the digital divide and improve educational outcomes for all students, especially those from marginalized communities who may lack access to necessary resources and training. Papadakis et al. (2024) argued that m-learning apps could boost the ability of cloud technologies to change and improve education by offering a variety of new methods and tools for different subjects and education levels, showing the challenges of limited access to physical resources, the need for flexible learning spaces, and the increasing importance of developing soft skills. Therefore, the present study extends existing research by linking digital pedagogy and sustainable education through empirical evidence. It demonstrates that integrating mobile technology into inquiry-based learning is not merely a technological innovation but a pathway toward building resilient, creative, and sustainability-minded learners.

CONCLUSION AND LIMITATION

This study demonstrates that integrating mobile technologies with inquiry-based instruction can enhance students' innovative thinking skills in sustainable higher education while advancing the goals of sustainable education. Through fostering questioning and exploration, the instructional model promotes critical inquiry, creativity, and engagement skills for addressing sustainability challenges in the 21st century. The findings of this study contribute to the growing body of research on Education for Sustainable Development (ESD) in illustrating how accessible digital technologies can support equitable, inclusive, and environmentally conscious learning ecosystems. Explicitly, this integration aligns with SDG 4 by improving the quality and accessibility of higher education through flexible mobile learning and with SDG 9 by fostering innovation and digital infrastructure within academic environments.

From a practical perspective, this study suggests that universities in developing countries can adopt mobile-based inquiry frameworks to advance digital literacy, reduce material consumption, and encourage collaborative problem-solving. Professional development should undoubtedly assist educational researchers in designing sustainability-oriented digital pedagogy and in scaffolding students' inquiry and self-regulation processes. The higher institutions should also consider policies that enhance digital accessibility and infrastructure, ensuring equitable participation across diverse socioeconomic contexts. It is important to acknowledge the methodological and conceptual limitations of this study, despite its contributions. First, the research employed a one-group pretest–posttest design, which is subject to well-documented threats to internal validity, including maturation, testing effects, and historical influences. Without a control or comparison group, it is not possible to attribute observed gains in innovative thinking skills solely to the mobile-supported inquiry-based intervention. Improvements may also reflect increased familiarity with the instrument or broader developmental changes over time. Consequently, the findings should be interpreted as indicative of potential associations rather than causal effects. Second, the study involved a relatively small sample drawn from a single university in Indonesia. While this context offers advantageous information regarding mobile learning and sustainability-oriented pedagogy in a developing-country setting, it limits the generalizability of the findings to other institutional, cultural, or disciplinary contexts, such as those found in developed countries or different educational systems that may have varying resources and challenges. The gender imbalance among participants may also have influenced group dynamics and learning experiences. Taken together, these limitations suggest that the present findings should be viewed as exploratory yet theoretically meaningful, offering a foundation for more rigorous, comparative, and longitudinal research on mobile-supported inquiry learning and sustainable higher education. Therefore, the study was theoretically informed by constructivism and inquiry-based learning. The complexity of digital learning ecosystems means that multiple interacting variables, such as instructor facilitation, students' prior digital literacy, and institutional infrastructure, may have influenced the results. Future studies should adopt more robust experimental or quasi-experimental designs and explicitly model these variables to strengthen explanatory power.

Acknowledgement

We received support from the Enhancing Quality Education for International University Impacts and Recognition (EQUITY) Program - THE University Impact Ranking 2025.

Funding

The research did not receive any funding.

Ethical statement

This study received ethical approval from the Directorate of Research and Community Service for Research Involving Human Subjects of the Research Ethics Review Committee in the Academic Group in Social Sciences, Humanities, and Fine and Applied Arts at Universitas Negeri Yogyakarta (approval number: T/258.1/UN34.9/PT.01.04/2025). The participants provided written, informed consent prior to their participation. The study adhered to the guidelines of the Declaration of Helsinki for studies involving human participants. The participants were informed of their right to withdraw at any time without consequences.

Competing interests

The authors declare no conflict of interest

Author contributions

Winarto and Galih Albarra Shidiq responsible for writing article, research concept and design, and critical revision. Misbah, Ariyatun, Erwinsyah Satria, Evita Widiyati, Sri Jumini, Pradina Parameswari reviewed the literature and edited the manuscript. All authors read and approve the final manuscript.

Biographical sketch

Dr. Winarto is a lecturer at the Department of Science Education, Faculty of Mathematics and Natural Science, Universitas Negeri Yogyakarta, Indonesia. His research focuses on science education and ethnoscience learning innovation.

Dr. Misbah is a lecturer at the Department of Physics Education, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Indonesia. Her research focuses on problem-solving-based physics learning, local wisdom in physics learning, ethnoscience, ethnophysics, ethnopedagogy, and technology-based media.

Dr. Ariyatun is a lecturer in the Department of Chemistry Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta, Indonesia. Her research focuses on chemistry education technology and integrating local wisdom (ethnoscience) into sustainable and innovative learning.

Dr. Erwinsyah Satria is a lecturer and researcher at the Department of Elementary Teacher Education, Faculty of Teacher Training and Education, Universitas Bung Hatta, Indonesia. His research focuses on elementary science education, STEM education, computational thinking, and educational technology.

Evita Widiyati, M.Pd is a lecturer in the Islamic Elementary School Teacher Education Program (PGMI), Faculty of Islamic Studies, Universitas Hasyim Asy'ari, Indonesia. Her research focuses on innovative learning, instructional media, digital learning, educational psychology, and Islamic elementary education.

Dr. Sri Jumini is a lecturer at the University of Science Al-Qur'an (UNSIQ) Central Java, Indonesia. Her research focuses on science education, science-Al-Qur'an, sciencetecnopreneurship, evaluation research, educational management, and renewable energy.

Dr. Pradina Parameswari is a lecturer at the Department of Elementary School Teacher Education Study Program at Universitas Negeri Surabaya, Indonesia. Her research focuses on mathematics education, particularly students' reasoning and thinking processes in solving mathematical problems.

Dr. Galih Albarra Shidiq is a lecturer at the Department of Primary Teacher Education, Faculty of Educational Science, Universitas Bhayangkara Jakarta Raya, Indonesia. His research focuses on educational technology, STEM education, science education, and elementary science education.

REFERENCES

Al-Qatawneh, S., Alsalhi, N., Eltahir, M., Althunibat, F., Jaradat, M., & Aljarrah, K. (2022). Effects and Perceptions of Mobile Learning in Higher Education. *Emerging Science Journal, 6,* 78–91. https://doi.org/10.28991/ESJ-2022-SIED-06

Aminatun, T., Subali, B., Dwiyani, A., Prihartina, I., & Meliana, D. (2022). Developing Android-Based Mobile through Local Ecosystem Materials to Improve Thinking Skills of High School Students. *Anatolian Journal of Education, 7*(1), 73-82.

Anderson, N., Potočnik, K., & Zhou, J. (2014). Innovation and creativity in organisations: A state-of-the-science review, prospective commentary, and guiding framework. *Journal of Management*, *40*(5), 1297–1333.

Avcı, Ü., & Yildiz Durak, H. (2023). Innovative thinking skills and creative thinking dispositions in learning environments: Antecedents and consequences. *Thinking Skills and Creativity*, *47*, 101225. https://doi.org/10.1016/j.tsc.2022.101225

Baričević, M., & Luić, L. (2023). From Active Learning to Innovative Thinking: The Influence of Learning the Design Thinking Process among Students. *Education Sciences*, *13*(5), 455. https://doi.org/10.3390/educsci13050455

Bhuttah, T. M., Xusheng, Q., Abid, M. N., & Sharma, S. (2024). Enhancing student critical thinking and learning outcomes through innovative pedagogical approaches in higher education: The mediating role of inclusive leadership. *Scientific Reports*, *14*(1), 24362. https://doi.org/10.1038/s41598-024-75379-0

Beghetto, R. A. (2017). Inviting uncertainty into the classroom. *Educational Leadership, 75*(2), 20-25.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. routledge.

Cohen, L., Manion, L., & Morrison, K. (2002). *Research methods in education*. routledge.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Criollo-C, S., Guerrero-Arias, A., Miftachul Arif, Y., Dwinggo Samala, A., Jaramillo-Alcázar, í□ngel, & Luján-Mora, S. (2025). Usability Evaluation of a Mobile Augmented Reality App for PC Hardware Training: A Comparative Study in Three Countries. *Emerging Science Journal, 9*(2), 977–994. https://doi.org/10.28991/ESJ-2025-09-02-024.

Deiri, Y. (2025). "You bring me light": Saudi women ulfa (األلفة (literacies through language, affect, and artifacts. *Asia Pacific Journal of Education and Society, 13*(2), 6. https://doi.org/10.20897/apjes/1759

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Dyer, J., Gregersen, H., & Christensen, C. (2008). Entrepreneur behaviors, opportunity recognition, and the origins of innovative ventures. *Strategic Entrepreneurship Journal*, *2*(4), 317–338. https://doi.org/10.1002/sej.59

Dyer, J., Gregersen, H., & Christensen, C. M. (2011). *The innovator's DNA: Mastering the five skills of disruptive innovators*. Harvard Business Press.

Eurostat, O. (2005). Oslo manual: Guidelines for collecting and interpreting innovation data. *Posjećeno*, *14*, 2022.

Fosnot, C. T. (2013). *Constructivism: Theory, perspectives, and practice*. Teachers College Press

Friedman, D. B., Crews, T. B., Caicedo, J. M., Besley, J. C., Weinberg, J., & Freeman, M. L. (2010). An exploration into inquiry-based learning by a multidisciplinary group of higher education faculty. *Higher Education*, *59*(6), 765–783. https://doi.org/10.1007/s10734-009-9279-9

Grass, K. (2024). The three logics of qualitative research: Epistemology, ontology, and methodology in political science. *American Journal of Qualitative Research, 8*(1), 42-56. https://doi.org/10.29333/ajqr/14083

Halpern, B., Aydin, H., & Halpern, C. (2025). Seeing multilingual learners through media and AI: Pre-service teachers' perceptions in an ESOL course. *Journal of Interdisciplinary Research in Artificial Intelligence and Society, 1*(1), Article 4. https://doi.org/10.20897/jirais/17647

Haryanto, H., & Arty, I. S. (2019). The Application of Project-Based Learning in Undergraduate Students: How Does It Work? *Journal of Physics: Conference Series,* 1387(1). https://doi.org/10.1088/1742-6596/1387/1/012074

Hwang, G.-J., Lai, C.-L., Liang, J.-C., Chu, H.-C., & Tsai, C.-C. (2018). A long-term experiment to investigate the relationships between high school students' perceptions of mobile learning and peer interaction and higher-order thinking tendencies. *Educational Technology Research and Development*, *66*(1), 75–93. https://doi.org/10.1007/s11423-017-9540-3

Kalyani, D., & Rajasekaran, K. (2018). Innovative teaching and learning. *Journal of Applied and Advanced Research*, *3*(1), 23–25.

Karagiorgi, Y., & Symeou, L. (2005). Translating constructivism into instructional design: Potential and limitations. *Journal of Educational Technology & Society, 8*(1), 17-27.

Keengwe, J., & Bhargava, M. (2014). Mobile learning and integration of mobile technologies in education. *Education and Information Technologies*, *19*(4), 737–746. https://doi.org/10.1007/s10639-013-9250-3

Keinänen, M., Ursin, J., & Nissinen, K. (2018). How to measure students' innovation competences in higher education: Evaluation of an assessment tool in authentic learning environments. *Studies in Educational Evaluation*, *58*, 30-36.

Kleysen, R. F., & Street, C. T. (2001). Toward a multi-dimensional measure of individual innovative behavior. *Journal of Intellectual Capital*, *2*(3), 284–296. https://doi.org/10.1108/EUM0000000005660

Krainer, K., & Zehetmeier, S. (2013). Inquiry-based learning for students, teachers, researchers, and educational administration and policy representatives: Reflections on a nation-wide initiative fostering educational innovations. *ZDM*, *45*(6), 875–886. https://doi.org/10.1007/s11858-013-0537-z

Leal Filho, W., Shiel, C., & Paço, A. (2021). Integrative approaches to sustainable development at university level: Making the links between research, teaching, and learning. *International Journal of Sustainability in Higher Education, 22*(2), 307–322. https://doi.org/10.1108/IJSHE-10-2019-0316

Lee, C. B., Hanham, J., Kannangara, K., & Qi, J. (2021). Exploring user experience of digital pen and tablet technology for learning chemistry: Applying an activity theory lens. *Heliyon*, *7*(1), e06020. https://doi.org/10.1016/j.heliyon.2021.e06020

Li, W., Song, Z., & Suh, C. S. (2022). Principles of Innovative Design Thinking. *Synergy of Extenics with Axiomatic Design Theory*, 35–54.

Lin, J., Li, Q., & Sun, H. (2020). Promoting pre-service teachers' reflective thinking through a design-based learning environment. *Journal of Education for Teaching, 46*(3), 383-397.

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., Verhagen, J., Ly, A., Gronau, Q. F., Smíra, M., Epskamp, S., Matzke, D., Wild, A., Knight, P., Rouder, J. N., Morey, R. D., & Wagenmakers, E.-J. (2019). JASP: Graphical Statistical Software for Common Statistical Designs. *Journal of Statistical Software*, *88*(2). https://doi.org/10.18637/jss.v088.i02

Lu, H., Hu, L., Liu, G., & Zhou, J. (2013). An Innovative Thinking-Based Intelligent Information Fusion Algorithm. *The Scientific World Journal*, *2013*(1), 971592. https://doi.org/10.1155/2013/971592

Luo, T., Arcaute, K., & Muljana, P. S. (2023). Integrating inquiry-based learning into engineering education: A case study. *Innovations in Education and Teaching International*, *60*(6), 836–847. https://doi.org/10.1080/14703297.2022.2130393

McClune, B., & Jarman, R. (2010). Critical reading of science-based news reports: Establishing a knowledge, skills and attitudes framework. *International Journal of Science Education*, *32*(6), 727–752.

Mirattanaphrai, P., & Srikoon, S. (2025). Design and development of innovator self-assessment questionnaire for students in grade 6: Utilizing educational design research. *Social Sciences & Humanities Open*, *11*, 101414.

OECD. (2016). *Innovating Education and Educating for Innovation: The Power of Digital Technologies and Skills*. OECD. https://doi.org/10.1787/9789264265097-en

Oschinski, M., Crawford, A., & Wu, M. (2024). *AI and the Future of Workforce Training.*

Papadakis, S., Semerikov, S. O., Striuk, A. M., Kravtsov, H., Shyshkina, M. P., Marienko, M. V., & Danylchuk, H. (2024). Embracing digital innovation and cloud technologies for transformative learning experiences. In *Proceedings of the 11th Workshop on Cloud Technologies in Education (CTE 2023). Kryvyi Rih, Ukraine, December 22, 2023 (No. 3679, pp. 1-21).* CEUR Workshop Proceedings.

Sáez-López, J. M., Sevillano-García, M. L., & Vazquez-Cano, E. (2019). The effect of programming on primary school students' mathematical and scientific understanding: educational use of mBot. *Educational Technology Research and Development, 67*(6), 1405–1425.

Samala, A. D., Papadakis, S., & Rawas, S. (2025). Global insights into mobile learning in higher education: A PRISMA-guided bibliometric analysis from 2007 to 2023. *International Journal of Educational Reform, 0*(0). https://doi.org/10.1177/10567879251341869

Santoso, H. B., Lawanto, O., Berliyanto, B., & Janf, P. (2018). Secondary school students' computer self-efficacy and their perception on computer-related tasks in Indonesia. In *Self-efficacy in instructional technology contexts* (pp. 245–257). Springer.

Saracaloglu, A. S., Yenice, N., & Karasakaloglu, N. (2020). An Investigation on the Creative Thinking Skills of Prospective Teachers. *International Journal of Contemporary Educational Research, 7*(2), 1082-1097

Satria, E., Sa'ud, U. S., Riyana, C., Sopandi, W., Nora, Y., Jusar, I. R., ... & Rusli, R. (2024, May). The development of computational thinking skills-based interactive learning media for PGSD students' problem solving task with scratch programming. In *AIP Conference Proceedings* (Vol. 3116, No. 1, p. 040016). AIP Publishing LLC.

Schar, M., Gilmartin, S., Harris, A., Rieken, B., & Sheppard, S. (2017). Innovation Self-Efficacy: A Very Brief Measure for Engineering Students. *2017 ASEE Annual Conference & Exposition Proceedings*, 28533. https://doi.org/10.18260/1-2--28533

Setuju, B. T., Muhtadi, A., & Widowati, A. (2022). Mobile Application Smartphone: Does It Improve the 21st Century's Competence of Vocational School Students?. *Int. J. Inf. Educ. Technol., 12*(12), 1286-1290.

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for the next generation: From artificial intelligence back to human intelligence. *Smart Learning Environments*, *6*(1), 1–11.

Strycker, J. (2020). K-12 art teacher technology use and preparation. *Heliyon*, *6*(7), e04358. https://doi.org/10.1016/j.heliyon.2020.e04358

Sultan, Y., Dautova, G., & Dalle, J. (2025). Examining the relationship among artificial intelligence literacy, cultural literacy, and intercultural communication proficiency of philology students. *Journal of Ethnic and Cultural Studies*, *12*(5), 345–362. https://doi.org/10.29333/ejecs/2839

Tabachnick, B. G., & Fidell, L. S. (2013). Using multivariate statistics, 6th edn Boston. *Ma: Pearson*.

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2.

Tilbury, D. (2011). *Education for Sustainable Development: An Expert Review of Processes and Learning*. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000210071.

Tolmie, J. (2024). Sarah Leavitt's *Tangles*: Teaching queer caregiving memoir on disability, and pedagogy as resistance. *Feminist Encounters: A Journal of Critical Studies in Culture and Politics, 8*(2), Article 35. https://doi.org/10.20897/femenc/14947

UNESCO. (2020). *Education for Sustainable Development: A Roadmap*. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000374802.

Ürek, H. (2024). The impact of a mobile phone and mobile application-supported science laboratory on the digital literacy of preservice teachers and their disposition toward using technology in class. *Journal of Science Education and Technology*, *33*(6), 983–997.

Van Doorn, J., Van Den Bergh, D., Böhm, U., Dablander, F., Derks, K., Draws, T., Etz, A., Evans, N. J., Gronau, Q. F., Haaf, J. M., Hinne, M., Kucharský, Š., Ly, A., Marsman, M., Matzke, D., Gupta, A. R. K. N., Sarafoglou, A., Stefan, A., Voelkel, J. G., & Wagenmakers, E.-J. (2021). The JASP guidelines for conducting and reporting a Bayesian analysis. *Psychonomic Bulletin & Review*, *28*(3), 813–826. https://doi.org/10.3758/s13423-020-01798-5

Wang, A., & Burdina, G. (2024). Developing students' creative thinking using innovative education technologies. *Interactive Learning Environments*, *32*(7), 3490–3500. https://psycnet.apa.org/doi/10.1080/10494820.2023.2184390

Webb, R. (2026). Post pandemic English language teacher development: A global perspective. *European Journal of Education & Language Review, 2*(1), Article 1. https://doi.org/10.20897/ejelr/17719

Winoto, S. (2022). Improving curriculum and lecturers: Challenges to quality based-technology. *Journal of Social Studies Education Research*, *13*(2), 221–242.

Winarto, Rosana, D., Wibowo, W.S., Rahayu, D.P., Pradana, P.W., & Shidiq, G.A. (2025). The Impact of STEM-EfSD Games on Enhancing Students' Creative Thinking and Environmental Literacy. European Journal of STEM Education, 10(1), 23. https://doi.org/10.20897/ejsteme/ 17354

Xu, Z., & Chen, H. (2010). Research and Practice on Basic Composition and Cultivation Pattern of College Students' Innovative Ability. *International Education Studies*, *3*(2), p51. https://doi.org/10.5539/ies.v3n2p51

Yıldırım, Z., Öztürk, G., Şahinoğlu, H. Ü., & Yıldırım, E. (2024). An ethical use guideline for AI-supported assignments: Design and effectiveness analysis. *ISophos: International Journal of Information, Technology and Philosophy, 7*(13), 34-50.

Yilmaz, A. (2021). The Effect of Technology Integration in Education on Prospective Teachers' Critical and Creative Thinking, Multidimensional 21st Century Skills and Academic Achievements. *Participatory Educational Research*, *8*(2), 163–199. https://doi.org/10.17275/per.21.35.8.2

Zorlu, K. (2018). Strategic thinking and dimensions of effective leadership. *Strategic Design and Innovative Thinking in Business Operations: The Role of Business Culture and Risk Management*, 173–188.

