Artificial Intelligence in Education

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Generative AI's implications on higher education students' 21st-century skills assessment: insights from a systematic literature review

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Received 24 February 2025
Revised 12 July 2025
21 October 2025
Accepted 3 November 2025

Abstract

Purpose – The increasing popularity of generative artificial intelligence (GenAI) in higher education has raised question marks about its implications for skills including 21st-century skills. While 21st-century skills, particularly the "four Cs" (critical thinking, creativity, communication and collaboration), remain vital, the existing literature lacks a synthesis of how GenAI reshapes their relevance and assessment. Therefore, this study examines GenAI's implications for higher education students' 21st-century skills' relevance and assessment methods in evolving digital learning environments.

Design/methodology/approach – This study used a systematic review methodology and analyzed 62 publications from 2020 to 2024, sourced from Google Scholar and Web of Science. Preferred Reporting Items for Systematic Reviews and Meta-Analyses and the GenAI epistemology, pedagogy and assessment (GenAI EPA) analytical framework guided methodological processes including inclusion/exclusion, screening, coding and presentation of findings.

Findings – This study revealed three key findings. First, 21st-century skills, such as the four Cs, remain highly relevant in the GenAI era, although they have evolved to suit GenAI needs (e.g. critical evaluation of AI outputs). Second, traditional assessment methods (e.g. standardized tests) are inadequate in GenAI contexts, whereas alternative approaches, including digital portfolios, have proven to be more effective in capturing 21st-century skills. Third, stakeholders (especially educators) emphasize hybrid assessment models that combine process-oriented and outcome-oriented strategies to balance the disruption of GenAI integration with the maintenance of academic integrity.

Practical implications – This study highlights four key implications for higher education. First, institutions must integrate GenAI tools into curricula to develop and assess 21st-century skills. Second, ethical concerns (e.g. bias and privacy) necessitate clear AI use policies. Third, traditional assessments should shift toward dynamic, authentic methods (e.g. AI-assisted portfolios). Finally, educator-industry collaboration is vital, including co-designed curricula, workshops and internships for real-world AI readiness.

Funding Statement: This work was supported by the National Natural Science Foundation of China (No. 62477039).

Conflict of Interest Statement: The authors declare there are no conflicts of interest related to this study.

Artificial Intelligence in Education
Vol. 2 No. 1, 2026
pp. 109-126
Emerald Publishing Limited
3049-5474
DOI 10.1108/AIIE-02-2025-0029

Originality/value – This study contributes to ongoing AI in education scholarship by mapping the interplay between GenAI and 21st-century skills, offering evidence-based recommendations for rethinking assessment paradigms. It highlights the urgency for institutional policies and practices that align pedagogical innovation with labor-market demands, ensuring graduates thrive in an AI-driven future.

Keywords Higher education, 21st-century skills, Generative artificial intelligence (GenAI), Assessment methods

Paper type Literature review

Introduction

Generative Artificial Intelligence (GenAI) refers to advanced AI technologies that utilize language models and algorithms to create new content (Ferrara, 2024), including text, images, and other media (Weng *et al.*, 2024). GenAI has profoundly affected knowledge acquisition, dissemination, and assessment methods in higher education (Yusuf *et al.*, 2024). Generative Artificial Intelligence (GenAI) enables personalized learning content tailored to individual student needs (Chere and WayiMgwebi, 2024; Hojeij *et al.*, 2024). GenAI also improves student engagement and learning outcomes by providing adaptive feedback and innovative assessment methods (Houssaini *et al.*, 2024; Wei *et al.*, 2025). Integrating GenAI into higher education poses significant adaptation challenges.

One pressing challenge of Generative Artificial Intelligence (GenAI) in higher education is the need to re-evaluate the development and assessment of skills critical for students' success in today's complex, technology-driven world, such as 21st century skills (Lytras and Ordonez, 2024). 21st century skills refer to higher-order thinking skills such as critical thinking, creativity, communication, collaboration, digital literacy, and problem-solving (Celik *et al.*, 2024), which require more than just memorizing what is taught in class. Another challenge is the growing disconnect between the skills taught in educational systems and those demanded by contemporary job markets, where employers increasingly prioritize practical skills, such as 21st century skills, over basic numeracy and literacy skills (Birru, 2024; Tushar and Sooraksa, 2023). Thus, educational practices must align with job market expectations to ensure that students are equipped with relevant competencies.

In spite of the aforementioned adaptation challenges, research on GenAI in higher education has rapidly expanded since 2022 (Saleem *et al.*, 2024). Recent studies highlight GenAI's dual impact on education: on one hand, it supports 21st-century skill development through personalized learning and adaptive feedback (Merino-Campos, 2025); on the other, it raises concerns about academic integrity, authenticity, and ethical use (Benvenuti *et al.*, 2023; Weng *et al.*, 2024). This duality illustrates the complex relationship between GenAI and 21st-century skills while GenAI fosters, and challenges 21st century skills. Building on these debates, scholars have increasingly presented diverse perspectives on GenAI's role in education. Some emphasize its transformative potential to enhance creativity, critical thinking, and learner engagement (Kasneci *et al.*, 2023; Yang *et al.*, 2024), while others caution that excessive reliance on GenAI may reduce originality, deepen dependency, and compromise authentic learning (Bower *et al.*, 2024; Chiu, 2023). Collectively, these contrasting viewpoints reveal that GenAI integration in higher education is both promising and disruptive, demanding a balanced approach that promotes innovation while safeguarding the integrity of students' 21st-century skills.

Regarding 21st century skills assessment, various frameworks have been established to define, conceptualize, and structure these skills, such as the Assessment and Teaching of 21st Century Skills (ATC21S) initiative and the Partnership for 21st Century Skills (P21) (Voogt and Roblin, 2012). ATC21S identified recurring 21st century skills such as problem-solving, collaboration, and digital literacy (Chiappe, 2024), while P21 emphasizes subcategories including learning and innovation skills, life and career skills, and information, media, and technology-related skills (Battelle for Kids, 2019; Saleem *et al.*, 2024).

Despite the increasing interest in both Generative Artificial Intelligence (GenAI) and 21st century skills, two critical gaps persist in the current body of research. First, while consensus has grown on the necessity of 21st century skills (Federiakin *et al.*, 2024) and GenAI

(Weng *et al.*, 2024), inconsistencies in implementation and integration strategies have led to discrepancies in the understanding of the intersection between Generative Artificial Intelligence (GenAI) and 21st century skills. For example, some institutions may adopt GenAI technologies without adequately trained educators, resulting in ineffective integration that fails to improve students' skill development. Therefore, it confuses the assessment practices. This discrepancy highlights the need for educational interventions that consider the implications of GenAI in skills such as 21st century skills development and assessment.

Second, it remains unclear which 21st century skills remain relevant and how they evolve in an AI-dominated environment. Previous studies have often overlooked the intersection between emerging technologies (Ng *et al.*, 2024), such as GenAI, and evolving 21st century skills (Aizenkot and David, 2022) relevance and assessment. To address these gaps, this study employed a Systematic Literature Review (SLR) to provide an overview of how GenAI reshapes the relevance and assessment of 21st century skills in higher education. Understanding the interplay between Generative Artificial Intelligence (GenAI) and 21st century skills could inform stakeholders on how to develop curricula and assessment strategies that equip students with the competencies needed for success in an AI-integrated world. This study was guided by the following research questions:

Research questions

(1) What 21st century skills are critical for higher education students in the age of Generative AI (GenAI)?

(2) Why do these skills (RQ1) maintain relevance in light of GenAI?

(3) What assessment practices are deemed effective in capturing the dynamics of these skills in light of the GenAI?

(4) How do higher education stakeholders (e.g. employers, and most especially educators) perceive the current assessment of these skills in the age of Generative AI?

Analytical framework

An analytical framework is crucial for conducting systematic literature reviews (SLRs). It defines the scope, providing a structured approach to analysis while ensuring that relevant literature aligned with the study objectives are included (Hart, 2018, pp. 13–45; Criado *et al.*, 2023). This will allow future researchers to reliably replicate or expand the study. In this study, the generative artificial intelligence epistemology, pedagogy, and assessment (GenAI EPA) analytical framework focuses on three main areas: epistemology (determining relevant 21st century skills), assessment (assessment methods), and pedagogy (how stakeholders perceive students' 21st century skills relevancy and assessment) as shown in Figure 1.

GenAI EPA analytical framework

Adapted from the epistemology, pedagogy, and assessment (EPA) triad by Knight and Shum (2017) and Knight *et al.* (2014). The epistemology, pedagogy, and assessment (EPA) triad was initially developed for learning analytics, which uses data to improve learning outcomes (Axelsen *et al.*, 2020). Unlike Learning analytics tools that collect data on students' content interactions (Mangaroska and Giannakos, 2018), Generative AI (GenAI) focuses on content creation (Amirjalili *et al.*, 2024; Holmes *et al.*, 2023). Both learning analytics and GenAI enhance learning through tailored experiences. The original epistemology, pedagogy, and assessment (EPA) triad framework is a conceptual framework that comprises three main components: epistemology, pedagogy, and assessment. This raises questions regarding what, how, why, who, where, and when in educational processes, facilitating an understanding of

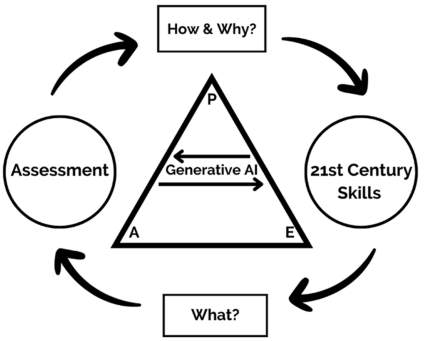

Figure 1. Generative AI epistemology pedagogy assessment (GenAI EPA) analytical framework, adapted and modified from Knight and Shum (2017, pp. 17–22) and Knight *et al.* (2014)

knowledge construction, pedagogical methods, and learning assessments. Our Generative AI epistemology pedagogy assessment (GenAI EPA) analytical framework emphasizes the what, how, and why aspects of the original EPA triad as shown in Figure 1.

E for epistemology. Epistemology refers to the study of knowledge (Steup, 2020), including its nature and its construction. In the EPA Triad context, (Knight and Shum, 2017, pp. 17–22; Knight *et al.*, 2014)'s epistemology addresses philosophical epistemology and epistemic beliefs. Philosophical epistemology explores the nature of knowledge, examining "what" knowledge is important in education, "how" it is conceptualized. In the GenAI EPA context, it questions which 21st century skills remain relevant as AI becomes more integral (Fleckenstein *et al.*, 2024). Epistemic beliefs are personal beliefs regarding knowledge acquisition and demonstration (Knight and Shum, 2017; Knight *et al.*, 2014). As AI tools such as ChatGPT become more prevalent, students' epistemic beliefs may evolve to view AI as a legitimate co-creator of knowledge (Thong *et al.*, 2023; Zawacki-Richter *et al.*, 2019). Thus, epistemology in the GenAI EPA context focuses more on the philosophical epistemology of "what" 21st century skills are essential and "why" they remain critical despite AI's growing impact (research questions 1 and 2).

P for pedagogy. Pedagogy encompasses teaching methods and practices that focus on instructional design, delivery, and teacher-learner interactions. The EPA Triad's pedagogical questions include: "Who is the education, learning analytics or our case GenAI for?" to address the intended audience (Knight and Shum, 2017; Knight *et al.*, 2014). In the context of Generative AI, the focus is still on the "who" (stakeholders), but extends to their perceptions of 21st century skills assessment as the result of GenAI (research question 4). These stakeholders include related parties, mostly teachers and employers (Luo, 2024; Luckin *et al.*, 2022), who are in a position to assess these skills.

A for assessment. Assessment is the third pillar of the EPA Triad, and involves methods to assess students' learning outcomes (Knight and Shum, 2017; Knight *et al.*, 2014). Conventional assessments typically occur in predefined environments at specific points in time (Khlaif *et al.*, 2025; Rudolph *et al.*, 2023). However, AI has transformed the assessment location, timing, and methodology. Traditional forms may be augmented or replaced by dynamic, ongoing evaluations that better capture 21st century skills complexity, including higher-order cognitive skills and creativity (Geisinger, 2016; Nawaz *et al.*, 2024). While the original EPA Triad considered "where" and "when" assessments occur, we focus on "how" and "what" kind of assessment methods can assess 21st century skills, especially in the Generative AI era (Research questions 3 and 4).

Methodology

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page *et al.*, 2021), we systematically identified, evaluated, and

synthesized relevant research. The following sections describe the eligibility criteria, information sources, search strategy, selection process, data collection methods, and extraction procedures used in this review.

Eligibility criteria and sources of information

The publication period spanned from January 2020 to June 2024. This is because Generative AI has become more feasible following OpenAI's release of ChatGPT GPT-3 in 2020 (Lin, 2023; Bozkurt *et al.*, 2024). The release of advanced versions of ChatGPT by OpenAI in late 2022 marked another significant milestone (Lin, 2023), offering accessible GenAI technologies with profound implications for higher education (Bozkurt *et al.*, 2024). Two databases were used: Web of Science (WoS) and Google Scholar. The search was conducted between July 15th and July 25, 2024.

Search strategy

The information retrieval strategy involved developing a set of keywords and controlled vocabularies pertaining to GenAI, higher education, and 21st century skills. Keywords and potential alternatives were also identified in this study. Keywords, including Generative AI and terms associated with higher education and 21st century skills assessments, were utilized to identify relevant literature. To capture 21st century skills assessment, combinations of terms along with Boolean operators (AND, OR) were employed to effectively combine search terms, as shown in Table 1.

Selection process, data collection, and data extraction

Adhering to the PRISMA 2020 guidelines (Haddaway *et al.*, 2022; Page *et al.*, 2021), we selected studies in multiple steps to ensure the inclusion of relevant and high-quality research. We retrieved 702 records from the database searches: 435 from Google Scholar and 267 from the Web of Science. In the first screening, 545 records were automatically excluded, as they were not indexed in Q1–Q4 ranking journals, which is consistent with Rapid Journal Quality checks. A total of 28 duplicates were identified; therefore, 129 records were subjected to abstract screening. Titles and abstracts were evaluated based on predetermined inclusion criteria (Table 2). During abstract screening, we excluded 67 articles (Figure 2), leaving 62 articles that met the inclusion and exclusion criteria (Table 2).

After completing the screening process, all eligible studies were subjected to a qualitative thematic synthesis. The analysis focused on identifying recurring patterns, conceptual frameworks, and evidence related to how Generative AI influences the relevance and assessment of 21st-century skills in higher education. Each study was coded according to key dimensions, including research objectives, methodologies, skill domains addressed, and

Table 1. Keywords and search strings

Focus area	Keywords/Combinations
Generative AI in Higher Education 21st Century Skills	"GenAI in higher education" OR "GenAI in higher education classroom" "21st century skills" OR "Critical thinking" OR "Creative thinking" OR "Collaboration skills" OR "Communication skills" OR "Problem-solving skills" OR "Innovation skills" OR "Higher order thinking" OR "Analytical skills" OR "Cognitive skills" OR "Metacognitive skills" OR "Reflective thinking" OR "Strategic thinking" OR "Decision making skills"
Generative AI and 21st century skills Assessment	"Gen AI and 21st century skills" OR "GenAI impact on 21st century skills" OR "AI influence on 21st century skills relevancy" OR "GenAI and 21st century skills evaluation"

Table 2. Inclusion and exclusion criteria

Criteria	Inclusion criteria	Exclusion criteria
Study Type	Peer-reviewed	Non-peer-reviewed
Availability	Available full texts	Unavailable full texts
Relevancy	GenAI technologies	Non-GenAI technologies (e.g. ICT)
Skills	Assess 21st century skills	Non-21st century skills (e.g. basic literacy and numeracy)
Educational Level	Higher education	Non-higher education (e.g. K–12, primary, secondary education)

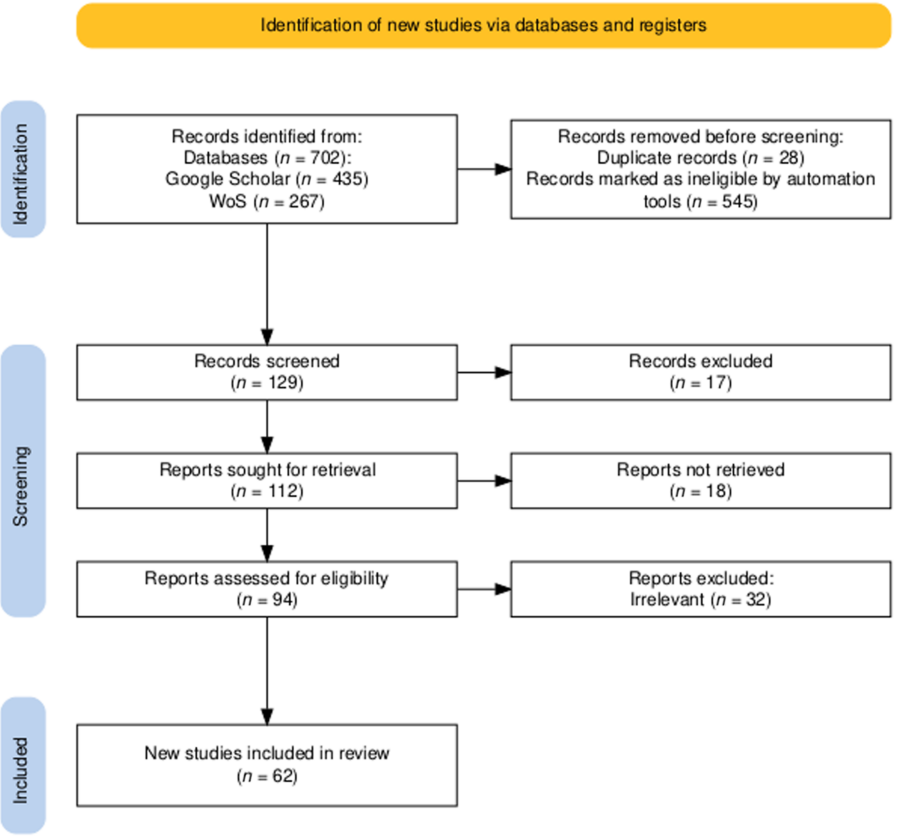

Figure 2. Data collection procedure. This figure was generated using the PRISMA protocol developed by Haddaway *et al.* (2022)

reported impacts of GenAI on 21st century skills assessment. Patterns and themes were then compared across studies to ensure consistency and capture both converging and diverging viewpoints. This approach enhanced transparency and allowed the review to systematically highlight emerging trends and knowledge gaps, consistent with the PRISMA 2020 recommendations of Page *et al.* (2021).

Results and discussion

A systematic review of the literature identified 62 relevant studies. These publications range from various sources and types, including 55 journal articles, 4 conference proceedings papers, 1 thesis, and 2 book chapters. Notably, our findings revealed an increase in scholarly interest in recent years; no relevant publications were identified in 2020 or 2022, whereas only one was found in 2021. However, this number has increased substantially from 22 in 2023 to 39 in 2024, as shown in Figure 3. This exponential growth suggests increasing attention to the implications of GenAI in 21st century skills assessment.

Relevant 21st century skills

To address our first and second research questions, we mapped the identified skills onto the Partnership for 21st Century Learning framework (P21) (Battelle for Kids, 2019; Care, 2018), focusing on three primary categories: (1) learning and innovation-related skills, particularly the "four Cs" (i.e. critical thinking and problem solving, creativity and innovation, communication, and collaboration); (2) life and career-related skills, such as adaptability, lifelong learning, and ethical awareness; and (3) information, media, and technology-related skills, including digital, information, and AI literacy.

Learning and innovation skills. Our findings indicate that the "four Cs" (critical thinking and problem-solving, creativity and innovation, communication, and collaboration) have emerged as non-negotiable skills in the GenAI era, but their application has fundamentally shifted. For instance, critical thinking and problem-solving skills (e.g. O'Dea, 2024; Tsopra *et al.*, 2023) are no longer merely about evaluating human-generated content but require metacognitive strategies to interrogate AI outputs for biases, logical flaws, and contextual appropriateness. Similarly, creativity and innovation now encompasses "prompt engineering" and other iterative co-creation with AI skills (e.g. Song, 2024). Thus, despite the advanced capabilities of GenAI, students must analyze information, ask questions, and make informed decisions based on AI-generated data (e.g. Song, 2024; Thanh *et al.*, 2023) to explore novel ideas, generate innovative solutions, and transcend traditional cognitive limits. These findings corroborate those of Lee and Yoke (2024), who emphasized the increasing significance of skills, such as critical thinking and creativity, in our technology-driven society. Our findings also concur with Chen (2021), who noted that while there is a consensus on the importance of these skills, the diversity of conceptualization presents challenges in assessing them in higher education, creating a complex situation.

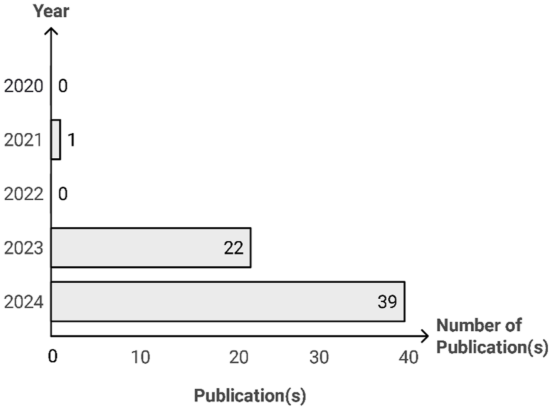

Figure 3. Number of included publications over time

Life and career skills. Life and career skills, such as adaptability, lifelong learning, and ethical awareness, have also remained relevant in the context of Generative AI. Research (e.g. Bowles and Kruger, 2023; Dahri *et al.*, 2024) emphasizes the importance of adaptability skills. These include proficiency in new AI tools, integration with automated processes, and the incorporation of AI into professional life. The pervasiveness of AI necessitates the active pursuit of learning new information to keep pace with technological advancements. Ethical awareness and judgment skills prevail (Brin *et al.*, 2023; Smith, 2024), wherein students need to comprehend the implications of responsibly utilizing AI technology. These findings are consistent with those of Tushar and Sooraksa (2023), who observed an increase in the demand for career and life skills. Koehorst *et al.* (2021) and Salhab and Aboushi (2025) further noted that while creativity has received attention, other critical skills, such as adaptability and ethical awareness, require greater emphasis in both workplace and educational settings.

Information, media, and technology skills. The findings revealed that information, AI, and digital literacy have become increasingly relevant, particularly in the context of GenAI. Chan and Lee (2023), Fruehauf *et al.* (2024), and Kumar *et al.* (2024) emphasize the need for students to develop literacy skills to critically evaluate AI-generated content, including assessing accuracy, reliability, and potential biases skills essential for mitigating misinformation and making informed decisions based on AI outputs. These findings align with the framework proposed by Van Laar *et al.* (2017), who categorized 21st-century skills into fundamental (e.g. technical proficiency, creativity, analytical reasoning, and problem-solving) and contextual (e.g. ethical awareness, adaptability, and lifelong learning) dimensions. This also corresponds with Ng *et al.* (2023) and Park (2025), who position AI literacy as a core 21st-century competency encompassing the knowledge, skills, and attitudes to understand and critically engage with AI, extending beyond technical ability to include the "4Cs" (critical thinking, creativity, communication, and collaboration) aspects of GenAI usage.

21st century skills assessment in GenAI era

The findings addressing research question 3, reveal the inadequacy of traditional assessment methods in contemporary higher education (see Table 3). Traditional approaches that prioritize

Table 3. 21st century skills assessment methods

Assessment method (type)	Assessment type (sub-dimension)	Article/Author(s)
Traditional Assessment Methods	Standardized Tests, Memorization	Binsztok *et al.* (2024), Meishar-Tal (2024), Fruehauf *et al.* (2024), Bearman and Ajjawi (2023), Bearman *et al.* (2024) and Liao *et al.* (2024)
Alternative Assessment Methods	Formative Assessments	Farrokhnia *et al.* (2023), Ruiz-Rojas *et al.* (2024), Hopfenbeck *et al.* (2023), Almogren *et al.* (2024), Yang *et al.* (2024) and Tsopra *et al.* (2023)
	Collaborative and Project-Based Assessments	Spanos (2024), Hopfenbeck *et al.* (2023), McDonald *et al.* (2024), O'Dea (2024), Kelly *et al.* (2023) and Lodge *et al.* (2023)
	Self-Assessment and Reflective Practices	Tabib and Alrabeei (2024), Meishar-Tal (2024), Bearman *et al.* (2024), Shackter and Karlsson (2023), Kanont *et al.* (2024) and O'Halloran (2024)
	Authentic Assessments	Tabib and Alrabeei (2024), Rudolph *et al.* (2023), Ifelebuegu (2023), Jaboob *et al.* (2024) and Chan and Lee (2023)
	Performance-Based Assessments	Mathew and Stefaniak (2024), Dunnigan *et al.*, (2023), Krammer (2023), and Almogren *et al.* (2024)
	Digital Portfolios	Binsztok *et al.* (2024), Jaboob *et al.* (2024), Ruiz-Rojas *et al.* (2024)

standardized testing and rote memorization fail to capture the breadth of students' 21st century skills (Bearman and Ajjawi, 2023; Liao *et al.*, 2024). These findings highlight the growing consensus on the need to critically reevaluate, adapt, or fundamentally redesign conventional assessment practices. Supporting this shift, Kain *et al.* (2024) advocate for adaptable assessment strategies to modernize higher education practices. Similarly, Van Laar *et al.* (2020) observed that while current assessments address certain 21st century skills, such as technical proficiency and information literacy, they often neglect critical dimensions, such as creativity and critical thinking.

This study identified several promising alternative assessment methods (Table 3). These alternative assessment methods, including formative assessments, particularly those integrating continuous feedback, have been frequently cited in the literature because of their ability to foster communication, critical thinking, and self-directed learning (Almogren *et al.*, 2024). Self-assessment and reflective assessment methods were shown to enhance metacognitive skills by encouraging students to critically evaluate their learning processes, strengths, and areas for improvement, while promoting ethical AI use (Shackter and Karlsson, 2023). In addition, authentic assessments that simulate real-world scenarios have been noted for their effectiveness in assessing the practical application of 21st century skills (Tabib and Alrabeei, 2024). Digital portfolios have emerged as valuable tools for tracking students' longitudinal development and skill mastery, particularly in the integration of AI and related technologies (Jaboob *et al.*, 2024). These findings align with Sondergeld and Johnson (2019), who note that while tests are widely used, their efficacy in evaluating 21st century skills hinges on thoughtful design and implementation, which at times requires alternative taste, a view supported by Kolade *et al.* (2024).

Stakeholders' perception of students' 21st century skills assessment in GenAI era

In addressing research question 4, we found that stakeholders, particularly educators and employers, perceived the significance of three primary approaches: (1) process-oriented, (2) outcome-oriented, and (3) a hybrid of both. Process-oriented assessments are not only about the end results, but also the learning process itself (Sun *et al.*, 2024), utilizing methods such as reflective and peer-based evaluations to analyze students' interactions with AI and their peers in collaborative settings. In outcome-oriented assessments, collaborative tasks are used to gauge students' ability to integrate AI, demonstrating creativity, communication, teamwork, problem solving, and technological proficiency (Mathew and Stefaniak, 2024). Hybrid approaches, such as reflective journal assignments and rubrics, encourage students to critically analyze their experiences with AI, discuss challenges, and evaluate their learning progress (Kelly *et al.*, 2023). However, Weng *et al.* (2024) cautioned that while rubrics and reflective journals are widely used, they may fall short in assessing advanced AI and computational thinking skills. Kolade *et al.* (2024) further argue for assessments that go beyond basic evaluations to measure students' deeper understanding of AI and 21st century skills.

Contributions, implications, limitations, and conclusion

This study makes three significant contributions to the literature and practice. First, it presents the GenAI EPA analytical framework that goes beyond the intersection of learning analytics and generic skills to examine the impact of Generative AI on higher education students 21st century skills assessment. Second, it identifies the inadequacy of traditional assessment methods and emphasizes the value of alternative approaches, such as formative, authentic, and reflective assessments. Lastly, it provides actionable recommendations for incorporating GenAI into curricula and aligning educational practices with the changing demands of the industry. By aligning educational practices, this review provides clear guidance for future curriculum design, educator training, and interdisciplinary collaboration.

The findings of this study have four important implications for higher education institutions, especially in relation to teaching practices. First, the results suggest that

institutions need to embed GenAI 21st-century skill development and assessments into their academic curricula. For example, educators are encouraged to leverage GenAI tools and features (e.g. learning personalization) to develop and assess these skills. Second, the results highlight ethical concerns (e.g. dishonesty, data privacy issues, or bias in AI-generated content) that cannot be overlooked. Institutions should establish clear policies for the responsible use of AI to mitigate these risks.

Third, the findings challenge traditional assessment methods, indicating that a shift toward more dynamic and authentic assessments is imperative. Rather than relying solely on traditional assessments, educators should prioritize modern methods that better assess 21st-century skills. For example, educators could encourage students to create digital portfolios featuring AI-assisted projects (e.g. case studies) to demonstrate their problem-solving and adaptability skills. Lastly, the findings emphasize the importance of collaboration between educators and industry stakeholders. To bridge the gap between education and employment, institutions should co-design curricula with employers, offer AI-focused skill-building workshops, and integrate internship opportunities that emphasize real-world AI applications.

Despite the aforementioned contributions, this study had several limitations, which serve as recommendations for future studies. First, this review was confined to the Web of Science and Google Scholar, potentially excluding relevant studies from other databases in educational research, technology, and artificial intelligence. Second, the timeframe (January 2020–June 2024) may introduce temporal bias and overlook foundational works; thus, expanding the temporal scope is necessary for greater comprehensiveness of the review. Third, although the GenAI EPA framework effectively structured the analysis around the "what," "how," and "why" of 21st century skills assessment in the GenAI era, its narrow focus may miss other critical dimensions. Future studies should therefore expand on the current study's limitations.

Author contributions CRediT statement

L.M.N.: Conceptualized the study, conducted literature search, selected studies, managed and analyzed the extracted data as well as wrote the initial draft, redrafts and final editing. L.M., H.O.L. and M.L.: Conducted the quality assessment on the selected studies, analyzed findings, as well as co-authored redrafts and final editing.

Data availability statement

Since this study is a systematic literature review, no primary data were generated. All data used in this review are publicly available and referenced in reference list.

Generative AI disclosure statement

The authors confirm the use of specific generative AI tools in the preparation of this manuscript. Generative AI technologies including Paperpal and GPT4 were used for the sole purposes of editing, language refinement and clarity nourishment. It is worth noting that these tools were exclusively used to improve readability while maintaining academic integrity. Therefore, all content remains under the authors' final oversight and responsibility.

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Note. * Symbolizes the included articles

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