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Review

Generative AI literacy and lifelong learning: A literature overview

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Abstract: As generative artificial intelligence (Gen-AI) becomes increasingly integrated into society, understanding how individuals can effectively use these technologies is essential. This paper examines the concept of Generative AI Literacy (Gen-AIL), focusing on the skills needed to navigate and apply Gen-AI tools in personal and professional contexts. Using a targeted literature review of recent studies from databases such as Google Scholar, Consensus.app, and Undermind.ai, the paper identifies key dimensions of Gen-AIL and explores its role in supporting lifelong and personalized learning. The study proposes an integrated framework to guide the development of Gen-AIL and highlights emerging trends shaping its future impact on education. These insights contribute to ongoing discussions on digital literacy and inform future educational strategies in an AI-driven world.

Keywords: artificial intelligence; generative AI; higher education; lifelong learning; digital competency; digital literacy; AI literacy

1. Introduction

Generative-based artificial intelligence (Gen-AI) rapid advancements, propelled by models like ChatGPT and DALL-E, have changed the content creation game and raised several important technical, ethical, societal, and educational issues. Characterized by its capacity to create novel content based on acquired data, Generation AI has emerged as a disruptive innovation in educational environments [1,2]. It is reshaping the way individuals interact with information and learn throughout their lives. The above development makes "generative AI literacy" an important element in lifelong learning—that is, the necessary know-how that will allow an individual to maneuver Gen-AI systems with understanding, critical thinking, and responsibility concerning the ethical use of these emergent and innovative systems [3,4]. The existing literature offers valuable insights into competence development, implementation for educational purposes and ethical issues, and considerations on gaps in the adjustment of these approaches to the new, diverse, and changing learners in different societal contexts. However, the conceptualization of generative AI in frameworks for lifelong learning is still largely underexplored [5,6].

Given the fast evolution in digital-driven technology, the learning process and education today need a redefinition. In this respect, learning today is not about ingesting monolithic information at a single point in time; it is rather about possessing the agility and resilience to cope with change. With the advent of generative AI technologies, greater attention is needed to figure out how humans can become well-versed users rather than focusing on the kind of things these techniques can do. Generative AI, therefore, is taken to be a partner in the learning process with the capacity to assume different forms in enriching the experience of lifelong learning [7]. Thus, the focus of this paper is on the intersection of lifelong learning and generative artificial intelligence.

In a rapidly changing world, learning does not stop when formal education is over. Lifelong learning, which refers to the continuous, voluntary, and self-motivated pursuit of knowledge for personal-driven or professional development [8,9], has been recognized as a necessity in the current age [7,10]. On the other hand, generative AI, a technology that creates text, images, audio, or other media in response to prompts, represents the latest advancement in artificial intelligence. Merging these two domains—lifelong learning and generative AI—is fundamental to where education should be moving.

Through a generalized review of relevant studies that showcase successful implementations of Gen-AI in educational settings, this paper will illustrate practical applications and distill valuable lessons for future endeavors in this domain. Further, the paper clarifies the upcoming developments and trends of generative AI that are going to have a much bigger influence on the educational landscape, emphatically underpinning the fact that research is needed to reshape and advance learning environments in alignment with the growth of technologies. This generic literature review, therefore, is geared toward offering a complete overview of generative AI literacy and the deep implications it has for lifelong learning to further support how best education can meet the challenges and opportunities in light of advancements in this innovative technology.

2. Methods

The methodology in this study is under a qualitative approach, using a generalized review of the literature to explore generative AI literacy and its implications for lifelong learning. Articles in this research work were only considered for inclusion if they dealt with scholarly peer-reviewed journal articles, conference proceedings, or book chapters found in reputable academic databases that include Scopus, Google Scholar, and most importantly, the AI-based databases consensus.app and undermind.ai. Considering publication year (most recent), language (English only), and subject filters, in addition to the targeted keywords and Boolean operators (i.e., “Generative AI literacy”, “Lifelong learning and AI”, “Digital literacy and generative technologies”, “AI in education”, and “Generative AI and personalized learning”), contributed to the strength of the set of sources relevant by relevance in the search for literature. The review maintained pertinent and valuable literature through some basic inclusion and exclusion criteria. The review excluded the literature that did not meet the criteria of directly discussing the topic, as well as duplicated and lower-quality literature. For all publications accessed on generative AI literacy, its application in education, and case studies explaining practical implementations, this research preferred those to ones that were irrelevant, of poor quality, or duplicative. By so doing, it helped ensure that pertinent issues, challenges, and possible opportunities were exposed and treated in the fullest possible measure in regard to the role of generative AI literacy in an evolving learning landscape.

3. Results and discussion

This section presents a detailed examination of major themes through a review of related literature as identified in this study. These themes capture the multiple

dimensions of generative AI literacy and its importance in the framework of lifelong learning. Specifically, the analysis highlights four major areas: (1) the conceptualization of generative AI, lifelong learning (LLL), and the transformative impact of Generative AI on education and lifelong learning, including its role in fostering personalized education and continuous skill development; (2) components of Gen-AI literacy (Gen-AIL), shedding light on its essential dimensions, the main dimensions of lifelong learning, and the combined framework of Gen-AIL-LLL; (3) challenges and barriers to the widespread adoption of Gen-AI literacy, with a focus on misconceptions, institutional constraints, and accessibility issues; and (4) emerging trends and advancements in Gen-AI that are shaping the future of educational practices and policy development. Thus, synthesizing insights from different sources, this section goes far to underline not only the vision of generative AI for change in education but also spots the areas that are critical for intervention, research, and policy action to ensure effective integration and use in learning environments.

3.1. Generative AI and lifelong learning

3.1.1. Generative AI evolution

Generative AI is fundamentally distinct from traditional AI methods due to its novel approach and functionality, which centers around creating content rather than simply making decisions or providing descriptions [11,12]. Generative AI has emerged as one of the most impactful technologies of recent years. Generative AI refers to computational models capable of creating original and innovative artifacts such as images, texts, audio, music, videos, and other formats [11,13]. These models analyze vast databases to discern a meaningful relationship and pattern, enabling them to generate new outputs that can replicate the style and statistical characteristics of the training data while remaining unique [11,14]. OpenAI's ChatGPT, a Gen-AI model, was the most popular web application in early 2023, captivating hundreds of millions of users worldwide [15]. Other generative AI models have proliferated across various media types. As a result, big tech firms, such as Google, Microsoft, and Meta, are putting a lot of money into generative AI since it can change the way folks use tech and remake many daily tasks. Moreover, the middle and high levels of generative AI architectures are being opened up for free use to institutions as well as individual parties that may want to test and experiment with AI technology. This democratization enhances access to generative AI assets, tools, applications, and experiences of learning.

Considering that generative AI can create new outputs based on existing content, it is fundamental to discuss approaches and new developments for creating, abstracting, and generating knowledge. Generative AI advancements could significantly impact how knowledge is produced, represented, and shared, in addition to altering communication modes [13]. The expansion of the internet and the web brought new possibilities for knowledge generation, organization, and dissemination. As a feedback loop, web development shaped and influenced knowledge processes. Therefore, knowledge processes are discussed in the context of generative AI developments. In expanding on knowledge processes, the lifelong learning perspective is worthy of addressing adequately. How generative AI developments can impact

learning processes throughout life is an essential discussion. Considering that education involves learning, training, or developing knowledge and skills, generative AI insights and developments bring potential changes to traditional educational practices, approaches, and paradigms [16]. It is a change not only in the response of teachers or educational institutions to students using generative AI for support in learning activities but also in the comprehension regarding generative AI support to the learning process, system, and environment. As the educational paradigm intertwines with generative AI developments, the lifelong learning perspective emphasizes learning beyond formal educational contexts.

3.1.2. Lifelong learning evolution

Lifelong learning has evolved from the concept of lifelong education, reflecting a shift in focus from formal education systems to a more inclusive and continuous learning process that spans an individual's entire life [17,18]. This transition marks a qualitative leap, responding to the demands of modern society and the need for a learning society [19,20]. The concept has been shaped by global events and policy developments, such as those discussed at international forums like the Shanghai International Forum on Lifelong Learning, which highlight its role in rural and industrial development and its integration with new learning media and higher education [21,22].

Lifelong learning is crucial in a knowledge-based society, where rapid technological and scientific advancements necessitate continuous knowledge updates. It is seen as essential for maintaining a competitive labor force, adapting to changes such as the rise of Gen-AI and robotics, and addressing the needs of an aging population [5,20,23]. The science of lifelong learning stresses the need for cross-field research and using brain (neural-based) science to help varied learners and support making inclusive knowledge [24].

Therefore, lifelong learning is an essential component of modern education systems, driven by the need for continuous adaptation to societal and technological changes. Its evolution from lifelong education reflects a broader understanding of learning as a lifelong process integral to personal and societal development. Addressing the challenges it faces will be crucial in ensuring that lifelong learning remains a viable and effective approach to education in the present Gen-AI emergency and the future of the education sector.

3.1.3. Generative AI in education and lifelong learning context

Generative AI creates new content, including text, images, and sounds. Currently, the most accessible generative AI content is text-based, with popular applications being available to the public for free. Gen-AI has the potential to generate educational content, creating new learning possibilities for people through lifelong learning [5,16]. This content can range from music notation for creative projects to multiple-choice questions about a specific topic, enabling learners to create content to support their learning objectives [12,25]. As generative AI applications become widely available for free, it is critical to understand how they can be practically used in lifelong learning. A literature review of the current generative AI applications or integrations in learning contexts was conducted, focusing on how produced text, images, audio, or code content can support learning and education. The findings include empirical case

studies on integrating generative AI applications in learning contexts.

Generative AI applications can assist learners in creating study materials. Given a text prompt, learners can request generative AI text systems to create content that directs their learning efforts, such as summaries or textual questions about specific topics. AI-generated content is most effective in supporting learning when the content that questions the learner's knowledge state is generated [26]. Generative systems can also enhance the tutoring experience for learners. Several case studies with generative AI chatbots showing the potential of virtual tutors are discussed. Generative AI significantly affects the creation of interactive learning environments. There are currently generative AI applications to reinforce collaborative learning among learners, co-generating content with text prompts in groups. Thus, the transformative effects of immersive technologies powered by generative AI applications are continuously being invented. For each Gen-AI application and learning context, there is an abundance of possibilities and limitations of generative AI content applications in education, with the intent of inspiring educators and all citizens to visualize innovative applications of generative AI content in supporting lifelong learning.

Integrating Gen-AI into lifelong learning processes offers notable benefits, particularly in terms of personalized education. Gen-AI's capability to tailor instructional approaches to each learner's unique needs and learning styles significantly enhances the personalization of education [27,28]. This personalized approach is instrumental in identifying students' strengths and weaknesses, allowing for targeted interventions that improve learning outcomes [27,29]. Furthermore, AI facilitates interactive and individualized learning experiences, thus increasing student engagement and motivation [27,30]. By providing real-time, personalized feedback, AI supports continuous learning and development, which is crucial for lifelong learners to remain adaptable in a rapidly changing world [27]. The creation of adaptive learning environments through AI not only makes learning more effective but also fosters collaboration and social interaction among learners, promoting a more holistic educational experience [31]. However, to fully realize these benefits, careful planning and the continuous provision of feedback are essential to optimize AI's integration into lifelong learning [5,14]. Nevertheless, all these Gen-AI benefits can only be effectively achieved by individuals possessing adequate Gen-AI literacy. Therefore, educational institutions must focus on strategic implementation and ongoing evaluation to ensure that Gen-AI's potential is maximized in fostering an engaging, personalized, and effective lifelong learning environment, especially by developing and nurturing Gen-AI competency.

In light of the rapid advancement of technology, learning processes need to be addressed in a new way. Learning is no longer about acquiring fixed knowledge at a certain point; it is more about adaptability and flexibility. With the development of generative AI technologies, the focus should be on how to competitively utilize these systems instead of merely knowing what they can do. Therefore, as Gen-AI systems continue seeping into different sectors, knowing how they work and their effects becomes very important, necessitating a look at generative AI literacy— a skill that helps people use these advanced technologies well and responsibly.

3.2. Generative AI literacy and lifelong learning framework

In today's digital age, literacy in generative AI is crucial as it not only addresses the challenges and opportunities presented by this technology but also facilitates a comprehensive understanding of its applications and implications [5]. As part of digital literacy, Gen-AI literacy, which encompasses understanding the generative AI systems' mechanisms, their potential biases, and their limitations, is essential for individuals to navigate the complexities of the modern technological landscape [32,33]. By integrating ethical frameworks such as deontological ethics and consequentialism, educators can guide students in the responsible use of AI tools, which is fundamental for fostering a culture of digital literacy [32]. Moreover, empowering students with skills in Gen-AI enables them to critically and ethically engage with AI technologies, preparing them for the evolving demands of the workforce [32,34]. As Gen-AI models continue to expand their capabilities, being literate in this domain allows individuals to leverage their tools for both creative and professional purposes, thereby enhancing their productivity and fostering innovation [34,35]. To effectively engage with these technologies, educational systems must prioritize teaching the ethical usage of Gen-AI, which in turn promotes digital literacy and prepares learners for the future challenges of an automated world [10,32].

For people to harness the potential of Gen-AI effectively in any environment, they must develop a multifaceted skill set that encompasses both technical and evaluative capabilities. At the core of these skills is "prompt engineering," which involves crafting precise and relevant queries to guide the Gen-AI in generating meaningful content [36,37]. This skill is particularly vital for knowledge and creative workers who will rely heavily on AI tools in the coming decade [36]. Additionally, individuals should engage with Gen-AI systems through active experimentation and iteration, leveraging tools like ChatGPT to refine their creative processes and outputs [36]. Such engagement not only enhances creativity but also nurtures a deeper understanding of the algorithms and interfaces that power these Gen-AI systems, thus enabling users to generate ideas and solutions more swiftly [36,38]. Moreover, developing critical evaluation skills is paramount, as users must assess the reliability and validity of Gen-AI-generated content to ensure its alignment with ethical and educational standards [39]. By adopting a comprehensive approach that integrates technical competency with critical analysis, individuals can effectively navigate and leverage generative AI in their personal and professional lives.

3.2.1. Elements of Gen-AI literacy

As generative AI becomes increasingly ubiquitous, so do calls for investigating it through the lens of AI literacy. Generative AI literacy (Gen-AIL) involves understanding and effectively interacting with generative AI technologies. Core elements of generative AI literacy include foundational knowledge, technical skills, and ethical considerations necessary for the responsible use or creation of AI systems [13,40,41]. Some of the core elements of generative AI literacy are elaborated in the following:

a) Foundational AI knowledge: This includes understanding basic AI concepts, how generative AI models work, and their applications across various domains, such as language, image, and video processing [40,41].
b) Technical skills: Technological competencies like prompt design or engineering

and algorithmic thinking are critical for interacting with or developing generative AI systems [14,33,37]. These will help develop the skill to create, analyze, and evaluate AI-generated content.

c) Ethical and responsible use: It is equally significant to understand the ethical implications and legal frameworks surrounding Gen-AI usage. This includes issues related to data privacy, bias, accountability, and the responsible deployment of AI technologies [13,40,42].

d) Digital literacy components: Developing generative AI literacy encompasses possessing general digital literacy that involves several key elements, including information processing, digital problem-solving, and concept formation, particularly in educational settings [43]. In the current literature, digital literacy is an ongoing concern, as many individuals possess inadequate levels of digital competency [44–46].

e) Creative and critical thinking: Generative AI opens up new creative possibilities in idea creation, design, and solutions. [47] On the other hand, such potential can only be fully realized if balanced with critical thinking, so users are able not only to find new applications effectively but also to evaluate the outputs of AI in terms of quality, logic, and trustworthiness [48]. Critical thinking will ensure that the adoption of AI-generated content comes to some particular goals in a rather orderly and very proper manner. This is a two-way harnessing of— promotion of innovation and avoidance of hazards resulting from the blind use of Gen-AI. Harnessing Gen-AI for creativity while critically assessing outputs ensures innovation and reliability.

Therefore, Gen-AI literacy is a blend of multiple aspects that include foundational knowledge of generative AI, technical skills, and ethical awareness, among others. Individuals need to navigate the complexities of AI technologies responsibly, and this is where literacy in interacting with Gen-AI comes into play. Educational frameworks and professional training programs should integrate these core elements to prepare users to engage with generative AI effectively and ethically.

3.2.2. Components of lifelong learning

Lifelong learning (LLL) is a broad, complex, multidimensional concept that has many definitions due to differing cultural values, educational systems, and social and economic priorities [49]. It is an ongoing, voluntary, self-motivated pursuit of knowledge for personal or professional development. Continuous learning, or LLL, is the ongoing, self-motivated, and voluntary pursuit of knowledge for personal or professional development [50,51]. Knowledge acquisition through LLL activities reduces skill gaps and raises awareness of new trends. It helps individuals to keep up with changes in the working environment and continuously improve their performance. Continuous education after traditional schooling is crucial in a dynamically changing world, especially considering the emergence of disruptive technologies like Gen-AI. In this section, we present the LLL framework—the characteristics of LLL—before presenting the combined Gen-AIL-LLL framework. Addressing this topic is essential for making individuals aware of what they should learn, how they should learn, and where they should learn. It also helps in the holistic understanding of different learnings (formally/informally, individually/collaboratively,

or actively/passively) and in determining the combinations of these learning methodologies to achieve certain objectives in the Gen-AI era. The following are some of the defining characteristics of lifelong learning practice.

- Self-motivation and initiative: Lifelong learning is driven by intrinsic motivation and a proactive approach to acquiring knowledge. Self-regulation and reflective practices enhance this motivation by creating a meaningful connection to learning outcomes [51]. Intrinsic motivation and agency are central to lifelong learning, supporting adaptability and resilience in various contexts [52].
- Autonomous learning: Autonomous or self-directed learning enables individuals to take charge of their learning processes, including goal setting, resource identification, and progress evaluation [53,54]. Autonomous learning improves self-regulation and initiative, key traits for fostering lifelong growth [55]. Thus, autonomy fosters lifelong learning behaviors.
- Goal-oriented approach: Clear, measurable objectives guide lifelong learners toward achieving personal and societal development goals, maintaining focus and motivation [52,56]. Goal-oriented learning links intrinsic motivation with tangible achievements, reinforcing lifelong commitment [57,58].
- Adaptability and resilience: Embracing change and learning from challenges strengthens resilience and flexibility in adapting to new knowledge and technologies [7,59]. Lifelong learners exhibit higher resilience and adaptability, which are developed through self-regulated learning strategies [60]. Thus, adapting to changing environments and being resilient are among the cornerstones of effective lifelong learning.
- Reflection and self-awareness: Reflective practices help learners identify strengths, weaknesses, and interests, guiding continuous growth and aligning learning efforts with personal goals [61]. Self-awareness in learning enhances resilience and informs goal-setting, promoting lifelong learning persistence [24,62].
- Collaboration and networking: Collaborative efforts with peers and mentors enrich learning through diverse perspectives, enabling shared growth and knowledge-building [63]. Networking fosters interdisciplinary knowledge exchange and the development of broader skill sets [64].

Therefore, the lifelong learning framework encapsulates motivational factors, autonomy, adaptability, self-reflection, collaborative attitudes, and goal setting to give people the power for continuous personal and professional development. These linked parts make sure there's resilience and relevance in a fast-changing world driven by Gen-AI technologies.

3.2.3. Gen-AIL-LLL framework

The Gen-AIL-LLL framework (see **Figure 1**) emphasizes the synergistic integration of competencies required for effective engagement with generative AI (Gen-AI) and fostering a mindset of lifelong learning (LLL). This integration bridges the technological and cognitive skills necessary for adapting to dynamic digital and professional landscapes.

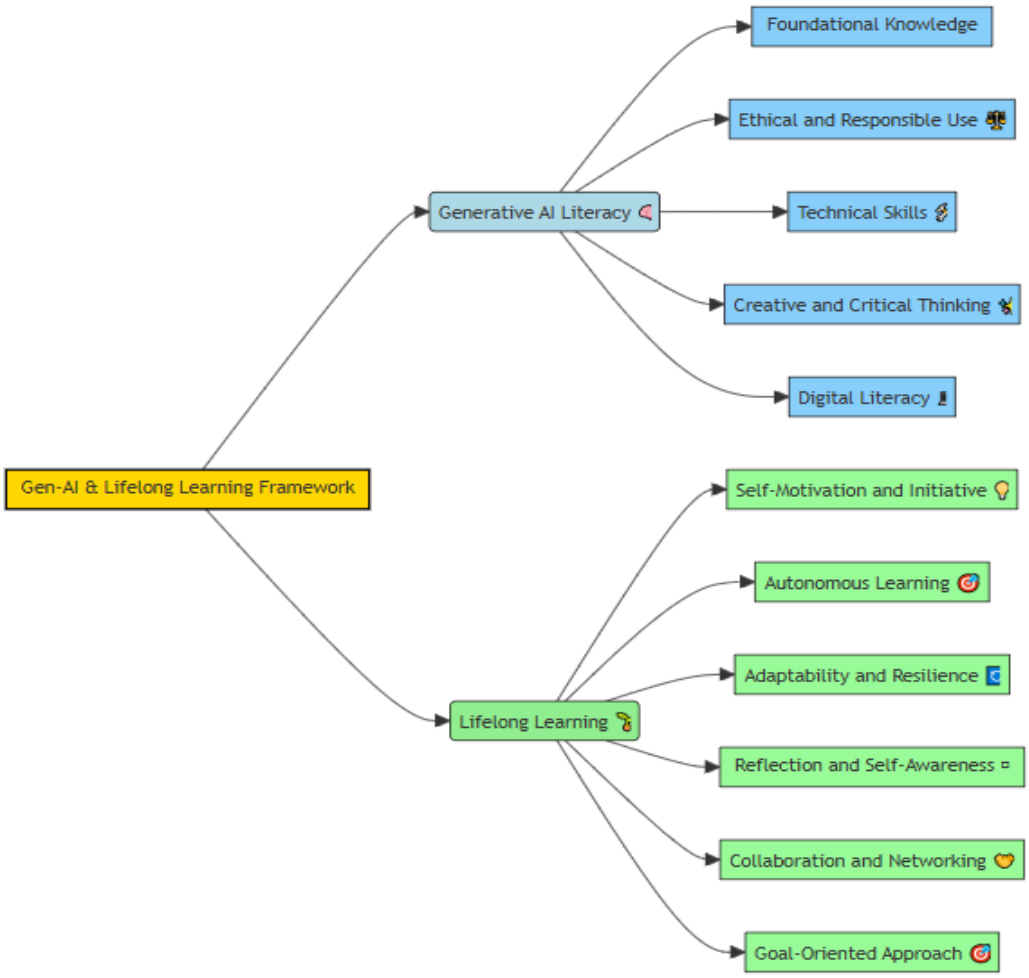

Figure 1. Gen-AIL-LLL framework.

Gen-AI literacy elements consist of basic AI knowledge, ethical and responsible approaches, technical skills, creative and critical thinking, and digital literacy, among others. They enable an individual to perceive, evaluate and effectively operate Gen-AI systems by developing a base of technical competence coupled with an understanding of the need for ethical consideration, critical analysis, and adaptability in the use of generative AI technologies. On the other hand, lifelong learning is a holistic concept that involves intrinsically motivated and self-directed learning, adaptability and resilience, reflection and self-awareness, collaboration and networking, and goal orientation. These dimensions represent the attitudes and behaviors needed for continuous personal and professional development in a fast-changing world full of Gen-AI systems. **Figure 1** depicts the Gen-AIL-LLL framework.

Therefore, the integration of generative AI literacy within the lifelong learning framework underscores the reciprocal relationship between technological proficiency and cognitive adaptability. While Gen-AI literacy provides the tools and knowledge to interact with advanced systems, LLL fosters the mindset and behavioral traits necessary to apply these tools effectively and ethically. This interplay is essential for empowering individuals to thrive in an AI-driven world, fostering innovation, adaptability, and continuous growth.

3.3. Challenges and ways to foster Gen-AI adoption for lifelong learning

One of the predominant barriers to understanding generative AI lies in the challenges associated with ensuring the accuracy and reliability of its outputs [65]. Inaccuracies within the data generated by AI systems can significantly impact critical domains such as healthcare, where they may lead to misdiagnosis or ineffective treatments, thus underscoring the necessity for rigorous validation and ethical oversight [66]. Furthermore, the inherent biases in generative AI, often stemming from the training data, complicate its interpretation and the trust placed in its outputs [67,68]. While complete elimination of bias may be unfeasible, acknowledging and understanding these biases are crucial steps toward informed decision-making in patient care [69]. Additionally, the complexity of unlearning as a solution demonstrates that it is not a one-size-fits-all method for managing generative AI model behavior, posing yet another barrier to comprehensive understanding [70]. Therefore, addressing these issues necessitates a multifaceted approach that includes educating stakeholders about potential biases, implementing stringent validation protocols, and fostering interdisciplinary communication to bridge the gap between technical methods and policy objectives.

To effectively address the multifaceted challenges in education, institutions must prioritize fostering transdisciplinary collaboration, which is essential for developing sustainable solutions across diverse fields [71]. By integrating discipline-specific methods within a transdisciplinary framework, educational institutions can better tackle complex problems, leveraging the strengths of various academic and practical domains [71,72]. As highlighted by a recent study [71], a conceptual framework for transdisciplinary education outlines how integrating knowledge from diverse domains (such as pedagogy, technology, and policy) can result in more sustainable outcomes. [71]. Moreover, the study emphasized that institutions should advocate for increased funding opportunities focused on transdisciplinary research, as current funding models often restrict resources for such approaches [71]. By building robust mechanisms for transdisciplinary curricula and learning environments alongside mentorship and leadership programs, educational institutions can cultivate an academic culture that is better equipped to manage contemporary challenges [71,73]. In doing so, these institutions not only address immediate educational hurdles but also prepare for future crises by enhancing readiness and emergency response capabilities [74]. Therefore, a comprehensive approach that includes collaboration, funding advocacy, curriculum development, and crisis management is vital for educational institutions to effectively overcome the Gen-AI-related challenges they face today and in the future.

3.4. Trends in generative AI and the future of educational practices

Generative AI is seeping more into society and the way people live and work. There is, therefore, a strong case for the application of generative AI in lifelong learning. From simple AI-based learning aids to game-changing generative AI technologies that could fundamentally change how people learn and come to understand things, it will be the role of generative AI in shaping the future of learning and discovery [75]. Thus, when looking to the future, several topics are on the horizon for potential developments relating to generative AI for lifelong learning.

One anticipation is to adopt an AI-centric perspective and speculate on the

developmental aspects of generative AI that lie beyond the existing ones. Generative AI, even in its current version, can highly personalize and engage learning experiences. There exists an expectation, however, that subsequent versions of generative AI might change, in a more fundamental manner, how knowledge is developed within an educational setting. This gathering represents a burgeoning interest in examining the implications of generative AI technologies on learning and education, viewed through the lens of lifelong learning [5,76]. Thus, there remains much work to be done in establishing clear and adaptable best practices and frameworks as generative AI's role in lifelong learning evolves.

Another perspective focuses on taking a lifelong learning and educational lens to explore how generative AI technologies can innovate learning, knowledge construction, and education. It is exhilarating to think about how existing generative AI technologies can act as a catalyst for the development of new learning models and pedagogies and new ways of knowledge-building [4,77]. Nevertheless, this excitement is tempered at the bottom with the contextual understanding, bearing in mind that technological developments come with their attendant risks and uncertainties. New educational models incorporating generative AI technologies should be guided by clear principles or frameworks rather than being hastily adopted for the sake of novelty or trendiness. This gathering aims to contribute to the foundational discussions surrounding necessary frameworks for employing generative AI technologies within lifelong learning.

One way or another, there is a manifest agenda for continued research into the role of generative AI in lifelong learning. As generative AI technologies multiply and advance at a whirlwind pace, it becomes critical to comprehend the ways in which they are being harnessed in learning and educational contexts. This ongoing research trajectory will help inform stakeholders, especially practitioners, of best practices as this landscape continuously evolves. Broadly, there will be a need for partnerships to develop between learning and educational organizations and those designing and developing technological solutions. For such technologies to be successfully implemented in educational and learning contexts, educators must work with developers to shape how these technologies function. Without this partnership, there is the potential for generative AI technologies to exacerbate educational inequities, misalign with pedagogical goals, or otherwise introduce more harm than benefit, especially when not intentionally and effectively implemented.

Finally, equally important—indeed, paramount—are the various trends and new developments bubbling to the surface that, as much as the generative AI technologies, are to be kept under observation. There is a movement toward collaborative AI, wherein the learners not only learn passively but actively engage with and co-create knowledge with AI tools [78]. It surpasses AI technologies, which are only tutors, collaborators, or mentors, to take the place of co-creators of knowledge along with human learners and educators. Though much is left to experience on the impacts of co-created knowledge, realizing what kind of learning and educational potential the activity might have is key. The second is at all times, with the surfacing of new technologies, a need to critically assess the ethical ramifications and chalk down cogent codes of ethics for their deployment. Making generative AI effective in learning and educational contexts is a critical need at this juncture. The validation has

to be thorough for effectiveness and impact by going beyond the demonstration of the potential benefits of technology through simple proof-of-concept studies.

4. Conclusion and recommendations

In conclusion, this study does foreground generative-based AI literacy as a core skill in maneuvering the ever-encroaching technological landscape with much broader and deeper implications for lifelong learning. By drawing together insights from an extensive range of academic and practical sources, the study highlighted the core competencies or dimensions that define generative AI literacy and its transformative capacity regarding personalized and continuous learning experiences, as well as the resistance factors impeding its diffusion. Despite generative AI having so much to offer in transforming traditional models of learning, several bottlenecks in between include misconceptions, institutional resistance, and asymmetric availability of these technologies. The paper presents a clarion call for specific strategic inputs from policymakers, educators, and institutions on these bottlenecks for facilitating a more inclusive and enlightened adoption of generative AI into the mainstream and informal educational systems. Moreover, the developing trends within this space highlight the necessity of future research in aligning educational environments with the fast-evolving dynamics around generative AI. Finally, this study sets a base for understanding what generative AI literacy is, with the goal of future studies using these technologies for better learning outcomes and achieving a more flexible and innovative educational environment.

Although this study proposes a conceptual foundation for Generative AI Literacy (Gen-AIL) and outlines its relevance to lifelong and personalized learning, several areas remain open for further investigation. First, there is a critical need to empirically validate the Gen–AIL framework proposed in this paper. Future studies should test its dimensions and interrelationships on a large sample from different educational and professional settings. This validation would help in strengthening the generalizability of the framework and provide an evidence-based grounding for its adoption. Second, further research is warranted to explore how Gen-AI manifests in specific learning contexts and professional domains.

Different disciplines and industries may require unique applications of generative AI tools; thus, domain-specific competency models should be developed and compared. For instance, the skill set that is required to use Gen-AI in the educational or healthcare sectors may be different from the requirements in the creative industry or business sector. An exploration into these contextual variations will make sure that the Gen-AIL framework is relevant and able to be applied across different settings.

The third and final fruitful research area would be the incorporation of Gen-AIL within the curricula of formal and informal lifelong learning. Pedagogical strategies, instructional designs, and institutional policies need a thorough investigation to see what can really help develop Gen-AI acumen in traditional and non-formal educational settings. This also includes how to help educators design learning experiences that can deliver not just technical competence but also the accompanying ethical reflection, critical thinking, and creative fluency regarding the use of AI.

To translate the Gen-AIL-LLL framework into practice, stakeholders must

implement deliberate strategies for embedding generative AI literacy within lifelong learning pathways. For educators, this includes designing AI-integrated learning activities that foster critical thinking, ethical reasoning, and digital creativity, such as using AI tools for personalized feedback, co-writing exercises, and problem-solving simulations. Educational institutions should provide ongoing professional development to upskill teaching staff in the use of generative AI tools and support the co-creation of open AI-enhanced learning materials aligned with the framework's competencies. Integrating Gen-AI literacy into digital skills curricula across disciplines ensures that learners are not only users but informed co-creators. Policymakers, meanwhile, should endorse national or regional frameworks that promote Gen-AI literacy as a foundational digital competence. This includes incentivizing AI-informed curriculum reforms, investing in infrastructure and equitable access, and setting ethical and pedagogical standards for AI adoption in lifelong learning systems. Collectively, these actions operationalize the Gen-AIL-LLL framework and support inclusive, future-ready education ecosystems.

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