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Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world

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Abstract

The pandemic has catalyzed a significant shift to online/blended teaching and learning where teachers apply emerging technologies to enhance their students' learning outcomes. Artificial intelligence (AI) technology has gained its popularity in online learning environments during the pandemic to assist students' learning. However, many of these AI tools are new to teachers. They may not have rich technical knowledge to use AI educational applications to facilitate their teaching, not to mention developing students' AI digital capabilities. As such, there is a growing need for teachers to equip themselves with adequate digital competencies so as to use and teach AI in their teaching environments. There are few existing frameworks informing teachers of necessary AI competencies. This study first explores the opportunities and challenges of employing AI systems and how they can enhance teaching, learning and assessment. Then, aligning with generic digital competency frameworks, the DigCompEdu framework and P21's framework for twenty-first century learning were adapted and revised to accommodate AI technologies. Recommendations are proposed to support educators and researchers to promote AI education in their classrooms and academia.

Keywords AI education · AI literacy · Digital competency · Teacher · Twenty-first century skills

Opportunities and challenges brought by the pandemic

The COVID-19 pandemic has caused a significant shift to online/blended teaching and learning that educators tried to incorporate new technologies in their classrooms (Ng et al., 2020; Sartika et al., 2021; Whalley et al., 2021). Among these, artificial intelligence in education (AIED) technology has gained its popularity during the pandemic. Studies have started discussions on how AI reshapes education to reduce teachers' workload

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by automating some non-teaching related tasks, enhancing data analysis and optimizing online teaching (Kexin et al., 2020). AIED has traditionally referred to intelligent tutors that help automate students' learning and track their progress so that teachers can offer personalized assistance. More recently, AI-driven tools have become more teacher-focused and help teachers identify effective pedagogies based on students' learning data, automate operational tasks, generate assessments, automate grading and feedback which greatly save teachers' time and enhance efficiencies (Chaudhry & Kazim et al., 2022). Some studies argued that AI technology can effectively promote students' personalized learning (Ahmad et al., 2022), advance their knowledge acquisition and motivate students' learning using intelligent agents (Chen et al., 2020a, 2020b; Hwang et al., 2020). However, without addressing the issue of teachers' roles and competencies, the claimed benefits could be questionable. Therefore, it is important to consider how teachers' competencies change in an AI context (Markauskaite et al., 2022).

A major part of teachers' responsibilities is to create meaningful learning environments to deepen students' learning experiences and boost their capacities. However, teachers may not be digitally ready to use AI-driven educational applications for teaching and learning purposes (e.g., Ally, 2019; Seo et al., 2021). They may lack technological experience to conduct data analysis, or to set rules to automatically generate assignments and feedback for students via AI-driven tools (Seo et al., 2021). Challenges such as AI-based misunderstanding, misleadingness, limitations, and hidden ethical issues behind different platforms have been identified (Akgun & Greenhow, 2021; Sijing & Lan, 2018). There is a broad consensus that teacher education is an important factor influencing student achievement which could lead to higher social and economic expectations (OECD, 2005). Instructional and theoretical frameworks are useful to set as a reference for teachers to identify necessary AI competencies to facilitate their teaching (Chiu, 2021; Ng et al., 2022a).

Although recent research effort has been put to address the need of fostering students' AI competencies (e.g., Kong et al., 2021; Ng et al., 2021a, b; Xia et al., 2022), rarely do studies reveal what digital competencies teachers need to become ready in an AI-driven learning environment. The pandemic has led to an unprecedented use of technology for education. It has also turned a crisis into an opportunity, and catalyzed a shift to AI-driven digital teaching/learning (Green et al., 2020; Moorhouse, 2020). AI has become one of the most essential and popular technologies adopted by university educators to process and analyze big data for distant learners (Aljarrah et al., 2021; European Commission, 2022). To develop teachers' competencies to adapt AI-driven teaching and learning tools and approaches, educators need to timely update their skills and knowledge so as to create suitable learning environments for their students (Williamson & Eynon, 2020).

This conceptual paper uses research examples as evidence to identify what types of AI competencies should be emphasized from both theoretical and empirical perspectives. First, it is important for educators to be aware of the opportunities and challenges when employing AIED technology (European Commission, 2022). Therefore, this article first explores the opportunities and challenges associated with AIED technology and identifies needs related to AI competencies. Second, the identified AI competencies are synthesized for better alignment with existing competence frameworks. In doing so, the new proposed framework could bring significant value to teachers by equipping themselves with necessary AI competencies so as to facilitate better teaching, learning and assessments in the post-pandemic context.

This paper will guide readers through the conceptualization, integration, and applications of the DigCompEdu framework, and revise P21's framework for twenty-first century learning to accommodate AI technologies. This article extends the proposal of

European Commission (2022)'s guidelines that views AI as an important twenty-first century competency.

Motivation for teachers' AI digital competency

AI turns online teaching crisis to opportunities

Due to the Great Online Transition (GOT), instructors have tried to respond to the pandemic and make changes in response to the global remote and online teaching (Howard et al., 2022). Among digital technologies, the use of AIED technology for online learning has become more popular than before to help educators to address teaching challenges such as social isolation, heavy workload and students' lack of motivation (Westera et al., 2020; Zhu et al., 2020). During the pandemic, school administrators and teachers have been seeking better alternatives to improve their teaching, enhance students' interactions (Ahuja & Nair, 2021; Kexin et al., 2020), and facilitate administration (Chen et al., 2020a, 2020b). For example, intelligent tutoring systems propose automatic personalized suggestions and tasks according to learners' profiles (Cao et al., 2021; Kochmar et al., 2020). AI-driven learning platforms record students' behavior and interaction sequences for educators to further analyze to understand their progress in their online learning (Tang et al., 2021), and recommend personalized learning resources for students (Whalley et al., 2021).

These benefits could facilitate teachers to address various online teaching challenges (e.g., learning diversity, motivation problem, social interaction) during the pandemic. AI technologies provide students with learning opportunities that facilitate teachers and students with interactive, personalized and just-in-time feedback (Dizon, 2017). AIED technology helps cater for different learners' needs on a case-by-case basis, addresses their needs during the online lessons (Chiu, 2021), and supports learners to overcome their learning disabilities and accommodate their learning styles (Ouherrou et al., 2019).

Overall, the rapid shift to online education during the COVID-19 pandemic has accelerated the incorporation of AI technologies into education systems around the world (Hwang et al., 2022). AIED applications offer effective support for teachers and students to facilitate their teaching and learning in different subject areas (e.g., language, medical education) (Ahuja & Nair, 2021; Liang et al., 2021). The way how educators teach and how students learn has been dramatically influenced by AI technologies to enhance students' learning outcomes, achievements and attitudes in the post-pandemic world.

For many teachers, it may be their first time to use AIED technologies for teaching. They may not have rich experience of using AIED technologies to teach, and they face various challenges such as technological difficulties, communication and collaboration problems when using these novel-to-teacher technologies (Kim et al., 2022). Teachers who are more capable of using AI-driven technologies tend to adapt more towards the digital transformation, and facilitate their teaching and administrative work (Huang, 2021).

To support educators with such digital transformation, it is necessary to understand what challenges they face when using AIED technologies so as to prepare them with adequate digital competencies to overcome these difficulties. They need to choose suitable AI-driven tools to connect their subject knowledge, and facilitate their teaching and classroom management. For example, voice-driven AI such as Siri is a good choice to teach language and lifelike interactional skills. Online examination software with facial recognition is applied to conduct tests and examinations in a fair way and reduce plagiarism issues in

online learning settings (Pandey et al., 2020). These technologies provide great potential for online educators to address their teaching challenges. However, they may be novel to educators, and not all of them are familiar with these technologies, which require teachers' technological knowledge and skills. Since AI brings opportunities to online teaching, there is a need to update teachers' digital competency to facilitate their teaching and work (Ng et al., 2022b; Zhang & Aslan, 2021).

Opportunities of using AIED for online teaching

AI-driven technologies bring opportunities for enhancing students' learning experience through intelligent tutoring, individualized learning and recommendation systems (e.g., Hwang et al., 2022; Zawacki-Richter et al., 2019). In the educational field, it is estimated that 47% of learning management tools will be enabled with AI capabilities by 2024 (Schmelzer, 2019). AI-driven systems can develop custom learning profiles for each student and customize their learning journeys and materials based on their needs, ability, preferred mode of learning, and experience (Fu et al., 2020). However, to many educators, it is their first experience to use AI technologies in an online learning environment, and they may not have adequate knowledge and skills to manipulate these AI applications (Guerrero-Roldan et al., 2021). This provides reasons why educators need to equip themselves with related digital competencies so that they can teach and learn effectively in online learning environments.

Many other publications highlight opportunities of using AI to conduct online teaching. For example, Seo et al. (2021) proposed that AI could facilitate teachers' generation of repetitive questions, and offer students learner-instruction connections, just-in-time personalized support and meaningful automatic communication for classmates. Torda (2020) used Sophya AI, an artificial intelligence system, as an example to reach larger audiences easily and enable more condensed access to experts. The AI-driven system could enhance instructor/machine-student interaction through the chat features. Moreover, AI elements provide high computational power, which simulates authentic environments (e.g., plant and animal growth as time passes) and acts like humans as non-player characters. Educators or instructional designers could program the pre-defined rules for learners to learn with virtual agents (tutors, peers and tutees) (Hwang & Chien, 2022). Torda (2020) incorporated simulations and 3D space for clinical practice and skill development into AI-driven systems. Another study by Ratten (2020) adopted AI technologies to create a sense of online community that strengthens bonds among students and enables them to express their knowledge in different digital formats. The study proposed that AI could be a meaningful teaching tool complementing existing pedagogical methods and providing a bridge between reality and simulated business environments. Havenga (2020) adopted AI robotics to introduce computer science concepts for engineering students via online collaborative problem-based learning. However, these features require teachers to connect the digital tools to content knowledge and pedagogy, and customize the settings before teaching so as to compromise the learners' continuity in the courses, personalize their learning, and encourage students to express and gain knowledge via AI-driven technologies.

On top of empowering students to engage in AI learning environments, teachers who can use AI tools can enhance their teaching efficiency and handle their routine administrative tasks (e.g., grading, repetitive paperwork). AI assists teachers in designing instructional content that suits students' needs to personalize students' learning through task automation. For example, Yang et al. (2022) embedded a predictive model into the AI-driven

system to facilitate teachers' assessment and analysis of learners' performance to detect the potential at-risk learners at early stages. It offers timely cognitive support in the course and effectively enhances students' academic performance. With data analysis, teachers can adjust their teaching strategies and prepare appropriate learning materials to customize students' learning throughout the courses. Teachers can adjust their teaching strategies to address the changing learning situations and learning goals from either educators or online learning platforms. Likewise, Whitelock-Wainwright et al. (2021) found that teachers could make good use of learning analytics to offer students automatic feedback to improve course outcomes. Abu-Dalbouh (2021) applied a data mining strategy to predict students' online learning performance during the pandemic to enable higher education educators to improve course outcomes, plan ahead to enhance student performance, provide better understanding of student enrolment structure in the course, and update and improve their decision, training, policies and methods for students. However, not all educators have the technological background and experience to operate different AI-driven equipment and systems. There is a need for educators to equip themselves with AI competencies to support them.

AIED technologies offer teachers new features and functionalities (e.g., chat function, personalized support, automatic communication, learning analytics) to facilitate their teaching. Teachers who are capable of using them for teaching can enhance their teaching effectiveness (Healy & Blade, 2020; Whitelock-Wainwright et al., 2021), motivate students' learning, raise students' self-efficacy, promote their self-regulation (Seo et al., 2021; Guerrero-Roldan et al., 2021), and help students interact with other learners in AI-driven environments (Torda, 2020). Teachers need to timely grasp the opportunity to develop their AI digital competency so as to enrich students with better (online) learning experiences.

Challenges of using AIED for online teaching

Teachers may not be familiar with these novel technologies to facilitate their teaching in terms of technical and other broader aspects (e.g., communication, collaboration, multidisciplinary skills). When designing an AI-driven learning environment, teachers may face a number of challenges such as technical difficulties in enabling students to use AI applications and compile algorithms (Vazhayil et al., 2019), as well as insufficient funding, immature AI curricula, lack of tools or evaluation methods (Ng et al., 2022c).

First, AI-driven platforms offer a new way of creation and delivery of instructional content (Ratten, 2020). Teachers are now challenged by digital transformation to meet new requirements that have not been part of the traditional repertoire of expectations for effective teaching during their professional teacher training. They feel challenged when meeting complex demands and new trends (e.g., online learning, AI education) in their classrooms. In the previous section, AI was found to facilitate teaching and administrative work; however, it turns out that teachers need to get rid of various technical problems and need additional time and resources to adapt to these AI technologies (e.g., Hwang et al., 2020; Luan et al., 2020). Teachers may not get ready with technological knowledge and skills that are essential for such digital transformation. Studies found that technical difficulties could seriously reduce the quality of teachers' delivery of content, instructional design, and assessments (e.g., Seo et al., 2021; Torda, 2020). To ensure well-qualified teachers in AI-enhanced classroom, studies suggested that teachers would need to equip themselves with AI-related technological skills to facilitate students' knowledge acquisition and expression (Healy & Blade, 2020), and interact with learners using AI technologies (e.g., chatbots, automatic feedback) (Guerrero-Roldan et al., 2021; Whitelock-Wainwright et al., 2021).

Therefore, teacher competencies have become necessary to enhance students' AI-driven online learning. Teachers need to upgrade their skills and knowledge, and connect the tools to content knowledge and pedagogy through continuous professional training (Kim et al., 2021) such as technical support, guidelines, and teacher education programs (Chiu & Chai, 2020; Luan et al., 2020). These can help teachers become well-prepared to reduce socialization gaps, technical issues, and barriers that prevent AI systems from achieving their intended goals.

Apart from technical skills, developing a positive leadership attitude and ethical mindset is important for educators to use AIED technologies for teaching. Some teachers worry that AI could replace them (Selwyn, 2019), and they feel negative about relying on AI interpretation to understand students' social interaction cues (Seo et al., 2021). In fact, researchers have pointed out that AIED technologies may be a "black box" that teachers may not know the working mechanism behind how AI provides such judgements and recommendations for learners (Pereira et al., 2021). Several potential risks and conflicts such as privacy concerns, changes in power structures, and excessive control have been identified between students and teachers due to such misunderstanding or misleadingness (Seo et al., 2021). Seo et al. (2021) warned that AI could give unreliable recommendations which may negatively impact students' performance, especially when teachers solely rely on AI-driven technologies to predict and assess students' learning outcomes. AI-driven platforms can probably misunderstand users and offer misleading suggestions for learners (Seo et al., 2021). These platforms could probably be trained and developed by certain groups of learners and may not be universal to all. In this way, educators should know the ethical concerns and limitations behind the AI-driven technologies. For example, AI systems should not offer standardized support for all students, and student learning outcomes and social interaction should not merely rely on AI interpretation. Lastly, the design of such platforms may not be human-centered (or even student-centered) enough, so it may cause students' discomfort because features such as eye tracking or facial expression analysis feel like surveillance to students (Seo et al., 2021). Overall, instead of worrying that AI will replace teachers' roles of socialization and mentoring in a physical learning environment one day (Torda, 2020), teachers need to become AI literate and learn about the ethical concerns, limitations and human-centered design behind AI technologies to facilitate students' learning process.

AI competencies

The term 'digital competencies' refers to a set of skills that everyone needs to live, learn and work in a society where people need to communicate and access relevant information through digital technologies such as internet platforms, social media and mobile devices (Falloon, 2020; Ng et al., 2021a, 2021b; Ng, 2012). In recent years, AI technologies such as robotics, chatbots, and smart devices have become common in our daily life. However, people may not understand the technologies, principles and ethical concerns behind (Ng et al., 2021a, 2021b). With more age-appropriate technologies, educators begin to design meaningful curriculum and pedagogy to develop students' related knowledge, skills and attitude to facilitate their learning, living and working (Su et al., 2022). AI competency has become one of the important twenty-first century technological skills nowadays. With AI competencies, people can critically evaluate AI technologies, communicate and collaborate effectively with AI, and use AI as a tool online, at home, and in the workplace (Long & Magerko, 2020).

Recent studies and reports have proposed important digital competencies to guide what abilities and skills people should gain. The Five Big Ideas in AI serve as a K–12 education framework to articulate what all K-12 should learn about AI in terms of four foundational concepts (perceptions, representations, reasoning, learning, natural interaction and societal impact) (Touretzky et al., 2019a, 2019b). Long and Magerko (2020) proposed 16 competencies that people should learn: recognizing AI, understanding AI, interdisciplinary skills, distinguishing general and narrow AI, identifying strengths and weaknesses of AI, imagining future applications of AI and their societal impacts, knowledge representations, decision making, understanding machine learning, recognizing the roles of human in AI, data competency, learning from data, critically interpreting data, higher-level reasoning of AI, sensors, and ethical concerns behind. The two proposed sets of competencies form the basis of what AI competencies students should learn, such that educators can design instructions and assessments around these competencies. Taking a step further, Ng et al. (2021b) categorized the necessary AI competencies into four cognition domains (i.e., know and understand; use and apply; evaluate and create; and ethical issues) to foster students' AI knowledge from low to high thinking skills, inspired by Bloom's Taxonomy. For example, "recognizing and understanding AI" suggested by Long and Magerko (2020) was categorized to the level of "know and understand"; "critically interpreting data" would be related to the level of "evaluate and create"; while societal impacts" by Touretzky et al., (2019a, 2019b) was grouped into "ethical issues". This model helps teachers understand what AI competencies that students need and develop models of learning to implement meaningful instructional design and pedagogies to enhance students' learning outcomes.

Teachers' AI digital competency

The aforementioned discussions suggest some opportunities and challenges of educators' use of AI for teaching. There is a lack of frameworks or guidelines to inform educators what particular digital competencies are necessary to help students become empowered learners. As suggested by Ng et al. (2021b), only few existing studies discuss how teacher education programs could strengthen teachers' AI digital competency to use AI for teaching, learning and assessment. Ng et al. (2022d) further suggested a set of teacher's AI competencies, including using basic applications, managing information, creating learning content, and connecting their students via technology. Xu (2020) proposed that developing AI digital competency is important for educators. Teachers who know how to use AI may replace the teachers who do not know how because AI can empower teachers and promote their role transformation, which greatly improves the efficiency of management and the level of decision-making (Ng et al., 2022b; Vazhayil et al., 2019). Markauskaite et al. (2022) suggested that educators need to integrate new digital technologies and support learning to meet educational standards through digital technologies, engage in professional learning to build competencies, and gain experience using AI-enabled tools. Moreover, they should learn how to use appropriate AI-driven technologies such as adaptive learning systems and intelligent agents to facilitate their daily teaching management and practices to collaborate with different parties (e.g., parents, colleagues), enhance personalized learning to understand students' learning progress and needs, and conduct various tasks such as offering automatic feedback, self-diagnosing, and promoting online collaboration among learners (Cavalcanti et al., 2021). On top of using AIED technologies, they also need to update their pedagogical and content knowledge on AI and learn how to develop suitable pedagogies (e.g., collaborative learning, problem-based learning), digital resources, learning materials

and assessments to empower learners (Vazhayil et al., 2019). This is consistent with Ng et al. (2021b)'s review that revises the Technological, Pedagogical and Content Knowledge (TPACK) framework to inform teachers' competencies and understanding of how AI can design their teaching and learning. The TPACK framework has been adopted in research of teachers' technology integration and offers a nuanced perspective on teachers' digital competencies via multiple types of knowledge (Koehler et al., 2013; Scherer et al., 2023). Content knowledge describes teachers' own knowledge of the subject matter. Pedagogical Knowledge describes teachers' knowledge of their teaching and learning practices, processes, and approaches. Technological Knowledge describes teachers' knowledge of, and ability to use, various technologies, technological tools, and digital resources (Falloon, 2020).

Educational frameworks for educators

Educators play a leading role in realizing the potential benefits of using AI in education. It is important that teachers and school leaders are aware of and appreciate the opportunities and challenges of employing AI systems mentioned in previous sections, and how they can enhance teaching, learning and assessment. To develop teachers' AI competencies, the European Framework for the Digital Competence of Educators (DigCompEdu) is complemented in Section "DigCompEdu framework", and revised and adapted the P21's frameworks for twenty-first century learning in Section "P21's framework for 21st century learning".

DigCompEdu framework

As teachers face rapidly changing demands, educators need to acquire a more sophisticated set of competencies than before (European Commission, 2022), especially when using digital technologies to help students become digitally competent. The DigCompEdu offers a sound framework that provides a guideline for educators to help educators implement tools and design their learning programs. It is an educator-specific competency framework that defines and describes teachers' key competencies, and proficiency levels which provide a general reference to support the development of educator-specific digital competencies (Caena & Redecker, 2019). This model includes a wide range of components organized within six major areas: (1) professional engagement, (2) digital resources, (3) teaching and learning, (4) assessment, (5) empowering learners, (6) facilitating learners' digital competency (European Commission, 2022) (see Fig. 1).

Professional engagement

Teachers' digital competency is important for enhancing teaching and facilitating their professional interactions with colleagues, learners, parents and other parties (Redecker, 2017). With digital affordances of AI technologies, teachers should consider different AI-driven tools and systems to help them develop and improve organizational communication strategies. AI could enhance organizational communication with other teachers, and enable teachers to share and exchange knowledge, teaching experiences and pedagogies (Bryant et al., 2020; Elnaggar & Arelhi, 2021).
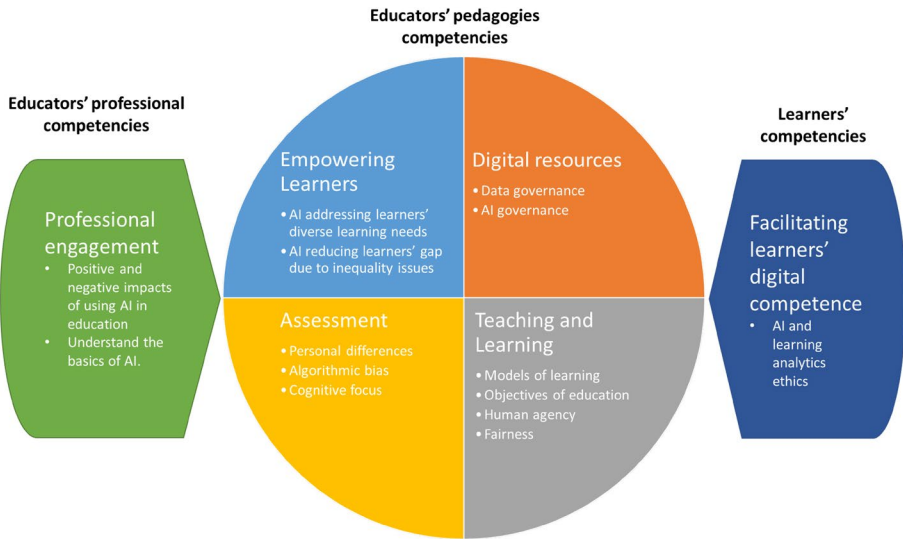
Digital resources

Educators are currently confronted with a wealth of AI-driven learning resources they can use for teaching (e.g., Archambault et al., 2022; Liu et al., 2021). First, AI can support teachers to manage teaching resources, facilitate their teaching, as well as source, create and share resources to fit learning goals, needs and teaching style (Archambault et al., 2022). For example, AI recommendation engines can support teachers to recommend specific learning activities and resources based on students' preferences, progress and needs (Klašnja-Milićević et al., 2015). Moreover, there are many free and open-source learning resources and tools online (e.g., Code.org, Teachable Machine, Microsoft AI900 learning resources) (Ng & Chu, 2021). Teachers should identify, select, modify and build on these existing AI resources and technologies for teaching and learning. They need to think about how to incorporate these resources according to different specific learning goals, learning environment, pedagogy, and learner group, when designing digital resources and planning their use.

Teaching and learning

When discussing how digital technologies can help teaching and learning, the DigCompEdu suggests four major elements, namely (1) teaching, (2) guidance, (3) collaborative learning, and (4) self-regulated learning (Vazhayil et al., 2019). It is believed the combination of these elements can prepare educators for getting ready for AI teaching and learning.

First, to plan for and implement digital technologies in the teaching process, teachers need to manage and design their interventions and develop pedagogical approaches wisely (Leung et al., 2021). With various AI technologies to support instruction, teachers need to restructure the lessons, activities and learning content to best support learning objectives. Among the pedagogical approaches, Ng et al. (2022c) suggested that collaborative

learning, project-based learning and learning with game elements for secondary students were the top three effective approaches to facilitate students to solve authentic problems. Second, to offer timely and targeted guidance and assistance, AI helps teachers to respond promptly to learners' questions and doubts. For example, intelligent agents and chatbots could provide personalized learning through the use of natural language processing to offer students timely guidance and feedback (Tisdell, 2018; Zawacki-Richter et al., 2019).

Third, collaborative learning is important for students to solve problems, complete tasks or create products with joint effort (Linden et al., 2000). Nowadays, AI technologies should help teachers to foster and enhance students' collaboration, communication, and knowledge co-construction. Zheng et al. (2019) adopted a machine learning classification to understand students' contributions and comment patterns on a virtual learning environment to support students' collaborative learning in STEM education. Fourth, recent research has drawn attention to how AI technologies permit more adaptive support and guidance for learners. These adaptive systems help students develop self-regulated learning which refers to a set of learning abilities (e.g., goal setting, self-monitoring, self-instruction, self-reinforcement) for students to understand and control their learning environment (Panadero et al., 2017). AI can support self-regulated learning processes; for example, by enabling learners to plan, monitor and reflect on their own learning, and making learning progress (Kay & Kummerfeld, 2019). Online learning platforms offer a mechanism and interfaces that enable learners to scrutinize and control their learning data and models, and support their meta-cognitive processes (Kay & Kummerfeld, 2019).

Assessment

When integrating AI technologies with assessment practices, teachers need to consider how AI can enhance existing assessment strategies. AI can support teachers in creating innovative assessment approaches (Chassignol et al., 2018; Chen et al., 2020a, 2020b). For example, AI-driven writing assistants can evaluate and grade students' written work automatically, and identify features such as word usage, grammar and sentence structures to grade and provide feedback (Ramesh & Sanampudi, 2021). Chatbots can serve as virtual teacher assistants to ask students questions with simple instruction and provide students with directions with a range of questions (Smutny & Schreiberova, 2020). AI can help teachers to understand learners' learning behavior by analyzing and interpreting data generated from AI systems. This helps teachers make better decisions and refine their learning interventions. For example, AI-driven learning analytics dashboard applications are applied to visualize learning patterns such as utilization, satisfaction and learning achievement (Verbert et al., 2013), and identify the feedback from students and teachers (Sedrakyan et al., 2020). Overall, teachers should learn how to utilize various types of AI technologies to direct monitoring learner progress, facilitate provision of feedback and allow themselves to assess and adapt their teaching strategies.

Empowering learners

AI technologies have the potential for supporting learner-centered pedagogical strategies, classroom differentiation and personalized learning to engage students in their learning process (Ouyang & Jiao, 2021). The use of AI in differentiated learning enables personalized learning, which was not possible in the past when teaching large classes (Renz & Hilbig, 2020). It enables teachers to understand the students' learning strategies, background,

progress and academic interests (Ouyang & Jiao, 2021). It addresses students' diverse learning needs, by allowing them to advance at different levels and speeds and follow their learning pathways. Second, it can help reduce learners' gap due to inequality issues, promote and ensure accessibility for all learners, including those with special educational needs. AI can help ensure accessibility to learning resources and activities. For example, NWEA (a Microsoft project) makes mathematics assessment more accessible for students with vision disabilities, which can exclude students from higher-level STEM careers (Microsoft, 2022). Other examples remove accessibility barriers through image and facial recognition for students with visual impairment, lip-reading recognition for students with hearing impairment, and real-time captioning and translations for students with hearing impairment and those who do not speak the language (Martinez, 2022).

Facilitating learners' AI competency

Educators enable learners to creatively and responsibly use AI technologies for information, communication, content creation and problem solving. The DigCompEdu framework proposes that educators need to equip themselves with five competencies: (1) information and media literacy skills, (2) digital communication and collaboration, (3) digital content creation, (4) responsible use of AI, and (5) digital problem solving.

First, information and media literacy skills are important for educators who need to incorporate AI into learning activities and assessments to fulfill students' information needs (e.g., find resources in AI-driven environments; organize, analyze and interpret information using AI). Second, educators need to enable students to effectively use AI for communication and collaboration. When students want to share their files publicly online, teachers need to be aware that the materials can be used to train AI on social media platforms (e.g., family photos, comments), which may lead to privacy issues (Westerlund, 2019). Third, AI can automatically create digital content (e.g., texts, news, essays, images) using existing digital content as its source (Salminen et al., 2019). The AI-generated content may be indistinguishable from human creations. Educators should incorporate learning activities and assessments for students to create content through creative writing (Clark et al., 2018), music composition (Lopez-Rincon et al., 2018) and stylising painting (Hertzmann, 2018). Third, it is important for teachers to be aware of the ethical concerns behind AI systems. Teachers need to take measures to ensure students' psychological and social well-being (e.g., self-image, self-efficacy) while using AI technologies. They need to recognize potential risks, ethical and safety concerns when using AI technologies for teaching, learning and assessment. They also need to remind their students of these issues. Recent ethical guidelines have been published to advise educators to pay attention to the ethical use of AI and data in teaching, learning, and assessment (European Commission, 2022; Holmes et al., 2022). Finally, AI can facilitate teachers' work and enable them to solve teaching problems, and empower learners to be creative problem solvers (European Commision, 2022). Teachers need to enhance their pedagogical and technological competencies to design appropriate learning environments for students to solve authentic problems using AI with their classmates.

P21's framework for twenty-first century learning

This section investigates what teacher competencies are desired for effective online teaching with AI technology using the P21's framework for twenty-first century learning. Based on the model, four key competencies that teachers have been summarized. The key competencies of teachers should not only focus on acquisition of basic AI knowledge and skills, but also cultivation of the qualities necessary for the teacher's adaptation to, survival in and control over future society as well as teachers' lifelong professional development.

The P21's framework for twenty-first century learning is famous for educators and business leaders to illustrate the knowledge and skills that they need to succeed in working, learning and living (National Research Council, 2012; Ng et al., 2022a). The framework is useful for teachers to establish effective learning standards and assessments, curriculum and instruction, professional development and learning environments. This paper does not focus on the digital competency of technological/ computer science knowledge. Instead, it aims to focus on broader digital competencies (e.g., instructional communication, collaboration) that support teachers to conduct online teaching using AI technologies. From this perspective, teachers should not be limited to knowing and using AI applications for empowering their students and preparing related teaching resources. The framework requires a further update on the other competencies about AI competency such as applying knowledge to different disciplines, demonstrating creativity and life and career skills, and communicating and collaborating with their students.

Core subjects, 3Rs and twenty-first century themes

Mastering key subject areas, 3Rs (reading, writing, arithmetic), and twenty-first century themes is essential for students to succeed in work and life (Kay & Greenhill, 2011). AI technologies have been used in applications for learning in almost every discipline such as language and arts (Liang et al., 2021), and STEM related areas (Zawacki-Richter et al., 2019). This extends to twenty-first century themes including global awareness (Kong et al., 2021), environmental, financial, civic, and health competency (Guerrero-Roldan et al., 2021), as well as the 3R competency (i.e., reading, writing and arithmetic) (Kandlhofer et al., 2016). Universities could educate the teacher workforce to integrate AI applications throughout students' lifecycle, to harness opportunities of using AI technologies in their fields to empower their students, and be aware of ethical implications and risks (Zawacki-Richter et al., 2019).

Teachers could use different AI tools (e.g., virtual laboratories, music pieces generation, chatbots) to enable students to express their subject (or even multidisciplinary) understanding and reach higher cognitive levels such as creativity, collaboration and communication. In this way, teachers have increased accessibility to empower their students to express knowledge in multi/interdisciplinary themes and subjects such as music (Miranda, 2021) and language learning (Liang et al., 2021). In higher education, universities across the globe have started to design AI learning programmes for students from diverse educational backgrounds (e.g., radiology, architecture majors) to develop their foundational AI knowledge, and equip themselves with skills and mindset to solve authentic problems using AI applications (Kong et al., 2021; Ng et al., 2022a, 2022b, 2022c, 2022d). Some courses focus on algorithms and programming for science and engineering students who need to learn underlying computer science concepts behind AI technologies (Long & Magerko, 2020).

Regarding the 3Rs, many AI technologies can help students to read, write and calculate in their learning cycle. For example, AI-driven book recommendation systems could suggest reading materials, practices and assignments according to learners' reading habits (Wu & Peng, 2017). When writing essays, students could use AI writing assistants and content generators to paraphrase texts, reduce grammatical errors and become faster writers (Lin & Chang, 2020; Nazari et al., 2021). Moreover, some applications (e.g., Wolfram Alpha, Symbolab) allow students to input photos of mathematical formulae to generate steps to solve complex problems by clicking a button. Suitable tools could help students solve problems and empower their learning. However, plagiarism problems may occur especially when students use these applications to complete their assignments and examinations (Francke & Alexander, 2019).

Learning and innovation skills

The skill sets include creativity and innovation, critical thinking and problem solving, communication skills and collaboration (Van Laar et al., 2017). Recent studies have suggested the use of AIED technologies to enhance learners' learning and innovation skills, which are essential to enhance their working and learning efficiency. Demchenko et al. (2021) identified a digital transformation in legal education that teachers need to equip their students with AI competencies. There is a need for law schools to innovate and form stronger interdisciplinary collaboration with AI experts to enhance their effective professional and everyday activities such as using AI-based tools to aid human judgement and identifying algorithmic bias (Yang et al., 2022). In business education, AI has a wide range of use in business to complete authentic tasks such as aggregating business data, managing customer relationships and predicting future trends. Business educators need to update their knowledge and enable students to integrate AI into their workplace and create a new user experience for their clients (Uzialko, 2022; Williamson & Eynon, 2020). These knowledge and skills are useful for teachers and students to become professionals/leaders in their knowledge fields to implement complex cognitive and decision-making tasks, and adapt to present scenarios.

Information, media and technology skills

Educators need to prepare themselves for becoming digital ready so that they will be able to teach students related skills such as information, media, and ICT competencies (Gleason & Von Gillern, 2018). Especially in recent years, teachers and students need to adapt to digital transformation and develop related technological skills. In AI-driven classrooms, teachers need to manipulate different AI-enhanced systems to design assessments, and examine students' performance using their historical and current data using the adaptive learning system (Guerrero-Roldán et al., 2021). In another study, teachers adopted an automatic mode in an AI-driven service called IBM RXN to enable students to draw target molecules, and generate chemical reactions and structure representations (Healy & Blade, 2020). Kostopoulos et al. (2021) introduced the use of an AI-driven system called DevOps to equip smart city professionals and educators with adequate technological skills to visualize urban innovation in an 11-week online course. These examples show that university educators from different disciplines need to equip themselves with technological skills to enable their students to express ideas, solve problems and manipulate AI-driven applications so that they will be ready to work in AI-driven environments.

Life and career skills

Life and career skills are important for preparing students for engaging as citizens in a dynamic global community and facing different challenges and opportunities in the workplace. Students need to develop a positive mindset, positive attitudes and other competencies (e.g., flexibility, adaptability, self-direction, social skills, productivity, responsibility) to navigate complex life and work environments (Van Laar et al., 2017). First, studies have suggested that AI has the potential for transforming youth employment, and students need to develop relevant skills to adapt to this change. For example, Singh et al. (2020) suggested that AI profiling would move away from merely collecting information about formal qualifications to a more holistic approach of capturing skills and life experiences. Educators need to upgrade their students to fit the future job market. Second, improving students' self-efficacy and self-regulation is important when using AI-driven systems to support students' online learning since these systems seldom consist of a physical teacher to monitor their learning (Guerrero-Roldán et al., 2021). Third, Cetindamar et al. (2022) highlighted four sets of workplace capabilities associated with AI: technological skills (e.g., data collection, analytics, ethics, security), work-related skills (e.g., decision making, critical thinking, teamwork), human–machine interaction (e.g., situation assessments, affordance analysis, adaptive expertise), and learning-related capabilities (e.g., lifelong learning, self-learning ability). Other studies have also highlighted the importance of life and career skills such as problem-solving (Mohammed et al., 2021), emotional intelligence, judgment, service orientation, negotiating and cognitive flexibility (Webber-Youngman, 2017), as well as communication and teamwork skills (Seo et al., 2021) in the fourth industrial revolution. Teachers can enable their students to become adaptive thinkers who equip themselves with technological literacies to solve problems, think critically, lead their teammates and implement reflective practice (Li & Du, 2017). With these life and workplace skills, students become more digitally ready to contribute to their fields and companies after graduation.

The four essential digital competencies inform how university policymakers design their educational standards for their countries/regions and schools, and provide related professional development for teachers. At the classroom level, teachers use them as guides to design suitable curricula and instruction, and create positive learning environments. Educational standards could define what AI competencies are essential to possess for university students. Such standards serve as a basis of educational reforms and digital transformation across countries/regions. Nation-wide standards can identify necessary learning outcomes such as enhancing student competitiveness, equipping students with futuristic skills, fulfilling job demands in the AI industry, and raising children to become responsible citizens. To implement the standards in classrooms, educators play an important role in making decisions on what learning elements (e.g., assessments, curriculum, instruction) should be included in the curriculum guide and learning environments. However, teachers may not be familiar with novel technology. As such, professional development is important for supporting educators to design appropriate learning activities that achieve teaching goals and learning outcomes. In this way, universities, professional organizations and companies could offer the guidelines and standards to research and develop appropriate materials, tools and platforms to support teachers and students via the standard-based AI education.

Discussion

The pandemic has led to an unprecedented use of technology for education and training purposes. Among technologies, AI has presented opportunities to improve the quality and quantity of teaching, support the digitalisation of pedagogy, and inclusive remote learning, as well as resolve different online learning problems such as social isolation and motivation (Cao et al., 2021; Havenga, 2020). Online applications and systems such as search engines, chatbots (Smutny & Schreiberova, 2020), smart assistants (Dizon, 2017), language translation, online games and simulations are now equipped with AI capabilities (Martinez, 2022). AI promotes new ways for students to learn and apply their knowledge. It helps diagnose students' learning problems and offer immediate assistance so as to meet learning needs of individual learners. Moreover, data generated from these applications are helpful for supporting students' online behavior and providing feedback and recommendations to facilitate personalized learning (Pereira et al., 2021). AI enables teachers to analyze students' behaviors, performance and characteristics. However, teachers may not be familiar with these novel technologies. There is a need to timely discuss what digital competencies are important for educators and school leaders to facilitate their teaching, learning and assessment (European Commision, 2022).

According to Ng et al. (2021b)'s review, four cognition domains (i.e., know and understand; use and apply; evaluate and create; and ethical issues) are proposed to support AI competencies according to Bloom's taxonomy. They further suggested the use of the TPACK model to support how teachers develop appropriate pedagogies, content knowledge and technologies for K-16 education (Ng et al., 2021a, 2022b). In this article, two existing generic digital competency frameworks (i.e., DigCompEdu and P21's framework) are discussed to add values to Ng et al. (2021b)'s four cognition domains of AI competency and their revised TPACK model to prepare teachers' adequate AI competencies for their teaching/learning.

Ng et al. (2021b) focused mainly on the four cognitive domains from knowing to creating AI, and AI ethics that help educators to choose their content in their curricula for specific learning goals. The P21's framework is consistent with these proposed aspects that AI competency include technological skills, and other higher-order learning and innovation skills (i.e., critical thinking, communication, creativity and collaboration). However, it further adds other critical and non-technical competencies such as interdisciplinary abilities, life and career skills to conceptualize AI competency. In fact, schools are seeking teachers and students with developed skills such as self-regulation, learning to learn, self-motivation, technological savvy, and time management (McGunagle & Zizka, 2020). Educators need to strengthen themselves and their students' a wider set of twenty-first century skills and abilities to become digitally competent, instead of merely obtaining technological skills, and learning and innovation skills. Other career and soft skills such as project management, leadership, professionalism are also important capabilities to facilitate their teaching (Caena & Redecker, 2019). In other words, when considering Ng et al. (2021b)'s four cognition domains and P21's framework, a broader set of AI literacy skills are suggested (e.g., socio-emotional, behavioral, cognitive learning, life and career aspects).

The DigCompEdu framework is wider in scope when considering educators' AI competencies as knowledge, skills and attitudes, with the skill domain dominating over the knowledge domain. However, the learning and teaching dimension in the DigCompEdu framework is narrower in scope compared with the Ng et al. (2021b)'s revised TPACK model, as it focuses more on the pedagogical dimension. It does not emphasize on the specificities

and constraints of different subjects (i.e., the content knowledge), and technological knowledge which DigCompEdu assumes the two elements are described in other guidelines such as learning and teaching, digital resources and empowering learners (Caena & Redecker, 2019). However, DigCompEdu outlines more specific actions to foster teachers to develop a high performing AI and online education. For example, teachers should learn the positive and negative impacts of AI and data use in education, and understand the basics of AI and learning analytics to enhance their professional engagement. Also, they need to know how to design and choose appropriate digital resources, understand how AI works and use various AI systems to implement their instructional design. After that, to empower students' learning, addressing learners' diverse learning needs is important. Teachers need to know different ways personalized learning systems can adapt students' behavior, and explain how AI technologies can benefit all students, independent of their learning backgrounds. They make adjustments related to pedagogy, content and technologies to meet learners' needs and learning goals. Therefore, it is important for teachers to equip themselves with necessary TPACK knowledge and learn how pedagogies that underpin a given AI system. They also need to know how the AI system addresses the learning goals and the ethical issues behind. Finally, assessment is crucial to understand students' learning progress using AI. The assessment should take care of students' different cognitive domains. Instead of merely examining the basic understanding of AI, there is a need to examine higher levels of thinking skills such as collaboration, communication, and creativity. Overall, the DigCompEdu framework proposes specific actions that support the TPACK model.

The three models provide guidelines from different perspectives that help teachers to design instructional support and learning/teaching content to reach students' learning goals and empower their competencies. The suggested elements of the three models have the potential to incorporate into a conceptual framework for future AI competency instructional design. The four key domains are illustrated as follows:

- "Teacher professional engagement" illustrates the abilities to enhance teaching and facilitate their professional interactions with stakeholders;
- "Instructional design" comprises three teachers' inputs that they need to obtain adequate knowledge to design appropriate pedagogies, and technologies and assessment tools to pursue students' learning goals;
- "Content choices" across disciplines comprise four cognitive domains measuring students' knowledge and skills achievement from lower (know and understand AI) to high-order thinking skills (evaluate and create AI), as well as AI ethics. The learning content can be designed to help foster students' AI lIteracy across different subject areas (e.g., mathematics, science, language).
- "Learning competencies" comprise a set of students' knowledge, skills and values and affect (e.g., life and career skills, learning and innovation skills, technological skills) that develop students a broad set of AI competencies.

This article proposes a new framework by extending the existing versions of the two frameworks (i.e., P21, DigCompEdu) and Ng et al. (2021b)'s model to include AI and achieve the latest learning standards with regard to digital upskilling of the population. The new framework suggests that AI competency should not merely include technological related competency (e.g., attitudes, skills, knowledge). On top of it, it moves towards a more holistic understanding that recognizes a non-technical, critical and complex competency that young people need to learn to manipulate AI technologies ethically, safely and wisely (Ng et al., 2022c; European Commission, 2022). Towards a broader picture,
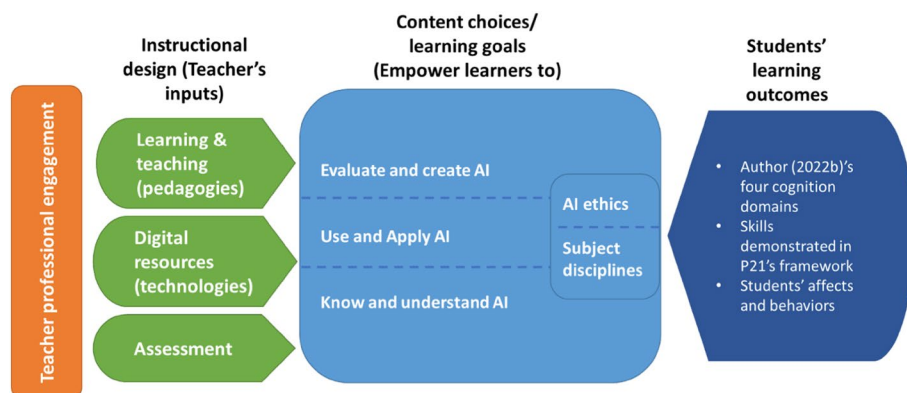
Fig. 2 Instructional design framework for AI literacy/competence education

teachers should not view AI competency as an independent technological domain but an avenue for developing other non-technical skill sets such as life and career skills, multi-disciplinary skills, learning and innovation skills. Second, it offers a revised model for teachers to develop meaningful interventions to foster their students' AI competencies via four processes: (1) teachers' professional engagement; (2) instructional support; (3) content choices across disciplines; and (4) students' learning competencies (see Fig. 2). It iss hoped that the examples and discussion in this article will inform educators of the necessary AI competencies to support their teaching, learning and assessment in the post-pandemic world.

Recommendations

Measures are suggested to promote AI digital skills by providing training programs, offering personal development paths, retraining specialists in different fields, and providing grant support for educational projects (Demchenko et al., 2021). Studies have proposed that educators should provide guidance that helps learners maintain long-term learning motivation, and improves their digital competencies to learn independently, thereby improving the quality of learning and making learning a spontaneous behavior (Xu, 2021). Recommendations are suggested to help teachers develop their digital competencies:

- Professional development, teacher training programs, guidelines and technical support are necessary to empower teachers to develop AI knowledge, skills and mindsets to use the teaching tools effectively.
- Schools should upgrade their infrastructure and digital equipment to enhance effective digital capacity and development.
- A lot of online technologies are used in education to complement AI-driven learning experiences such as Metaverse, blockchain, cloud computing and big data. Teachers should always update their knowledge and learn the potential of using these technologies in their classrooms to be digital competent.

- Teachers should not merely focus on technological knowledge and skills. Instead, they need to develop other important skill sets such as life and career skills, multidisciplinary skills, learning and innovation skills, as well as ethical mindsets and risks.
- More digital competency frameworks should be proposed to inform the key competencies for educators to establish effective learning standards and assessments, curriculum and instruction, professional development and learning environments. The EduCompEdu and P21's framework for twenty-first century learning are two of the models that provide guidelines for teachers to develop necessary digital competencies for AI-driven learning environments.

Conclusions and recommendations

The pandemic has catalyzed a significant shift to more AI-enhanced teaching/learning in higher education. Educational institutions and universities have conducted digital transformations that include machine learning and artificial intelligence (Bygstad et al., 2022). However, teachers may not be AI competent enough to manipulate AIED technologies to facilitate their teaching, learning and assessment. Although they know about the existence of these AIED services, they may not understand the ethical concerns and limitations behind (Ng et al., 2021b, 2022d), not to mention other non-technical competencies such as collaboration, teamwork, decision making, communication, and multidisciplinary skills, (Cetindamar et al., 2022; Demchenko et al., 2021). A set of challenges for teachers such as technical difficulties, ethical concerns and limitations behind when using AI tools in their learning, have been identified.

To respond to the pandemic and adapt to changes in response to the trend of online/blended learning, a set of knowledge and skills are proposed for teachers based on the EduCompEdu framework and the P21's framework for 21st Century Learning. Evidence is suggested to show what digital competencies are important for university educators to equip themselves with necessary technological skills to enable their students to express ideas, solve problems and manipulate AI-driven applications so that they are ready for working in AI-driven environments. First, teachers need to learn technological and operational skills to access AI devices and software, and work with other colleagues for teaching purposes. They also need to equip themselves with other working skills such as data analysis (Kexin et al., 2020), assessment and evaluation using AI-driven technologies (Sánchez-Prieto et al., 2020). On top of these technical skills, there is a need to include broader digital competencies such as ethical concerns, teacher identity, attitudes and mindsets as components of teacher education in AI competency education (e.g., Akgun & Greenhow, 2021; Seo et al., 2021).

Although this conceptual paper provides the foundations for building a theoretical basis for teachers' AI digital competency, several limitations are identified. First, the discussion is based on existing literature rather than experimental and empirical study, the proposed model is less fact-based compared with empirical research, and follow-up research is necessary to support its reliability and validity. Second, the model is subjective since the model is adapted and generated from existing studies instead of practical experimentations. However, most of the existing studies only touch on the emerging ideas (teachers' AI digital competency). A timely paper is necessary to explore the conceptual underpinnings and accumulate the evidence to introduce a frame to facilitate how educators conduct their

digital transformation using AI smoothly. Future research could address these limitations. Researchers can design meaningful AI competency programs with reference to the Edu-CompEdu, P21's and Ng et al. (2021b)'s frameworks for teachers with experimental and empirical design. Through evidence-based research, quantitative and qualitative evidence could then support the refinement of the frameworks and programs and suggest useful recommendations for teachers.

Declarations

Conflict of interest The authors have no conflicts of interest to disclose. The manuscript has not been published previously and is not being simultaneously submitted elsewhere. There are no any real or potential conflicts of interest that could be seen as having an influence on the research.

Ethical approval No reproduction of copyrighted material is evident in this manuscript hence there is no need to apply for any necessary permission.

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