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Using digital twins in education from an innovative perspective: Potential and application areas

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ABSTRACT

Despite existing for two decades, digital twin technologies have failed to catch up with similar emerging technologies. The education sector is one area that could use the functionalities provided by digital twins. Defined as virtual replicas of physical reality, digital twins mirror the real objects they represent, including components, infrastructure, architecture, and functionality. Therefore, one should expect a virtual lab to look like a physical one. Educational institutions fast-tracked the digital transformation during the COVID-19 pandemic, as all industries and sectors did. As such, online and distance learning received much hype from stakeholders. However, many institutions failed to utilize digital twins in designing the new digital educational systems. However, similar technologies featured prominently, including virtual reality and artificial intelligence. As outlined in this research, digital twin technologies could encompass all technologies used to design and deploy distance, virtual, or online learning. Current applications illustrate that many institutions focus on developing a digital platform for learners and, in some cases, educators. The full potential of digital twins is yet to be fully realized, meaning that digital twins could develop further to help the education sector reach the necessary evolutionary milestones.

Introduction

Emerging technologies critically influence human lives across all dimensions, including education. Adopting new technologies causes fundamental changes in how systems function and interact with others. For example, the Internet of Things (IoTs) can automate communication and sharing of information across devices and networks. Educational technologies entail integrating technology into education to promote a more diverse learning environment and allow learners to use technologies for learning and assignments. The potential for educational technology continues to grow as institutions find new technologies or applications for current technologies (Ganimian et al., 2020). The emergence of digital twin technology provides a new dimension of educational technology. By definition, a digital twin entails a representation of a physical object to be used in observing, analyzing, and simulating the behavior of the physical object. As an educational innovation, digital twin avails a variety of uses in enhancing and improving educational or learning environments.

Overview of digital twins

The digital twin concept is still novel, meaning a universal definition remains elusive. However, many scholars agree that a digital twin involves a real-time digital representation of a physical system (Berisha-Gawlowski et al., 2021). However, definitions often differ depending on the perspectives used in research, especially the digital representation of the properties and functions of the physical world. In other words, a digital twin is a digital replica of a physical object. Therefore, the basic feature of a digital twin is its ability to exchange data with the physical object automatically. According to Berisha-Gawlowski et al. (2021), automatic data exchange distinguishes a digital twin from a digital model since only a manual data exchange takes place between a model and the physical aspect it represents. In computing terms, a digital twin comprises a digital cyberspace or a virtual world interacting, collaborating, and communicating with the physical space.

Some definitions are more prominent in academia and the industry. However, the basic tenet is that digital twins are virtual representations designed to interact with physical objects through their lifecycles to provide intelligence for prediction, evaluation, and optimization (Eriksson et al., 2022). Two models of digital twins exist: the three and the five-dimensional digital twins. The three-dimensional digital twin comprises three major components, namely virtual space, physical space, and connection. On the contrary, the five-dimensional digital twins have two extra components: service and data (Eriksson et al., 2022). Since digital twins comprise dynamic behavior, they go beyond static product designs such as computer-aided design (CAD) models (Attaran & Celik, 2023). As such, these technologies promise a wide array of applications, which explains the exponential growth rate in the number of applications.

Despite the tremendous growth over the past few years, the concept is relatively novel. Professor Grieves of the University of Michigan introduced digital twins in 2003 when teaching a total product lifecycle management course (Attaran & Celik, 2023). He described a digital twin as digital mapping and a digital mirror. Since then, the digital twin concept experienced shifts and evolutions in definitions.

Current literature regarding digital twin innovations revolves around the uses, applications, and underlying technological developments. Many scholars adopt a more general overview of the concept focusing on those industries that widely deploy digital twins. Examples include manufacturing, retail, utilities, automotive and aerospace, agriculture, construction and real estate, mining, and healthcare (Attaran & Celik, 2023). Each industry has different uses for this technology. For example, the manufacturing industry uses digital twin technologies to customize designs, simulate and validate development stages, reduce overall engineering costs, and enhance operations. In the retail sector, digital twin technologies help to optimize supply chains, manage fleets and routes, and design facilities and operations (Attaran & Celik, 2023). Regardless of the industry or sector, the common theme in the digital twin application is that the technologies help create virtual replicas to test the real object's performance, safety, or reliability. With the help of simulations, many applications also involve making predictions or forecasts by manipulating the variables and observing the outcomes. Additionally, digital twin technologies are deployed at the unit and process levels (Yao et al., 2023). While the unit-level applications focus on the individual parts and products, the process level focuses on multiple parts or products.

Education is another sector increasingly attracting the interest of digital twin technology. There is a growing body of literature regarding how the education sector deploys digital twins in the classroom and the general learning environments. However, most scholarly papers explore the potential of digital twins in transforming education. Recently, the education sector witnessed the emergence and proliferation of e-learning and distant or remote education. These concepts find digital twins useful in enhancing learning processes and outcomes. For example, the benefits that e-learning derives from digital twins include personalized learning, collaborative learning, improved assessments, better virtual reality experiences, and enhanced accessibility (Hawkinson, 2022). The digitization of education also forces institutions to handle huge volumes of data. Recent studies show that digital twins play a vital role in educational big data management practices (Zhou & Wu, 2022). Therefore, the future of online learning or distance education may depend on how well institutions adopt and deploy digital twins.

Problem

Even though the concept of digital twins is about two decades old, industries and organizations seem too slow to adopt the technologies. Static designs remain prevalent, even when modeling and simulating reality. Virtual and augmented reality may have a head start and seem a better option for creating digital replicas of physical objects. However, digital twins seem not to enjoy similar enthusiasm, including in education. The emergence of COVID-19 fast-tracked digital transformation across all sectors. Experts predicted that many of the digital changes would most likely become permanent and persist even after the end of the pandemic. With online learning becoming a reality, schools and other stakeholders no longer need to concern themselves with the safety of the school environment, as was the case during the pandemic (Soykan et al., 2023). On the contrary, the focus should turn towards improving online learning environments for better student outcomes.

The main issue is that schools do not seem to fully comprehend the potential of digital twins as an educational innovation. Currently, many studies overgeneralize the applications of digital twins in education. By simply highlighting virtual learning environments or learner collaboration, the studies fail to fully understand the real potential of digital twins in transforming education. From an innovation perspective, stakeholders in the education sector must understand what the concept of digital entails and how it fits within the scope of educational innovation. Additionally, many applications remain unexploited, which necessitates an assessment of the potential areas of application.

Method

The research method used depends on the nature of the research and the data collected and analyzed. The research examines how learning institutions can deploy digital twin technologies. Therefore, an ideal starting point is exploring secondary data regarding current applications and future potential manifested through areas largely ignored in theory and practice. As such, this study falls under the category of secondary research. Secondary research entails compiling existing data sources from different channels, including external and internal sources. In many cases, secondary research uses past studies to compile findings from multiple to present a unified position regarding a research question. This study examines various sources, including government reports and scholarly research, to produce a unified view of how digital twin technologies revolutionize the education sector.

The search strategy and criteria are important elements to consider because they determine the quality and trustworthiness of the data. Today, the internet provides a wide pool of resources researchers can use for their studies, including databases and websites hosting scholarly and other sources. Google Scholar is one such web search engine offering a simple way to search broad scholarly literature. Since it is freely accessible, it becomes the ideal tool for searching for materials on various topics and disciplines. The search strategy deployed in this study considers the challenge of balancing specificity and sensitivity (Bramer et al., 2018). Therefore, a systematic search strategy must have a clear, focused question to guide the search process. The strategy must also consider what articles have answers to the question and what core concepts address the various aspects of the question. This study's primary question explores digital twins' current and potential applications. As a scholarly study, the best choice of articles is past scholarly research and other expert commentaries on the subject. While scientific research papers pose few problems, expert commentaries present a challenge because the researcher must develop criteria for qualifying experts whose opinions are academically acceptable.

Another important aspect is that this research uses a literature review as a methodology. Some scholars believe traditional literature reviews lack rigor and thoroughness due to their ad hoc nature. However, when conducted systematically following a specific, literature reviews become an ideal research methodology for interdisciplinary studies (Snyder, 2019). Literature reviews can be the best methodology for certain research questions. For example, when a researcher seeks to evaluate a theory or evidence in an area or examine the accuracy or validity of a theory or competing theories, a literature review becomes more effective than most methodologies. The rationale is that literature reviews offer an ideal basis for building new theories or conceptual models considering past studies or theoretical developments.

Since the current study aims to examine evidence of digital twin use in education, a systematic literature review becomes the most effective methodology. A systematic literature review takes place in several phases. The initial steps entail defining the research question and determining the research scope. This study's question and scope revolve around digital twin technology's current and potential application areas in education. After the question and scope, the search for data begins, where a researcher deploys a set strategy for obtaining materials that effectively address the research question (Mengist et al., 2020). A search always yields many results, some more useful than others. Therefore, selection criteria help determine which sources to use and which to discard. After selection, an analysis of the data follows, and the research can use different methods. A report marks the end of the systematic review process.

Findings and discussions

The chapter summarizes and describes the results of the systematic literature review. As explained in the methods section, Google Scholar was an ideal source of materials for this research. The search strategy was simple since it entailed developing relevant keywords and using them to generate results.

Obtaining the results

Mainly, the researcher focused on such keywords as the 'applications of digital twins in education' and 'prospects of digital twins in education.' These keywords help address the two main aspects of this research: current applications and future/potential applications. A detailed description of each of these appears in a separate subheading.

As expected, the search strategy and keywords used yielded multiple results. Therefore, the need for selection criteria emerged, and the researcher adopted relevance and currency as the main criteria. Relevance entailed assessing whether the materials had relevant and sufficient content addressing the research question. Currency entailed selecting only the most recent sources, preferably below five years since publication (Teaching & Learning, n.d.). Recent materials allow the researcher to present the most recent findings and account for the most recent developments surrounding the topic. Therefore, the newest applications and comments regarding potential future applications become easier to assess. The researcher ensured to stick to journal articles and books. However, relevant content in credible online publications, especially expert commentaries, offered clearer insights into the future of digital twin technologies. The credibility of online sources manifests through the author and publisher’s authority and expertise on the subject.

Findings on the current applications

The literature on the current application of digital twins in education covers a broad spectrum of issues without any particular classification or categorization. Each scholar seems to have a different idea of what the current applications entail and what area of education uses these technologies. Therefore, summarizing the findings in this section may require a table describing what each scholarly source establishes regarding digital twins in education. Table 1 below accomplishes this objective:

Table 1 A summary of findings on current application areas of digital twins in education

Author(s)	Area of application	Brief description
(Eriksson et al., 2022)	Digital labs	The scholars establish that digital twins effectively replace labs by creating digital replicas. The key concepts include data fusion and virtual commissioning.
(Zacher, 2020)	Simulations and web labs	The author explains how digital twins are applied in simulating industries and developing web laboratories.
(Pirker et al., 2022)	Virtual labs and training scenarios and procedures	This source highlights that training and education use digital twins to develop virtual labs. In training, institutions design procedures and create scenarios using digital twins.
(Erdei et al., 2022)	Virtual labs and training models	The study assesses the usefulness of digital twins in creating virtual or digital labs. Additionally, the source highlights the application of digital twins in training and testing models in education.
(Kaarlela, 2022)	Remote education using robotics	The scholars assess the use of digital twins in developing educational robots that facilitate remote learning as a solution to societal inequalities.
(Han et al., 2022)	Intelligent campus systems/smart campuses	The research examines the use of digital twins in designing smart campuses. Beyond learning on campuses, digital twins help design other smart systems used in managing campuses, including transportation, disaster management, and other campus infrastructure.
(Iakovides et al., 2022)	Virtual Library	The conference paper discusses the use of digital twins in designing and building virtual libraries using graphic user interfaces (GUI) or virtual agents.
(Razzaq et al., 2023)	Deep learning for on-campus classrooms/distance education	The article discusses the use of digital twins in deep learning frameworks for on-campus classrooms as part of the growing trends toward distance learning. Using deep learning, the ‘DeepClass-Rooms’ perform teaching tasks in a virtual platform similar to how teachers teach in physical classrooms.

(Sepasgozar, 2020)	Web-based virtual gaming for online education	The research focuses on using digital twins to develop virtual web-based gaming platforms for online education.
(Nikolaev et al., 2018)	Digitization in engineering education	The source explores ways to digitize engineering education using digital twins to overcome challenges posed by traditional engineering education
(Kartashova et al., 2022).	Blended learning	The article explores using digital twins to design digital prototypes of educational institutions.

As illustrated in Table 1 above, the current literature on the application of digital twins in education only offers a broad view, with only a few cases offering narrow and specific descriptions. However, assessing the core areas where digital twins find the most applications is still possible. Looking at the table, it is apparent that education deploys digital twins across the various aspects of digitization. For example, virtual labs and libraries, training robotics, virtual classrooms, blended learning, and virtual gaming represent deliberate efforts to support online or distant learning initiatives forming the core of the education digitization efforts. Before exploring the application areas, it is important to highlight the key elements of digital twins that make these technologies applicable in educational settings.

The main defining feature of digital twin technology is the ability to simulate reality. In other words, digital twins are digital replicas of physical objects, spheres, or environments. A digital twin also fits the description of the virtual representation of the real object or product. Therefore, digital twins have a lot in common with virtual reality. Using similar concepts, the technologies help create simulated environments that allow users to see and interact with all dimensions and functionalities of the real thing. This means that a digital twin must follow all architectural components of what it represents. In education, the ability to simulate reality helps deploy digital twins in re-creating real learning environments. In a learning application, digital twins capture the entire learning environment. For example, a virtual lab created using digital twins captures all real or physical lab components, including the equipment and a workbench (Palmer et al., 2021). If presented using virtual reality, the learner should see and operate lab equipment, move around the lab area, see and read instruction manuals for lab experiments, and generate results like working in a physical lab.

The findings regarding current applications hint at one min point – that digital twins are critical tools that can facilitate the digital transformation of education and support online or distance learning initiatives. Virtual libraries and labs all indicate a digital platform that learners can use to access educational material and instruction (Zacher, 2020). Without the need to visit physical libraries and labs, learning can occur remotely through web-based or other systems that facilitate virtual interactions between learners, educators, and instructional materials. In other words, virtual platforms easily translate into remote or distance learning platforms. However, it is important to note that such learning platforms do not necessarily mean detaching from the human touch or eliminating human input. On the contrary, the design of these systems also captures human involvement through human-centric approaches that focus on human-machine interaction (Kaarlela et al., 2022). Such systems emphasize the importance of societal values. Through teleoperation platforms, teachers can teach through the digital twins of classrooms or labs. As such, the idea of a digital twin of an educational institution implies a digital replica of that institution.

Potential application areas

Searching the internet for potential areas of application of digital twins in education does not yield results much different from current applications. On the contrary, scholars and expert commentaries furthered the debates on digital classrooms, distance learning, and human-computer interaction in education. However, a few ideas for the future use of digital twins in education emerged, including integrating artificial intelligence (AI) with digital twins to create more personalized learning environments (Liam & Yan, 2022; Ahuja et al., 2021). Some scholars perceive digital twins and AI as tools to help teachers in their practice (Liam & Yan, 2022). The teaching aids proposed in these articles include digital sensors and teaching experiments designed to give learners a deeper understanding of core concepts. The role of AI in such teaching models includes enhancing the operability of the systems due to their complexity. For instance, such teaching models consider the characteristics of different students, meaning massive amounts of student data require analysis and course modules tailored to each student (Liam & Yan, 2022). Without AI, accomplishing such a feat becomes increasingly challenging.

A keen look at the findings on current applications also reveals that the primary focus of researchers was on the students and their learning needs. With the integration of AI, some scholars have shifted the focus to the teachers and their teaching needs. AI-augmented pedagogical professional development entails the teaching systems working with the professionals to support instructors, help them attend every class, help them observe and reflect on semester trends, and capture the finest details for all occupants (Ahuja et al., 2021). Such feats may not be possible in a physical classroom. The new systems also help instructors obtain feedback through the specially-designed end-user interfaces. As such, the idea of a digital twin to these scholars involves digital teaching tools designed for teachers.

It is important to emphasize the concept of personalized learning. As mentioned earlier, scholars believe that the use of AI in digital twins of educational systems makes it possible for educators to capture and cater to the needs of individual students (Liam & Yan, 2022). Other scholars emphasize that digital twins and AI are the pillars of personalized learning (Furini et al., 2022). The need for personalized learning models emanates from the observation that modern education systems fail to meet the needs of modern students. The rationale for such an observation includes the high dropout rates among university students. For example, the United States has the highest dropout rates among the developed countries, with an estimated 40% compared to 10% in Europe (Furini et al., 2022). AI and digital twins can change the situation by helping build personalized, accessible, and inclusive learning models.

Inclusion in education considers more than the individual characteristics of students. Inclusion in education must ensure that environmental, social, cultural, and economic factors form part of the education system design. Many students drop out because of financial constraints. An inclusive system built around AI and digital twin technologies accounts for such students. Technologies are effective in facilitating cost savings. For instance, virtual classrooms do not require expensive physical infrastructure. Therefore, cheap virtual classrooms ensure that even the financially-constrained students can access education and finish university. Even though personalization is more of a policy issue in education, scholars acknowledge that digital twins present the future of education as it acts as a social equalizer in educational systems (Arantes, 2023). According to Furini et al. (2022), AI and digital twins will make it possible to achieve some of the sustainable goals of the United Nations General Assembly. Education is a critical component of the UN's SDGs, and any too or instrument helping facilitate access to education is an enabler of the educational pillar of the SDGs.

Therefore, the potential and prospects of digital twins depend on emerging educational needs and the extent to which institutions deploy new technologies to enhance the functionality and output of the digital twins of educational institutions (Arantes, 2023). As such, AI is simply one of the technologies supporting digital twins. In other scholarly sources, digital twins function with the help of the Internet of Things (IoT), which facilitates high spatial resolution monitoring of physical twins (Maddahi & Chen, 2022). The objectives of digital twins differ across educational institutions. While some seek to improve learning among students, others focus on assisting teachers in their profession. Therefore, different models of digital twins of educational institutions may appear driven by different visions and goals. The different models may also account for interoperability such that teaching models interact with learning models.

Conclusions and recommendations

Digital twins in education are an interesting subject that illustrates emerging developments in education. At the same time, significant gaps emerge in the literature on this subject. However, a possible explanation for such gaps is that digital twins are part of a broader digital transformation trend in the education system. Another possible explanation is that digital twins in education mirror the developments in online and distance learning, two aspects that digital twins facilitate. Therefore, many people may perceive online learning as virtual reality applications in education where AI and other immersive technologies help create virtual versions of the physical classroom. From the definition of digital twins, it is possible to establish that they are virtual replicas of real objects, spheres, or environments. In such a case, discussions of digital twins of educational institutions mirror are synonymous with those of digital, virtual, or online classrooms. As an educational innovation, digital twin technologies comprise a set of enabling technologies that facilitate the simulation of the physical educational infrastructure to facilitate or support virtual, online, or distance learning.

The findings indicate a general need for more detailed descriptions of the application areas of digital twins in education. Therefore, the first recommendation is that scholars be more vivid in articulating digital twins in education. For instance, digital, distance, or online learning have become buzzwords over the last few years, especially after the emergence of COVID-19. The pandemic necessitated and fast-tracked digital transformation across all sectors, including education. However, many scholars argue that online learning is the future of education without offering adequate insights into how to accomplish that goal. Therefore, a more technical approach to the subject becomes more desirable as it helps understand the mechanisms and functionality of such systems. Most importantly, the architectures and system design elements need greater articulation to help gain a better understanding of how such systems work. With empirical evidence already confirming the usefulness of new technologies, the lack of understanding from various stakeholders could explain the slack in their implementation. A digital twin of an educational institution may seem like a fancy word with little practical sense to educational policymakers. However, by explaining how digital twins function and the technologies incorporated into the new systems, policymakers would pick an interest and consider pursuing digital twins for more inclusive, personalized, and accessible learning models.

Another recommendation is that future developments in digital twin technologies in education should emphasize emerging educational needs. In other words, digital twins of educational systems should seek to plug educational gaps in society. As highlighted earlier, digital twins and AI can be social equalizers in education. Today, many young people fail to accomplish their educational aspirations, as the high dropout rates illustrate. Additionally, educational policymakers are interested in solutions to inequalities in education by considering the disabled and vulnerable groups. From a scholarly perspective, it is recommended that future studies must consider researching how digital twins accomplish this purpose. From a practice perspective, educational systems must develop system designs to accomplish these objectives.

Disclosure statement

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