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An Exploratory view of Application of Digital Twin Technology in Education

Swati V. Chande
Department of Computer Science
International School of Informatics and Management, Jaipur

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ABSTRACT

Digital twins have gained significant attention and become a buzzword in recent years. The advancement of technologies such as the Internet of Things (IoT), artificial intelligence (AI), data analytics, and cloud computing has made it easier and more cost-effective to collect, analyze, and process vast amounts of data. This has enabled the creation and implementation of digital twins on a larger scale.

Digital twins provide valuable insights and data-driven information to support decision-making. They enable organizations to simulate scenarios, test different strategies, and assess the impact of changes or interventions before implementing them in the physical world and thus help minimize risks and uncertainties associated with decision-making processes. Applications of Digital twins are not limited to specific industries or sectors. They have versatile applications across domains such as manufacturing, healthcare, transportation, smart cities, energy management etc. This broad applicability has contributed to the widespread interest and buzz around digital twins.

The academic world has also not remained untouched with the advancement in this technology and efforts are on in the direction of designing Digital Twins for various aspects of education including supporting teaching, research, and administrative processes. As the technology continues to evolve, new and innovative applications are likely to emerge, transforming various aspects of teaching, learning, research, and administration in the academic sphere.

In this study an effort is made to bring together the work carried out in the field of application of digital twins technology for teaching. Existing studies have been deliberated upon to analyze the progress and discover the prospects of bringing the digital teachers closer to human teachers.

It can be inferred that as the technology continues to evolve, new and innovative applications are likely to emerge, transforming various aspects of teaching and learning in the academic sphere. It is also important to note that while digital twins of teachers hold potential benefits, their implementation and adoption in real-world educational settings are still developing. Ethical considerations such as data privacy, algorithmic bias, and the need for human involvement in teaching roles needs to be carefully addressed to ensure their effective and equitable use in education.

Key words: Digital Twin, Education, Teaching, Learning, Technology in Education

1. INTRODUCTION

The concept of digital twins has gained significant attention in recent years as can be seen from the trends over the last five years, and has been implemented in various industries, including manufacturing, healthcare, transportation, and urban planning.

In industries such as manufacturing and engineering they find applicability in providing virtual replicas of physical assets, enabling real-time monitoring [1] [2] [3], predictive maintenance [4] [5] [6], and optimization of operations [7]. They are utilized to simulate and test scenarios, improve efficiency, and enhance decision-making processes [8] [9]. They are also being deployed in urban planning and management to create virtual replicas of entire cities or specific infrastructure systems [2] [8] [9]. City planners and policymakers are using digital twins to simulate and analyze various scenarios, optimize resource allocation, and improve urban services such as transportation, energy, and waste management [2] [10] [11] [12]. In healthcare sector, personalized medicine, disease modeling, and treatment optimization is facilitated by using digital twins. They can simulate patient-specific physiological systems and help predict individual responses to medications or interventions. They also aid biomedical research by providing virtual models for drug testing and clinical trials [13 [14] [15]. In the field of construction and maintenance of buildings and infrastructure, they help architects, engineers, and facility managers visualize and optimize design, monitor structural health, and efficiently manage maintenance and repairs throughout the lifecycle of structures. Development and testing of autonomous systems, such as self-driving cars and drones [16] [17] can also be done using digital twins. In Education, they have the capacity to create simulated learning environments, analyze student data,

and provide adaptive instruction. They provide a virtual environment to simulate real-world conditions, train AI algorithms, and evaluate system performance and safety [18] [19].

The field of digital twins is dynamic, and advancements continue to be made in various domains. As the expanse of the applications of digital twins grows, and we find them acquiring greater significance in product design, simulation, customer modeling, product life cycle management, disaster management and several such diverse areas, their study, and their application in education thereof, will find greater significance.

2. DIGITAL TWINS IN EDUCATION FIELD

With education witnessing a big shift since the pandemic era, and teachers and learners getting used to the electronic way of education, use digital twins in education has taken a leap. The research and application though still is in its nascent stage. Studies reflect application of digital twins with a student-centric view, in creating simulated learning environments that replicate real-world classroom settings, to provide personalized learning experiences for students, student assessment and progress tracking, support teacher professional development by providing continuous feedback, suggesting areas for improvement, and offering resources for ongoing learning, facilitate collaborative learning environments by connecting students virtually, adaptive instruction, and providing virtual laboratories and simulations for conducting experiments or engaging in scientific inquiry [18] [20]. From the teachers' perspective, digital twins are being researched as tools to enhance teaching practices, personalize education, and support professional development of teachers. Some key areas of academics that digital twins find application in are discussed here.

As discussed in [21] [22] [23], digital twins can provide virtual lab environments that simulate real-world laboratory settings. This allows scholars to perform experiments, make observations, and analyze data in a virtual environment, providing valuable hands-on experience even when physical labs may be inaccessible or inadequate. Scholars can also perform simulation & modeling of complex phenomena or systems in academic disciplines such as engineering, physics, chemistry, and biology. Students and researchers can thus explore different scenarios, analyze data, and understand the behavior and interactions of complex systems [24] [25].

By creating digital twins of individual learners, personalized learning experiences can be designed by way of tracking students' progress, identifying their strengths and weaknesses, and adapting educational content to meet their specific needs. This approach, as discussed by [26] [27] can enhance engagement and learning outcomes.

Real-world locations, historical sites, or natural environments can be replicated by these digital models. This enables students to virtually visit and explore these places, even if physical visits are not feasible. Virtual field trips provide engaging learning experiences and enable understanding of different cultures, historical events, and natural phenomena [28] [29].

To provide real world experience to teachers, teacher training programs can be visualized to simulate classroom scenarios, allowing teachers to rehearse teaching techniques, classroom management, and student interactions in a controlled virtual environment. This helps the teachers develop and polish their knowledge delivery skills and supports the development of more effective pedagogical skills [30] [31].

Digital twins of research mentors can facilitate research by providing virtual representations of research issues or objects in some subjects. Researchers can use digital twins to conduct experiments, collect and analyze data, and simulate scenarios. This allows for efficient and cost-effective research while minimizing the need for physical resources [32] [33].

Administrative processes within academic institutions can also be automated by digitizing the expertise of the staff of academic institutions. For example, they can simulate campus layouts and infrastructure to optimize laboratory and equipment utilization, space utilization, energy management, or emergency planning. Digital twins can also support administrative decision-making by providing data-driven insights [34] [35] on organizational and executive issues.

3. DIGITAL TWINS FOR TEACHING

The concept of designing and creating digital twins for well-defined processes in different aspects of teaching has been studied by researchers. Various academic domains have been deliberated upon for application of digital twinning.

Digital twins of teachers refer to virtual replicas or simulations of real-life teachers that utilize technologies such as artificial intelligence, machine learning, and data analytics.

These digital teachers can create virtual classrooms or learning environments that simulate real-world teaching scenarios. They can mimic various aspects of teaching, including lesson delivery, student interactions, and classroom management. This simulation capability allows teachers to practice and refine their instructional techniques in a risk-free and controlled environment. [36] depicts one such scenario in his study.

Another aspect of education, the teacher-pupil connect and personalized tutoring which could be seen as a difficult task can be addressed with digital twins of teachers providing personalized instruction by analyzing student data and individual learning profiles. They can adapt the pace, content, and instructional strategies based on each student's unique needs, preferences, and learning styles. This personalization enhances the learning experience and helps

students engage with the study material more effectively. [37] have studied creation of personalized tasks for students using digital twins of teachers.

Providing feedback and assessing students for their progress in learning is another important factor of significance in academics. Digital twins can analyze student responses, identify misconceptions or areas of improvement, and provide tailored feedback in real-time. This adaptive feedback supports student learning by addressing individual challenges and guiding them towards proficiency. [31] has proposed a new way to train users in using digital twins suggesting them a gamified and virtual environment. The author also describes future challenges that may be considered critical to enabling a more effective education/training approach including adaptive and personalized feedback.

The virtual teachers can facilitate collaborative learning environments by connecting students virtually. They can support group discussions, peer interactions, and collaborative projects. Virtual teachers can guide and moderate these interactions, fostering collaboration, communication, and critical thinking skills among students. [39] have studied knowledge-generation opportunities based on new models of collaboration between workforce and industrial processes.

Digital teachers can monitor student performance and behavior in real-time. By analyzing data such as student engagement, progress, and emotional states, virtual teachers can identify early signs of learning difficulties or emotional distress. This enables timely intervention and support from teachers to address individual needs [40].

The virtual teachers can use data analytics to provide insights and support data-informed decision making. They can analyze student performance trends, identify patterns, and generate reports for teachers, administrators, and parents. These insights enable stakeholders to make informed decisions about teaching strategies, resource allocation, and student support.

The Digital twins can also serve as tools for professional development for teachers. They can provide feedback and suggestions to educators, helping them refine their teaching practices, experiment with new instructional strategies, and enhance their pedagogical skills. They can simulate classroom situations, allowing teachers to practice and receive guidance on their performance [30]. One interesting study in this field has been done by [38] they developed a new computer-vision-driven system that powers a 3D “digital twin” of the classroom and studies whole class behavior.

4. RESEARCH PROGRESS ON DIGITAL TWINS FOR EDUCATION

The concept of digital twins of teachers is relatively new and has gained increasing attention in the field of education. Researchers have been exploring the potential applications, benefits, and challenges associated with integrating digital twins into teaching practices [41. Here are some key areas that researchers have focused on for designing digital twins in general and for teaching and learning particular.

Researchers such as [42] have developed conceptual frameworks to define and conceptualize digital twins. These frameworks provide a foundation for understanding the various components, functionalities, and interactions involved in the implementation of digital twins. The frameworks can further be refined to be applied in teaching and learning also.

Studies have examined the technological aspects of integrating digital twins into the teaching process [43]. This includes exploring the use of AI, machine learning, data analytics, and other emerging technologies to create virtual replicas of teachers, simulate teaching scenarios, and personalize instruction based on student data [44] [45]. In order to enhance pedagogical strategies and instructional practices [43] [46] have investigated how virtual teachers can adapt instruction, provide personalized feedback, facilitate collaborative learning, and support student engagement and motivation.

A significant focus has been on how digital twins of teachers can enable personalized and adaptive learning experiences. Studies have made an attempt to find out how virtual teachers can analyze student data, assess individual needs, and deliver tailored instruction to optimize learning outcomes [47] [48].

Several studies have examined the role of digital twins in supporting teachers’ professional development [30] [49]. They have investigated how virtual teachers can serve as tools for practicing and refining instructional techniques, providing feedback, and fostering continuous learning for educators.

In [50] the authors have explored the use of digital twins of teachers for learning analytics and assessment. This includes analyzing student data, monitoring progress, identifying learning gaps, and providing real-time feedback to improve student outcomes.

In [51] ethical considerations and challenges associated with the implementation of digital twins of teachers have also been addressed. They have examined issues such as data privacy, algorithmic bias, equity in access and usage, and the importance of maintaining a balance between human and virtual teacher roles.

5.CONCLUSION

Though digital twins can imitate certain characteristics of human teachers, they cannot replace the intrinsic qualities that human teachers possess, such as empathy, intuition, creativity, and the ability to establish meaningful relationships. Human teachers play a vital role in nurturing students' social and emotional development and

providing personalized guidance. Therefore, the objective should be to use digital twins as supportive tools to enhance the capabilities of human teachers rather than attempting to replicate or replace human teachers completely.

Research on application of digital twin technology in education is in its initial stages, and there are challenges to consider, such as the development of high-quality simulations, integration with existing educational systems, and ensuring equitable access to technology. Nevertheless, with advancements in technology and continued exploration, digital twins have the capability to enhance and transform the educational scene in the future.

As educational institutions and technology providers continue to explore and refine the potential of digital twins, their impact on education is expected to be significant, revolutionizing teaching and learning methodologies, expanding access to practical experiences, and fostering personalized, engaging, and collaborative educational environments.

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