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Integration of Digital Twins Technologies in Education for Experiential learning: Benefits and Challenges

Dr Rakesh Kumar Pathak[1], Dr Prakash Upadhyay[2]*
[1, 2] Assistant Professor, Department of Computer Science, St. Xavier's College of Management & Technology, Patna, India.
Emails: *rakeshkumarpathak@sxcpatna.edu.in[1], prakashupadhyay@sxcpatna.edu.in[2]*
***Orcid ID:** *https://orcid.org/0009-0003-3501-1850*

Abstract

In order to provide an immersive and engaging learning environment, digital twins in education are virtual representations of real-world items, settings, or people. From elementary to secondary school to higher education establishments, digital twins can be employed in a variety of educational contexts. For instance, students can imitate scientific experiments that would be hard to execute in the classroom owing to safety issues or a lack of resources, by using digital twins to create virtual versions of the investigations. With the help of digital twins, educators may even plan virtual field trips that let learners travel the globe without ever leaving the classroom. For instance, students might be able to study history, tour of Taj Mahal in Agra in-depth, and even engage with historical personalities through a digital duplicate of the wall. Students can communicate with lecturers or subject matter experts virtually by using digital duplicates to build virtual versions of them. In remote learning environments, where students do not have access to actual classrooms or in-person instructors, this can be especially helpful. This research study discusses the advantages of using digital twin technologies extensively in the educational system, as well as the technological, social, and ethical constraints.

Keywords: *Digital Twins Technology, Experimental Learning, Education.*

1. Introduction

In industry 4.0 revolution Digital Twin technologies have revolutionized the fields of engineering, architecture, and medicine. These cutting-edge technologies allows to create a live digital replica of any physical object, providing us with a powerful tool for simulation, investigation, and decision-making purposes. As the technology continues to evolve, the use of Digital Twins is becoming increasingly popular across different industries, offering a new level of insight and understanding of complex systems. Digital Twins (DT) can be used in education sectors for a variety of purposes, such as providing students/learners with the opportunity to use virtual Replicas of real laboratory equipment, planning and Developing campus infrastructure, creating and testing course designs, and supporting teacher's professional development. The application of DT technology in the context of education is quite flexible, despite the fact that it is still in its infancy. A potential approach to support learner agency in learning would be to create learner-centred teams (DTs) for specific learning objectives, such as tailoring learning experiences, finding flexible ways to provide feedback, promoting career readiness, and supporting study and well-being of learners [1]. The application of DTs in higher education is still a relatively new topic, with few published studies to date. The potential of digital twin technology to supplement and improve teaching and learning is examined in this research.

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We define the notion that captures the key elements relevant to educational situations because there isn't already a widely agreed definition of a DT in higher education. Additionally, we evaluate the relevance of understandings DT design that have arisen from other industries to education. Our proposal comprises three primary types of DTs for education: a DT as an object (like a campus or lab instrument), a DT as a human (like a learner or educator), and a DT as a process (like a learning design, administrative procedures associated with the learner experience, etc.). Although DTs provide a plethora of opportunities, putting them into practice presents numerous obstacles. A DT that is continuously changing, for instance, faces the difficulty of never being finished. The amount of data that may need to be gathered in order for the DT to operate in real time and be updated, poses numerous issues for data governance and technical infrastructure [2]. We'll identify and talk about these and a number of other issues. This paper tries to makes a significant contribution by investigating the feasibility of building a digital twin of a human being in an educational setting, such as a student. Although examples of this kind of DT are beginning to appear in some educational settings, the complexity of such an attempt has stopped student DTs from developing much to this point (Martynov et al., 2022; Sylvester et al., 2023; Tong et al., 2022) [7]. The use of learner data to enhance the educational experience has been better understood in recent years thanks to the work of fields like Learning Analytics (LA) and Educational Data Mining (EDM), which have the potential to further advance the use of data [3]. The use of data could be enhanced significantly with the help of DT technology. In order to improve learner experiences and outcomes, DTs can be employed in higher education. This debate encourages future ideas for their application as well as the challenges that must be overcome.

2. Understanding the definition Digital Twin Technology

There is no universal definition for the concept of a DT, despite the fact that numerous definitions from other disciplines have been proposed in the past. After analysis of several papers based on Digital Twin technology application, five key characteristics of a DT are as follows: (1) object and process (2) integration (3) digital representation (4) scale or structure and (5) data. Examples of the DT's purpose are also included in some definitions; however, since there are a growing number of applications for DTs, this can never capture all potential uses. It is customary for definitions to begin with an overview of the DT's representation. The expressions of Digital Twin include a set of virtual information constructs [4], an object model [5], a digital/virtual representation [6], a software analogue [8], or a digital replica [9]. The idea that there is a digital or virtual model that simulates the object or process being twinned is introduced into our definition through the usage of the word "digital representation. "In order to facilitate real-time data transmission among the DT and the original objects or processes being digitalized, a communication channel must be established, which is known as the integration feature. Due to this feature, DTs can be distinguished from both "Digital Shadows" and "Digital Models," which only transmit data in a one-way fashion [10]. According to [13] and Wright and Davidson (2020), the model can be dynamically updated to reflect changes made to the object or process across its lifecycle, due to two-way communication [11]. While some definitions of the necessary frequency of synchronization state that it must be live and dynamic [8], others (Digital Twin Consortium, 2020) contend that a specific frequency and fidelity can be met. The prospect of live integration is becoming more likely as the technologies that enable DTs advance. As such, we have stipulated in our definition that DTs must incorporate a living process that enables bidirectional communication between the twinned entities. In the past, a DT represented a tangible item. Over time DTs' potential applications have grown to include processes and people. Some of the articles that were studied make explicit reference to the object's physical nature, while others use terms like "real-world entities and processes" (Digital Twin Consortium, 2020) and

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"living or non-living organisms" [6]. We have broadly defined "object or process" within our definition to cover people, physical items, and processes. The degree of model applicability is indicated by a DT's scale or structure. This attribute is only mentioned in two of the sampled definitions, which refer to it as the "micro atomic level to the macro geometric level" [4] or the state and structure [8]. This feature acknowledges the various magnification levels at which the DT can be utilized. As an illustration, IBM, distinguishes between four categories of DTs based on increasing scale: asset twins, system/unit twins, process twins, and component/part twins. Taking into account the scope and depth of the DT, level was thought to be a helpful part of a comprehensive definition. A variety of sources are capable of offering the data needed for DT technology to change and adapt in real-time. In the investigation of earlier definitions, references were made to behavioural and operating information [12], as well as data from the past, present, and/or future (Sylvester, 2023; Digital Twin Consortium, 2020). In this paper, it has included the idea of past, present, and future data in our definition in order to facilitate scenario prediction and real-time decision-making [7]. Considering these five characteristics, we characterize a Digital Twin as a “multi-level digital model of a living or non-living thing or process that is dynamically updated with data from the past, present, and/or future about the twinned object/process”. This definition includes components of DT technology that have developed recently as a result of technological and computational process advancements. It encompasses the ability of DTs to be made for and of learners, educators, campuses, and procedures, therefore it may also be utilized in the educational environment.

3. Integrating Digital Twin Technologies in Education

Digital twin technologies are applicable in a variety of environments, areas, and industries. The aim of using Digital Twins in industries is to "carry on simulation, validation, optimization, evaluation, and give suggestions, prediction, and controls to the real entity for people to make decisions, to improve the performance, to prolong the lifecycle of a physical entity" is the stated goal of employing a DT in an industry setting [19]. For instance, DT technology can help with urban landscape planning in the fields of civil engineering and construction (Sepasgozar, 2020. To find design defects and assess performance capabilities for optimizing the entire manufacturing process, DTs have been utilized in the manufacturing industry to construct virtual models of physical items [4]. DTs are employed in the agriculture sector to manage, track, and forecast the future of animals and crops (Purcell & Neubauer, 2023). By employing human DTs to create smart diagnoses, digital twins are now opening up new avenues for the medical industry to deliver personalized healthcare [5]. It makes sense that with all of these fascinating new uses for the technology, the focus is now shifting to DTs' potential applications in educational context [14]. In order to develop an interest in education and retain students, higher education institutions must improve their instructional services, settings, and procedures in an increasingly competitive market. Digital twins can be applied in a variety of ways to enhance educational environments and outcomes, which can assist universities in addressing this difficulty. Among the advantages of DTs are there a) capacity to enhance learning environments' adaptability, 2) personalization of education as per need and requirement, 3) sustainability, and 4)optimization in the context of higher education (Furini et al., 2022). The effectiveness of DTs for higher education is largely dependent on these four components, which also serve as grounds for investigating potential applications of DTs. In [15] highlights two prevalent applications of digital technologies in higher education, with a focus on how these usage match with the four elements.

3.1 Digital Twins Technology for Teaching Assistant

Although the idea of a "Digital Twin" is still relatively new in the context of higher education, a number of applications are beginning to take shape, opening up intriguing new possibilities for

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the use of DTs as instructional aids in academic institutions. For instance, the development of DTs for laboratory equipment enables students to use and experiment with it both inside and outside of the classroom, assisting in the integration of theory and practice. By allowing students to use this virtual equipment to test and experiment with different scenarios, we may enhance their learning experience and improve their situational awareness by giving them the possibility to learn from their failures. An investigation on the application of a DT for an airplane flight simulation system revealed that learners reacted favorably to the technology, showing an increase in their degree of curiosity and readiness to employ DTs going forward. It was discovered that students enjoyed having the freedom to experiment and modify the system's settings using the DT to see how the changes affected the system's overall behavior. When there is a high risk of mishandling the equipment, digital twins can be employed to help students get ready for the switch to using live equipment. From a sustainability point of view, an ability to produce digital clones of sometimes costly and/or highly sensitive/ specialized equipment might aid in cost management for instruction and save needless expenses that might arise from equipment mistreatment [16]. Another way that the DT virtual learning experience can be more sustainable is by allowing learners to engage with huge equipment, like an excavator, while saving time and money on equipment and transportation (Sepasgozar, 2020). In order to address equity issues and environmental aims, digital twins also give students access to equipment that might not be available to them in their current location. By adjusting to the learner's level of understanding and knowledge and giving them access to resources and platforms outside of the classroom, digital twin technology allows for the personalization of learning by enabling students to experiment and explore outside of scheduled class times. Learning activities centered on the DT can be adapted to each learner's requirements and preferences, providing them with formative exercises and focused resources (Walkington, 2020). An intelligent learning platform was developed around the DT in a research on the use of DTs to teach mechatronics. This platform allowed students to track their progress and eventually provide customized lesson plans based on learner ability and progress.

3.2 Virtual Replicas of Campus Infrastructure Using Digital Twins

Creating a digital twin of a real campus offers the chance to conduct simulations to investigate various scenarios that can affect the campus, such as how an increase in enrolment might affect available space or introducing new courses in campus can will affect the overall activities, how a natural disaster might affect buildings and services. With the aid of Internet of Things (IoT) sensors, ambiance factors pertaining to thermal, auditory, visual, and indoor air quality can be balanced and optimized on digital twin-developed smart campuses (Zaballos et al., 2020). The University of Bologna in Italy is employing IoT devices as part of DTs to track student movements and classroom occupancy rates in order to66 identify and direct individuals with disabilities to accessible routes between classes [17]. When it comes to resilience, DTs can support academic institutions in handling scenarios such as pandemic like covid-19, which required the relocation of studies online during lockdowns and the implementation of social distancing measures. Universities can employ DTs to monitor occupancy and people flows in order to encourage social distancing, thanks to Internet of Things devices and thermographic cameras [18]. When additional pandemics or natural disasters strike the world, DT simulations of online course capacity can aid in optimizing the delivery of online and hybrid learning.

To create a virtual campus for an educational institution, Digital Twin technology can be integrated with Augmented Reality (AR), Virtual Reality (VR), and Metaverse technologies. The University of Iowa debuted "Metaversity," a digital twin campus, in April 2023. Here, students can take business courses virtually [19]. It is also possible to build digital twins of university operations that enhance student experiences. One

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potential improvement might be in the administrative procedures that facilitate learner enrolment and career advice, thereby offering learners personalized and flexible options. As part of a DT, data about a learner's prior experiences and future learning objectives could be utilized to find the best courses and study program pathways automatically]2].

3.3 Digital Twin Technologies for Learners

In initial stage of Digital Twin technologies, real objects and processes were the main focus of DT development in virtually every sector. Due to 3D printing technologies, VR/AR technologies it is possible to create human DT to a greater extent. The development of a human-like digital twin (DT) is now feasible due to technological advancements and the capacity to store and process vast amounts of data. Research is being conducted in several industries to determine the potential applications of this technology. For instance, the domains of health (Laubenbacher et al., 2021), sports science (Lukač et al., 2022), and product design (Lo et al., 2021) are already using human digital twins. To monitor a patient's physical state and reduce the likelihood of disease development, doctors use digital twins (DTs), which serve as "a digital copy of a person with exact analogues of all vital systems, allowing doctors to track data on the health of clients and the condition of medical equipment in real-time. "Due to rapid development in the fields of learning analytics and educational data mining, it is possible to utilize data about students and learning environments in the educational environment. Based on the result of learning analytic and students and students data mining information it is possible to generate learner DTs to enhance student learning capacity. The DT of students at the micro level can be used to provide real-time feedback to students regarding their current academic activities related to current course work. On the other hand, by analyzing the student's behavioral patterns, a teacher can change his teaching methodologies to increase the level of interest of students. Creating a digital twin for human beings in all aspects of /life is a complex procedure, it is suggested by Shengli, 2021, p. 1, to lower the complexity of human DTs by clearly define the purpose for which they are to be used. This is because learner behavior can be highly subjective and frequently unpredictable, which contributes to the complexity of DTs (Sylvester et al., 2023). Strategies like creating frameworks for recommendation systems as a component of DT learning environments are being suggested as a way to deal with this complexity (Tong et al., 2022). Agrawal et al. (2023) [[9]] have suggested the Levels of Digital Twin (LoDT) concept, which aims to tackle complexity by delineating the respective roles that humans and digital twins (DT) assume. Learning environment and assistance can be improved in innovative ways by creating a learner context-sensitive environment by analyzing its personal and social data through data mining. Learners who struggle with work commitments, family responsibilities, and disabilities can be supported by the real-time analysis of their data using DTs (Furini et al., 2022). Providing learners with timely, personalized notifications on time management advice, like reminders for lectures and assessments and suggested reading lists, could be one of the future uses for DTs. According to Martynov, the creation of an educator's DT may help to analyze and refine instructional techniques as well as identify professional skills to enhance academic practices. To enable simulations and decision-making based on potential future learning scenarios, an instructor DT could include information on the traits of the educator as well as curriculum design, research skills, and knowledge (Tong et al., 2022).

4. Essential elements for developing a learner's Digital Twin

The Digital Twin Consortium (DTC), an international organization that unites government, academia, and industry to create a common key concept of digital twin technology, has created the Digital Twin Capabilities Periodic Table (CPT), which defines the technological and architectural requirements for the creation of a DT (Digital Twin Consortium, n.d.). The following six components are defined by DTC to create a functional DT.

Data: Data can originate from a variety of educational systems and methods and is essential to the creation of a learner DT. The digital footprints that students leave in the learning management system, assessment results, enrollment statistics, and the use of academic skills support and library services are a few examples of this type of data. In order to measure learners' emotional and attentional states, more complex data sources are also beginning to become easier to gather, such as auditory and sensor data (e.g., eye tracking) (Martynov et al., 2022).

Intelligence: The rules, models, analysis, and reporting that power the DT's operation are all part of the intelligence component. The pedagogical lens plays an important role in creating models and selecting which context will be suited best to design DTs in an educational environment. Developing successful learner interventions also depends on understanding the learning design of the activities and assessments when analyzing the results of DTs [11]

Management: In an educational environment, it is crucial that DT management and design follow the rules and regulations governing other educational systems and that plans be made for the DT's sustainability. Here Management refers to terms like data management, device management, system administrating, and activity logging.

UI/UX: This describes the ways in which dashboards, AR/VR, visualisations, and interfaces are used by learners and educators to engage with the DT. To promote engagement and involvement, it would be ideal to look into how these interfaces may be connected with other educational systems, providing educators and students with a seamless experience.

Integration: In order to facilitate data gathering, processing, and storage for DT development, an infrastructure is needed, which is known as integration. To integrate data across multiple learning platforms, applications such as Twin Builder tool or application programming interfaces can be utilized to facilitate communication between various platforms (Martynov et al., 2022).

Trustworthiness: This component addresses how a DT can be created to operate by strict ethical standards. Data encryption, DT security, privacy, dependability, and resilience are a few examples of such factors.

5. Challenges to implement Digital Twin in Real World

There are several issues that must be resolved in order for DTs to be used in higher education. The first is about the data required for the DT's creation and periodic updates. The growth of DTs may be hindered by the amount of data that must be continuously gathered, stored, and processed if sufficient infrastructure with respect to software and hardware are not in place. There may not be an issue for tiny data sets (DTs) of items and processes, but for DTs of teachers and students, it is crucial to gather as much information as we can so that the DT can be utilized for prediction and simulation. In reality, it is almost impossible to get all of the information that could be known about a student especially when students are doing coursework in offline mode, any models or procedures about the usage of the learner DT will also need to take the impact of "missing" data into account. Teachers' digital literacy, especially for non-technical backgrounds, in handling such sophisticated technology is a significant barrier to the adoption and usage of DT in higher education. A wide range of fields, including computer science, psychology, statistics, and mathematics, are combined in the design of DTs. Although a user doesn't have to be knowledgeable about every one of these topics, using DTs in educational settings will be easier with at least a basic understanding of some of the main principles. It is essential to understand how the DT's sustainability will be handled from a management standpoint. Maintaining DTs take into account the cost of continuous development and processing in addition to assigning responsibility for this maintenance. Protecting the integrity and security of the DT requires consideration of a number of additional factors, depending on its size, particularly when confidential information may be involved. Ensuring that the use of DTs in higher

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education is both appropriate and ethical is a significant difficulty, which is related to the concept of data governance. To make sure that students are not put in risk, care must be taken in the collection, storage, and use of the data that powers DT technology. The data that powers the DT must be disclosed to learners, and if at all possible, the designers and managers of DTs must figure out how to allow learners to take control of their data (Berisha et al., 2021).

Conclusion

The transformation of DT from parametric digital replicas of devices and processes to complex physical and human integration has given opportunities to apply digital twin technologies to enhance experiential learning. However due to limited resources and technological constraints, the utilization of digital twin technology in education is in its initial state. There are a few important considerations that need to be addressed before applying the DTs to educational practices.

1. To what extent can multidimensional data be collected, stored, and analyzed to provide the learner feedback and help the DT make proper decisions?
2. If DT provides incorrect feedback to learners, then how will it be corrected?
3. What should be rules and regulation for interoperability of data among different institutions?

   And so on.

Further research is required to fully understand each of the six components that have been identified as essential DT building blocks, how well they connect with the educational environment, and how using DTs affects students' learning results.

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