Unveiling the potential of Digital Twin technology for Higher Education

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The concept of the Digital Twin (DT), a digital replica of a physical object or process, is relatively new to the higher education context. The increase in the application of DT technology across many industries has prompted the call for greater exploration of the possibilities for DTs in education along with a consideration of the challenges to their implementation. There are also questions being raised about the opportunity to develop DTs of learners to extend the use of data to inform learning and teaching, which has been boosted by the recent rise of learning analytics and educational data mining. In this paper we will explore what DT technology is and offer a new definition of DTs that can be used in the educational context. Current uses and the potential future applications will be explored, as well as consideration of what is necessary to build DTs of learners (and educators). The use of DT technology also poses many challenges due to the complexity of DT design and application, and these will be outlined. The paper concludes with a discussion of future directions and areas where more research is needed to fully explore the potential of DT for higher education.

Keywords: Digital twins, higher education, personalisation, optimisation

Introduction

The ability to create a live digital copy of a physical object for the purpose of simulation, exploration, and/or decision making has become increasingly popular in industries such as engineering (Jiang, Ma, & Chen, 2021), architecture (Al-Sehrawy & Kumar, 2021), and medicine (Laubenbacher et al., 2021). These digital copies are commonly known as "Digital Twins" and their application to different industry contexts and objects is continually expanding as the technologies that enable their creation improve. The use of Digital Twins (DT) in higher education is starting to occur in a number of different ways, including as a teaching tool to allow learners to use digital versions of physical laboratory devices, as a way to plan and develop campus infrastructure, to develop and test course designs, and for professional development of educators. While this technology is still emergent, there are many possibilities for the application of DT technology in the higher education context. One such possibility would be the creation of DTs of individual learners for purposes such as the personalisation of learning experiences, identifying adaptive ways of providing feedback to learners to support their agency in learning, fostering career readiness, and providing learner study and well-being support.

As an emerging field, there has been relatively little published about the uses of DTs in the higher education context to date. In this paper, we explore the possibilities of Digital Twin technology to support and enhance the learning and teaching experience. As there is currently no universally accepted definition of a DT in higher education, we propose a definition of the concept which encapsulates the core elements relevant to educational contexts. We also bring together understandings about the design of DTs that have emerged from other industries and consider their relevance to education. We propose three main categories of DTs for education which include a DT as an object (e.g., a campus, lab instrument, etc.), a human (e.g., a learner or educator), and a process (e.g., a learning design, administrative processes related to the learner experience, etc.). While the possibilities of DTs are vast, there are also many challenges to their implementation. For example, in creating a DT that is constantly evolving there is the challenge that it can never be complete. The scale at which data may need to be collected to enable the live operation and updating of the DT also presents many challenges in terms of technical infrastructure and data governance. These, and several other, challenges will be identified and discussed.

A key contribution of this paper is the exploration of the possibility of creating a Digital Twin of a human within the educational context - for example, a learner. The complexity of such an undertaking has prevented considerable development of learner DTs to date, although examples of this type of DT are starting to emerge in some educational settings (Martynov et al., 2022; Sylvester et al., 2023; Tong et al., 2022). Over recent years, disciplines such as Learning Analytics (LA) and Educational Data Mining (EDM) have contributed much to the understanding of the use of data about learners to improve the educational experience, but DT technology offers the potential to take the utilisation of data to a new level. This discussion inspires a look at future ideas for the use of DTs in the higher education context, as well as the issues that will need to be resolved in order for DTs to be used appropriately and ethically to improve learner experiences and outcomes. Through this exploration, the paper aligns with the ASCILITE Conference sub-theme of "critical insights into the role of digital technologies in tertiary education". We begin this discussion with a consideration of how DTs can be defined in the higher educational context.

What is a Digital Twin?

The original idea behind the creation of a Digital Twin emerged in the 1960s when NASA employed a "living model" to evaluate failures in the oxygen tanks which had caused an explosion in the Apollo 13 mission (Allen, 2021). The first publication of the term 'Digital Twin' came in 2010 in a NASA Roadmap report which referred to a product they were using as a "Digital Twin of the flight system with comprehensive diagnostic and prognostic capabilities to enable continuous safe operation throughout the service life of system" (Piascik et al., 2010, p. TA12-1). Although it should be noted that the idea of the DT concept had been used by many in the intervening years, such as Grieves (2014) who started to use the concept in his course on product lifecycle management at the University of Michigan in 2003. Digital Twin technology has since been used in a range of diverse fields such as aerospace, engineering, aviation, civil and urban planning, health, manufacturing, agriculture, defence, natural resource conservation, transportation, cyber security, and telecommunication.

While there have been many different definitions subsequently put forward for the concept of a DT across different domains, there is no universal definition. An analysis of 10 papers on DTs found that there are five main defining features of a DT which include: (1) digital representation, (2) integration, (3) object and process, (4) scale or structure, and (5) data. Some definitions also include examples of the purpose of the DT, although as DTs can be used for an ever-increasing range of applications this can never encapsulate all possible ways the DT could be used. While the purposes will therefore not form part of our proposed definition, they will be explored in greater detail in the next section of this paper.

It is common for definitions to start with a reference to the way the DT is represented. This has been expressed as a set of virtual information constructs (Grieves & Vickers, 2017), a software analogue (Martynov, 2022), a model of an object (Miller & Spatz, 2022; Wright & Davidson, 2020; Zhou & Wu, 2022), a digital/virtual representation (Hawkinson, 2022), or a digital replica (Agrawal et al., 2023). We have used the term "digital representation" in our definition to incorporate the idea that there is a digital/virtual model that replicates the object or process being twinned.

The integration feature refers to the fact that there must be some communication channel that enables real-time data flow between the DT and the original object or process being replicated. This feature distinguishes DTs from a "Digital Model" which has no data exchange, or a "Digital Shadow" which only has one-way data exchange (Liljaniemi & Paavilainen, 2020). The two-way communication allows the model to be dynamically updated to evolve over the lifecycle of the object/process (Miller & Spatz, 2022; Wright & Davidson, 2020). There is some inconsistency in established definitions as to the frequency of synchronisation required, with some saying that it should be live and dynamic (Martynov, 2022; Wright & Davidson, 2020), while others suggest that there can be a specified frequency and fidelity (Digital Twin Consortium, 2020). As the technologies that facilitate DTs evolve, the possibility of live integration has become more feasible. Consequently, we have included in our definition that DTs should involve a live process that facilitates two-way communication between the twinned entities.

Traditionally a DT referred to a physical object. However, over time this notion has changed as the possible uses of DTs have expanded to incorporate processes and humans. Of the 10 papers reviewed, three specifically mention the physical nature of the object, whereas one refers to "living or non-living organisms" (Hawkinson, 2022, p.1) and another uses "real-world entities and processes" (Digital Twin Consortium, 2020). For our definition we have used "object or process" at a generic level to include physical objects, humans, and processes. The ability to create a DT of a human, as opposed to other physical objects will be discussed in greater detail below.

The scale or structure of a DT refers to the level of application of the model. Only two of the sampled definitions refer to this feature, calling it the state and structure (Martynov et al., 2022) or the "micro atomic level to the macro geometric level" (Grieves & Vickers, 2017, p. 94). This feature recognises that the DT can be used at different levels of magnification. For example, IBM (n.d.) defines four types of DTs in increasing levels of scale as: component/part twins, asset twins, system/unit twins, and process twins. Acknowledging the size and granularity of the DT, level was considered to be a useful component of an overall definition.

The data that enables the DT technology to evolve and adapt in real-time can include many different sources. The review of previous definitions included reference to operational data (Miller & Spatz, 2022; Zhou & Wu, 2022) and behavioural data (Miller & Spatz, 2022), as well as data from the past, present and/or future (Sylvester, 2023; Digital Twin Consortium, 2020). In our definition we have chosen to incorporate the concept of past, present, and future data to support real-time decision making as well as to predict scenarios.

Taking into consideration these five features, we define a Digital Twin as a multi-level digital representation of an object (living/non-living) or process that is integrated and dynamically updated with past, present and/or future data related to the twinned object/process. This definition is inclusive of elements of DT technology that have evolved in recent times due to advances in technology and computational processes. It can also be applied to the educational context, as it encapsulates the ability of DTs to be created for and of learners, educators, campuses, and processes.

General applications for Digital Twins

The range of contexts to which Digital Twin technologies can be applied continues to grow as the idea permeates into many different industries and the technologies that support its use improve. Within an industry context, the purpose of using a DT 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" (Shengli, 2021, p.2). For example, in civil engineering and construction DT technology can be used to facilitate the design of urban landscapes (Sepasgozar, 2020). In the manufacturing sector DTs have been used to create virtual models of physical products to identify design flaws and test performance capabilities for optimising the overall manufacturing process (Grieves, 2014). In the agriculture industry DTs are used for monitoring, managing, and predicting the future of crops and livestock (Purcell & Neubauer, 2023). Digital Twins now also offer new opportunities for the medical field to provide customised healthcare through the development of smart diagnoses using human DTs (Miller & Spatz, 2022; Shengli, 2021). With all these exciting new applications of the technology, it is unsurprising that attention has now turned to how DTs can be applied to the educational context.

Digital Twins in higher education

Higher education institutions exist in an increasingly competitive environment where it is necessary to optimise educational offerings, environments, and processes to attract and support learners. Digital Twins can be used in many different ways to help universities to address this challenge by providing enhanced learning environments and improved outcomes. The benefits of DTs include the ability to improve the sustainability, optimisation, resilience, and personalisation of learning environments within the higher education context (Furini et al., 2022). These four elements are key to the utility of DTs for higher education and can help in providing justification for further exploration of the opportunities that exist for their use in the future. In this section we will profile two popular current uses of DTs in higher education taking into consideration how these uses align with these four elements.

Digital Twins as teaching tools

While the concept of the Digital Twin is still fairly new within the higher education context, several applications are starting to emerge, offering exciting possibilities for the use of DTs as teaching tools in universities. For example, the creation of DTs of laboratory equipment allows learners to use and experiment with such equipment within and outside the classroom, helping to bridge the gap between theory and practice. Giving learners the chance to try and experiment with various scenarios using this virtual equipment provides an opportunity for them to learn from their mistakes, deepening the learning experience and improving situational awareness (David et al., 2018). Research into the use of a DT of a hydronic heating system showed that the technology was received positively by the learners with an increase in their level of curiosity and willingness to engage with DTs into the future (Johra et al., 2021). It was found that learners appreciated the opportunity to freely explore and change the parameters of the system via the DT in order to observe the outcomes on the overall system behaviour (Johra et al., 2021). Digital Twins can be used to prepare learners for the transition to the use of live equipment, especially where there is a high-risk factor if the equipment is handled incorrectly.

From a sustainability perspective, the ability to create digital replicas of potentially expensive and/or fragile specialised equipment can help manage teaching costs and avoid unnecessary charges that may result from mishandling of equipment (Johra et al., 2021; Maksimović & Davidović, 2022). The ability to save time and money on transportation and equipment for a scenario where learners need to interact with large equipment, such as an excavator, is another example of how the DT virtual learning experience can be more sustainable (Sepasgozar, 2020). Digital Twins also offer the possibility for learners to access equipment that may not be available to them in their geographic location to help address equity issues as well as sustainability goals.

In terms of resilience, DTs enable learning when experiencing the real tools/scenarios would require exposure to hazardous working conditions. For instance, the simulation of an excavator with its DT helped learners to practice dealing with risky situations of on-site civil construction activities, such as underground excavation and drilling, which are not safe for learners (Sepasgozar, 2020). DTs of laboratories can be used so learners can study dangerous chemicals without coming into direct contact with them in a physical laboratory, especially when these chemicals are capable of emitting radioactive or bio-health risking elements (Klami et al., 2022).

Digital Twin technology offers the ability to personalise learning by adapting to the level of understanding of the learner and allowing them access to systems and equipment outside of the classroom so they can practice and explore beyond timetabled class time. The design of learning activities around the DT can be personalised in a way that offers learners targeted resources and formative activities in response to their learning needs and preferences (Walkington, 2020). A study of the use of DTs to teach mechatronics introduced an intelligent learning platform around the DT to enable learners to monitor their performance with a view to being able to offer personalised lesson plans based on learner profiles (Machado et al, 2022).

Digital Twins of campus infrastructure

Another exciting application of DTs in higher education is to optimise the university campus and associated processes. Building a DT of a physical campus provides opportunities to run simulations to explore different scenarios that could impact the campus, from the effect of an increase in enrolments on available space, to the consequences of a natural disaster on buildings and services. Digital Twins can be used to develop smart campuses where ambience variables related to thermal, acoustic, visual, and indoor air quality can be balanced and optimised with the assistance of Internet of Things (IoT) sensors (Zaballos et al., 2020). In Italy, the University of Bologna is using IoT devices as part of DTs to monitor classroom occupancy rates and learner movements to identify and orient those with a disability to accessible paths between classes (Furini et al., 2022).

From a resilience perspective, DTs can help universities to respond to situations like the recent COVID-19 pandemic, where social distancing measures were in place and studies had to be moved online during lockdowns. IoT devices and thermographic cameras give universities an opportunity use DTs to monitor occupancy and flows of people to help support social distancing (Furini et al., 2022). DT simulations of online course capacity can help to optimise education provision of online and hybrid learning in the event of other pandemic or natural disaster episodes around the world.

Digital Twin technology can also be used in conjunction with Augmented Reality (AR), Virtual Reality (VR), and Metaverse technologies to design a virtual university campus. In April 2023 the University of Iowa launched its Digital Twin campus called “Metaversity” where learners can study business courses in the virtual environment (Halawith, 2023). Digital Twins can also be created to replicate the processes that occur in a university which support learners’ experiences. For example, the administration processes that enable learner enrolments and career guidance could be optimised to provide personalised and flexible choices for learners. Information about a learner’s previous experiences and future learning goals could be used as part of a DT to automatically search for the most suitable choices of units and pathways through a study program (Martynov et al., 2022).

Digital Twins of learners - is it possible?

For a long time the focus of DT development across all industries was on physical objects and processes. It is only in recent years that the idea of being able to create a DT of a human has become a feasible prospect. Advances in technology as well as the capability to store and process large amounts of data now mean that the creation of a DT of a human is now possible, and work is emerging on what this could look like in different industries. For example, human digital twins are already being used in fields such as medicine (Laubenbacher et al., 2021), sports science (Lukač et al., 2022), and product design (Lo et al., 2021). In the medical field, DTs are used as “a digital copy of a person with exact analogues of all vital systems in order to monitor the patient's physical condition and prevent the risks of developing diseases, which will allow doctors to track data on the health of clients and the condition of medical equipment in real-time” (Martynov et al., 2022, p. 1).

In the education context there has been an increase in interest in the use of data about learners and learning environments for many years, which is evident by the rapid development of the fields of learning analytics and educational data mining. The ability to create DTs of learners would build on this interest and expand the possibilities of harnessing the power of data to improve the learning experience for learners. At a micro level, DTs of learners could be used to provide individual learners with real-time feedback on their studies. At the meso level, aggregating the DTs of a group of learners could help to identify behavioural trends that an educator could use to adapt their teaching strategies. At the macro level, a university could use information generated through DTs to enhance graduation rates and inform organisational decision-making and development (Sylvester et al., 2023).

It has been said that a “human being is a complex system” (Shengli, 2021, p.1), which has led researchers to highlight the complexity in creating a DT of a learner. The behaviour of a learner can be very subjective and often unpredictable which adds to the complexity of DTs, so identifying a clear goal for the use of DTs is another proposal for reducing the complexity (Sylvester et al., 2023). To address this complexity, approaches such as the development of frameworks for recommendation systems as part of DT learning environments are being proposed (Tong et al., 2022). The Levels of Digital Twin (LoDT) framework proposed by Agrawal et al. (2023) seeks to address the complexity by identifying the roles that the human and DT take. These roles include observer, analyst, decision maker, and action executer and are allocated depending on the application of the DT.

Creating DTs of learners opens up new possibilities for the improvement of learning environments and support. For example, the real-time analysis of learners’ data through DTs can be used to support diverse learners who face challenges with work commitments, family obligations, and disability by informing the design of more inclusive and accessible learning models (Furini et al., 2022). A future application of DTs could be to provide just-in-time customised notifications to learners on time management tips such as lecture and assessment reminders and recommended learning resources.

Digital Twins can also be used as a basis for informing curriculum and learning design as well as for professional learning for educators. The prediction, real-time simulation, and optimisation capabilities of DT technology provide useful development opportunities for learning designers, learning analytics specialists, educators, and learners. A DT model of a learner can be used to monitor and match learning journeys, including past experiences and present gaps, with future goals to rapidly identify any deviations for the development of learner agency (Sylvester et al., 2023). Near real-time data from DTs of learners at a cohort level can provide behavioural trends of the group to be useful for educators in designing effective learning interventions.

In addition, the development of a DT of an educator could be useful for examining and developing teaching strategies and identification of professional competencies for improving academic practices (Martynov et al., 2022). An educator DT could incorporate information on the attributes of the educator as well as curriculum design, research expertise, and knowledge to allow for simulations and decision-making based on possible future learning scenarios (Tong et al., 2022). For example, a teaching competency evaluation model based on machine learning and DT technology showed practical applicability to identify an educator’s abilities and make targeted suggestions (Siyan et al., 2021). Moreover, the ability to test hypotheses regarding a novel teaching method or an educational tool in near-real time without disrupting the real-world instance creates value for the use of DTs in the educational space (Sylvester et al., 2023).

Building blocks for creating a Digital Twin of a learner

If the idea of creating a DT of a human learner is deemed possible then it is important to consider what building blocks are necessary to make this a reality. The Digital Twin Consortium, an international group that brings together industry, academia, and government to develop a shared understanding of DT technology, has developed the Digital Twin Capabilities Periodic Table (CPT) to outline architectural and technological requirements for the development of a DT (Digital Twin Consortium, n.d.). The CPT is made up of the six elements necessary for the development of a functional DT. In Table 1 we outline how each of the elements can be adapted to enable the creation of a DT of a learner.

Table 1: Applying elements of the Digital Twin Capabilities Periodic Table (CPT) to DTs of Learners

DATA	Data is central to the development of a learner DT and can come from a range of educational systems and tools. This data could include the digital traces learners leave in the learning management system, assessment outcomes, enrolment information, usage of support services like the library and academic skills support, etc. More sophisticated sources of data are also starting to become more possible to collect such as auditory and sensor data (e.g., eye tracking) to be able to gauge the emotional and attentional states of learners (Martynov et al., 2022).
INTEGRATION	Integration refers to the infrastructure required to support data collection, storage, and processing for DT development. Application programming interfaces or middle ware systems like Twin Builder tool can be used to allow different platforms to communicate with each other for integrating data across all the learning platforms (Martynov et al., 2022).
INTELLIGENCE	The intelligence element relates to rules, models, analyses, and reporting that drive the functioning of the DT. An important consideration for the use of DTs in the educational context is the pedagogical lens that should be applied when developing models and choosing appropriate analyses to apply to learner data. The importance of referring to the learning design of activities and assessments when interpreting the outputs of DTs is also key to developing effective learner interventions (Bakharia et al., 2016).
USER EXPERIENCE	In designing a DT it is important that close consideration is given to the user experience. This refers to the ways that users interact with the DT through interfaces, visualisations, AR/VR, and dashboards. Exploring how these interfaces can be integrated with other educational systems so that learners and educators can have a seamless experience would be ideal to encourage engagement and interaction.
MANAGEMENT	Management refers to considerations around aspects such as device management, event logging, system monitoring, and data governance. In an educational context it is important that the design and management of DTs align with the guidelines and policies that govern other educational systems, and strategies for sustainability of the DT are developed.
TRUSTWORTHINESS	This element refers to how a DT can be designed so that it meets a high ethical standard of operation. This can include considerations such as data encryption, DT security, privacy, reliability, and resilience. In order for users such as educators and learners to engage and benefit from the system, they need to be able to trust that it is reliable and that their data and interventions are safe.

Challenges to using Digital Twins in higher education

For DTs to be utilised effectively in higher education, there are a number of challenges that need to be addressed. The first relates to the data that is necessary for the creation and continual updating of the DT. The scale at which data is required to be collected, stored, and processed on an ongoing basis can be prohibitive to the development of DTs if adequate infrastructure is not available. For small DTs of objects and processes, this may not be a big issue, but for DTs of learners/educators it is important that as much data as possible is collected to enable the DT to be used for simulation and prediction purposes. The lack of a unified data structure could lead to inconsistency in building a DT in higher education because of the siloed maintenance of learner data in different platforms like portfolio systems, LMSs, and career development systems (Martynov et al., 2022). There is also a challenge of capturing the more 'informal' learning data that help to understand the complex nature of a learner as well as the multimodal data (e.g., movement, audio, etc.) that can help to understand and inform the learner journey. It is acknowledged that it will never be possible to collect everything that there is to know about a learner, and consideration of the impact of 'missing' data will also need to be factored into the development of any models or processes related to the use of the learner DT.

Another key challenge to the introduction and use of DT technology in higher education is the digital literacy of educators to be able to work with such complex technology. The design of DTs brings together elements from many different disciplines including computer science, psychology, statistics, and mathematics. While a user doesn’t need to know about all these areas, an awareness of some key concepts from at least some will enable more effective use of DTs in educational environments. Understanding the best use cases for DTs is something that educators need, but also institutional managers and support teams. It is also important that educators are capable of interpreting the outputs of models applied to DTs to be able to determine the most suitable interventions to make in response. An additional related challenge is the workload required for educators to set up resources and support for more personalised approaches which may identify many different ways a learner needs to be supported in their learning.

From a management perspective it is important to know how the sustainability of the DT will be managed. In addition to determining who is responsible for this maintenance, the cost of ongoing development and processing needs to be factored into any implementation discussions. Depending on the scale of the DT being used, there are various other aspects that need to be factored into protecting the integrity and security of the DT, especially when sensitive data may be involved. Processes and guidelines around the design and implementation of DTs can help to determine the level of management required as well as a link to institutional policies on data governance.

Related to the idea of data governance, a major challenge for the use of DTs in higher education is ensuring that their use is ethical and appropriate. Consideration must be given to how data that drives DT technology is collected, stored, and used to ensure that learners are not placed at any risk. Learners need to be aware of the data that is being used to power the DT and the designers/managers of DTs need to determine how learners may be given the ability to control their data if possible (Berisha et al., 2021). In the case of an institution that implements a learner DT it is important to consider whether and how learners may have the option to opt out of their data being used. For a DT of a university campus, consideration needs to be given to the security implications of collecting location data of learners, and the protection of the privacy of this data. A useful approach for institutions seeking to implement DTs appropriately is to apply the eight ethical principles proposed by Corrin et al. (2019) which cover key topics including privacy; data ownerships and control; transparency; consent; anonymity; non-maleficence and beneficence; data management and security; and access.

Conclusion and future directions

The emergence and impact of DTs in industries such as manufacturing, urban planning, transport, medicine, and engineering have pointed to the interesting and exciting potential this technology can have for education. The evolution of DTs from digital replicas of devices and processes with fixed parameters, toward more complex physical and human objects opens up even greater possibilities for their application in sophisticated ways that can enhance learning experiences and the learning environment. However, this also creates challenges to their implementation that need to be addressed in order to ensure effective and appropriate use of DTs. It is important that we learn from the lessons of related fields such as LA and EDM who have had to tackle similar challenges in their pathways to implementation.

From our exploration of the definition, design, and application of DT technology in the higher education context we have identified several key questions to be answered in order for DTs to be widely integrated into educational practice. These include:

1. How feasible is the collection, storage, and analysis of multimodal data that can inform the DT and provide feedback to the learner?
2. Do the advantages of using a DT of a learner over a learner record system outweigh the potential cost of implementation?
3. What background information about DTs needs to be given before learners will be willing to provide the breadth of data required to generate a DT capable of being used for personalisation of the learning experience?
4. Who is responsible if there is a mistake when using a DT to predict an outcome for a learner?
5. How can a DT be kept secure and reliable?
6. How can the creation and maintenance of DTs be done in such a way that they could be transferable to another institution/educational context (e.g., vocational education, higher education provider, etc.)?
7. What should happen to a DT of a learner when the learner completes their studies?

This is not an exhaustive list of questions, and more will certainly emerge as the complexity of the use of DTs in higher education becomes more apparent. There is a need for more research into each of the six elements identified as necessary building blocks for DT development and their alignment with the educational context, as well as the impact on learning outcomes for learners who use DTs as part of their studies. It is important that this research includes the voices of all stakeholders, especially those of the learners whose data could form the basis of DT models and applications. Evaluation of the benefits of DT technology over current ways of utilising learner data to optimise learning environments should be undertaken to determine whether such a sophisticated approach can be justified and provides adequate additional benefit.

In summary, the potential uses of Digital Twins in higher education are many and varied. It is an exciting time to learn from the development of object and process DTs across industries, but in particular the development of human DTs to inform their development in education. Learning from the precedents set around using learner data from other related fields (e.g., LA and EDM) is also important in ensuring the most effective and appropriate use of DTs in the educational context. We look forward to observing the ways that this technology is applied in higher education over time and hope that the definition of a DT for education set out in this paper can contribute to broader discussions into the future.

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