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Digital Twin Monitoring of Classes and Students

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Abstract: Higher education institutions accumulate substantial data, yet their underutilisation for understanding student performance persists. Conventional monitoring methods fall short of effectively capturing the nuances of student performance and class dynamics. Adopting a positivist research paradigm and using design science research methodology, this research investigates the integration of digital twin technology in Education. The study endeavours to bridge the gap between traditional monitoring approaches and a new era of data-driven technologies, offering real-time insights into student performance and influencing factors. This research contributes to the evolution of educational monitoring systems, fostering a more responsive and insightful educational environment.

Keywords: Digital Twins, Human Digital Twins, Student Performance Monitoring.

1. Introduction

Technology integration into the educational field is a topic of global interest, especially with the advent of digital twins. The concept of a digital twin is often utilised in various industries, such as manufacturing and urban planning. It involves creating a digital replica of a physical entity or system to simulate, analyse, and control its real-world counterpart [19]. This technology enables real-time monitoring, emulates real-world scenarios, and provides predictive data, all in a virtual space [13]. Given digital twins' comprehensive and real-time data management capability, its application in the educational sector, particularly in monitoring student performance and class activities, presents a fertile ground for exploration and research.

Traditional methods of monitoring student performance, grounded in data collection, assessments, and minimal technological intervention, are hindered by challenges. These include drawing insights into student performance based on existing data, adapting to diverse student needs, managing large class sizes, and providing timely feedback [3]. Notably, learning management systems (LMS) have been used to attempt to mechanise the monitoring process. However, they often provide insufficient insights into students' performance and do not account for numerous factors that could influence academic outcomes. Consequently, a more holistic, nuanced, and technologically advanced method, such as implementing digital twins, becomes imperative.

Therefore, this research project explores the viability of and implementation of digital twins for monitoring classes and students in a higher education context. It thoroughly explores the principles of digital twins, scrutinises existing monitoring methodologies, and defines and implements the Digital Twin Student Monitoring System (DTSMS) that integrates digital twin technology into the educational framework.

Subsequent sections outline the study's objectives, the methodology used for conducting the study, current practices in student monitoring, digital twins and human digital twins, and leveraging digital twins for student performance monitoring and conclude with recommendations for future studies and a conclusion of the study.

2. Objectives

This study seeks to assess contemporary student monitoring methods and, concurrently, develop a digital twin system tailored for real-time monitoring in the educational domain. Objectives encompass evaluating existing student monitoring approaches, examining digital twin principles, adapting these principles to the specifics of student and class performance monitoring, and developing the Digital Twin Student Monitoring System (DTSMS).

3. Methodology

The research adopts a positivist paradigm because it emphasises empirical focus, quantitative methods, and objectivity [8]. This aligns with the study's goal to gather, analyse, and comprehend empirical and objective data, validating digital twin technology theories and student monitoring theories.

The design science methodology is employed to address its imperative. Design science aims to improve organisational processes and task execution [5, 18], aligning with the research goal of enhancing student performance monitoring. Emphasising three essential cycles – relevance, design, and rigour [5]. The methodology ensures systematic problem identification, iterative system development, and rigorous evaluation. The relevance cycle involves critical reviews of existing student and class monitoring methods. The design cycle facilitates the systematic development of the digital twin-based student performance monitoring system. The rigour cycle, represented by the evaluation phase, assesses the system's effectiveness in real-time data visualisation and student engagement analysis.

4. Literature

4.1 Current student monitoring techniques and technologies

Monitoring student performance is a pivotal aspect of Education, gauging comprehension and learning abilities [6, 19].

Traditional approaches, like manual attendance logs and subjective observations [7], are longstanding methods, but they tend to be labour-intensive and may not capture holistic insights. Peer assessments [11], relying on subjective opinions, suffer from a lack of objectivity [7]).

Technological advancements offer promising solutions; this section summarises papers based on various technological applications for student monitoring their limitations. A web-based system proposed in [7] can facilitate teacher-parent engagement to monitor students' academic performance. However, it lacks student access to reports and automated feedback since teachers must fill in daily reports on the system. In contrast, the computer-vision-based approach detailed in [11] records student behaviours during lectures but faces challenges in user-friendly data visualisation and intensive computation. Authors in [21] propose data mining tools for student data analysis, noting the need for integration and potential computational intensity. The analytics platform in [14] offers weekly performance feedback and predicts course grades but falls short in providing insights into certain student interactions, like interactions with resources and announcements. Meanwhile, the authors in [2] discuss enhancing Education through data mining and analytics, emphasising the need for integrated and interoperable systems.

4.2 Digital Twins

A digital twin is a virtual representation of a physical entity or system that extends beyond a static model by synchronising real-time data, enabling a continuous reflection of the physical entity's state, behaviour, and interactions [3, 16].

A digital twin comprises a physical environment, a virtual environment, data, and the connections between these components. These connections serve as communication mediums, ensuring synchronisation between the physical and virtual environments and facilitating and allowing for real-time reflection, interaction, and convergence. The virtual environment takes advantage of real-time data updates from its physical counterpart, allowing for self-evolution [19]. Table 1 outlines the key characteristics of a digital twin: real-time reflection, interaction, convergence, and self-evolution.

Table 1: Characteristics of digital twins [19].

	Description
Real-time reflection	The virtual space is an authentic and accurate representation of the physical space.
Interaction and convergence	Integration between the virtual and physical spaces facilitates the connection of data generated across different phases. The interaction and convergence between real-time data and historical data is supported.
Self-evolution	Real-time data updates to continuously improve virtual models by comparing and aligning with the physical space.

4.3 Human Digital Twin

The representation of humans, such as students, in a virtual space is supported by the Human digital twin (HDT) concept. HDT is a comprehensive database encapsulating personal information, interactions, and behaviours, continuously synchronising with real-time data and individual changes in the physical world [16].

HDTs are unique, with each real-world individual having a corresponding and distinctive HDT in the virtual environment. Beyond data recording, HDTs perform tasks like data analysis using cloud computing and deep learning technologies. This results in actionable insights, including predictions and suggestions tailored to the individual [16].

While both HDTs and traditional digital twins serve as digital replicas facilitating bi-directional interactions, the complexity of human systems distinguishes HDTs. [10] emphasises the inherent variability in humans, requiring a more tailored approach to developing and managing HDTs.

The application of HDTs spans diverse fields, including medicine, sports, and Education. In all of these applications, humans and their behaviours are monitored [3, 9].

Unlike machines in the manufacturing industry and IoT devices in smart cities, influencing the state of humans in the physical environment might not be automatic; however, mechanisms are required to allow for modifications in the physical environment. This can be through notifications or alerts [10].

4.4 Digital Twins in Education

Digital twins and HDTs also have applications in Education, as shown in Table 2. These applications indicate the potential of digital twins and HDTs to offer real-time insight into class and student behaviour, engagement, and performance of students. In comparison to some existing work done in the field of Education leveraging digital twins, the DTSMS is a solution that is focused on personalised feedback. However, unlike Example A, the feedback is available to educators and students. The solution offers a comprehensive approach with real-time monitoring and alerts, enhancing responsiveness.

The DTSMS provides a proactive approach that focuses primarily on predicting the outcome of the student's performance based on their interactions and activities on learning platforms like the LMS and their attendance, allowing for timely interventions.

Virtual models in the form of profiles set this solution apart, offering a nuanced understanding of student behaviour and performance.

The real-time monitoring of the DTSMS and its automated alerts for at-risk students add a layer of responsiveness that surpasses the other three examples in addressing performance concerns promptly.

Table 2: Application of digital twins in Education.

	Example A [15]	**Example B** [9]	**Example C** [17]	**DTSMS**
Scope	Enabling personalised monitoring and feedback for students using control engineering and Education robotics.	Creating a virtual environment that mirrors an educational institution to support blended learning and address disruptions in Education.	Manage teaching facilities for educational purposes and optimise energy consumption.	Enable personalised monitoring and feedback for students and educators by creating a dynamic visualisation of the collected data on the students and the class.
Goal	Predict students' performance based on recorded activities and interactions with robots.	Self-evolution, to continuously update and align the digital twin with changes in educational and technological context.	Effective management of teaching facilities and energy consumption	Predict the outcome of students' performance based on interactions on LMS, attendance and other recorded data.
Interactivity and Engagement	Provides personalised feedback and guidance for students	Allow educators to monitor, manage and optimise educational processes in a blended learning environment.	Streamlines classroom and resource allocation processes.	Provides personalised feedback, real-time monitoring and automated alerts for at risk students.
Virtual Models (Virtual Environment)	Models of students and robots that they interact with.	Model of an educational institution and its components	Models of campus, individual classrooms, and other components	Profiles of students and their interactions with the learning environment

5. Digital Twin Student Monitoring System

Developing the Digital Twin Student Monitoring System (DTSMS) involved a comprehensive process to ensure its efficiency and alignment with the research objectives. This section outlines the system's architecture, the data used, the technology stack, and its services and functionality.

5.1 Architecture

The proposed artefact, the DTSMS, is a proof-of-concept solution that follows a comprehensive architecture inspired by [12]. The architecture is framed in a 5-dimensional model encompassing the following aspects:

1. Physical Environment: Includes the class and individual students.
2. Virtual Environment: Data visualisations showing students' interactions with their resources and in their class.
3. Data: Extracted from learning management systems, attendance records, and other performance-influencing factors.
4. Services (These are the system's tasks): Data integration, analysis, visualisation, real-time monitoring, and alerts.
5. Connections: interactions between all the components.

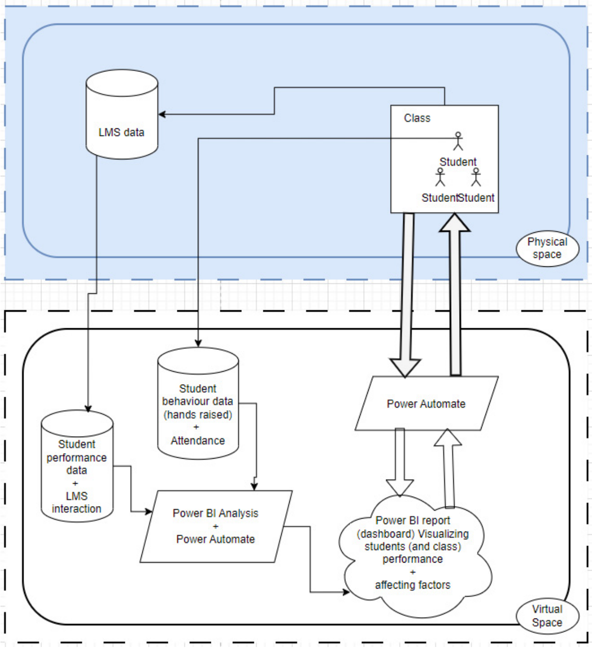

Figure 1: Architecture of DTSMS

Figure 1 visually represents the proposed solution and its architecture, highlighting the interconnected components.

5.2 Data integration and manipulation and Technology stack

The DTSMS employs synthetic data from Kaggle, specifically the Student Scores and Student Performance datasets. The former contains student numbers and marks for twelve tests across 56 Students, which were averaged monthly to align with a three-month monitoring model. The student performance dataset, including attendance, class behaviour, and interactions, underwent preprocessing, excluding demographic info and randomising attendance.

The technology stack comprises Python pandas for data transformation, Power BI for analysis and customisable reports, Power Apps for hosting the reports, and Power Automate for data integration and real-time monitoring, ensuring effective bi-directional communication between environments.

5.3 Services and Functionality

The table below highlights the services and functionality of the DTSMS.

Table 3: DTSMS services and functionality

Data Integration	The DTSM combines various data sources, including student records, student interactions with resources and announcements on the LMS, class attendance, academic performance, and factors that influence student performance.
Data analysis	The DTSM analyses the data and creates specific measures that will aid in the visualisation of data to allow for meaningful insights to be drawn from the visualised data.
Data visualisation	The DTSM employs interactive visualisations to represent data. These visuals enable educators and administrators to grasp performance trends and issues in real time.
Real-time Monitoring	Data is refreshed regularly and updated frequently to ensure that educators can access up-to-date information. Real-time monitoring is crucial for promptly identifying and addressing performance concerns, such as those of students at risk of failing.
Performance metrics	The DTSM includes key performance metrics and Key Indicators (KIs) relevant to students and the class, enabling educators to assess and track progress effectively.
Automatic alerts	At-risk students are automatically identified (if their average is below 50%) and notified of this via email. They are then prompted to respond to the email with their next steps.

6. Results

In student monitoring, the DTSMS allows for integrating the various systems used in higher education institutions and their data to provide a data-driven environment, requiring little human intervention. The DTSMS is reasonably good at monitoring individual student and class performance in real-time, thus allowing educators to create individual profiles of students and their classes (see Figures 2 and 3).

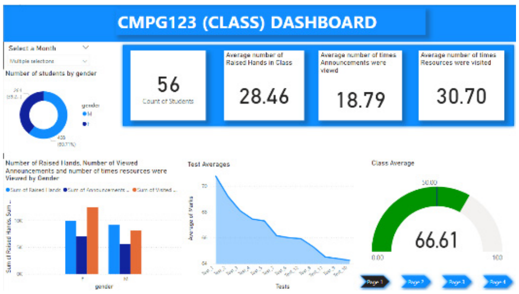

Figure 2: DTSMS Class dashboard

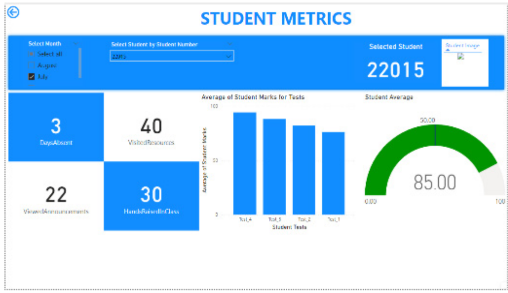

Figure 3: DTSMS passing student dashboard

The system automatically identifies at-risk students after a couple of test marks are received, allowing for interventions, and aligning seamlessly with the study's objectives. Compared to EoS [14] and the system proposed by [11], the DTSMS improves traditional monitoring methods. The DTSMS is available soon after a semester starts to collect the information required to create the dashboard reports and is also available for students and teachers at all times.

Instead of having to physically observe student's participation and go through their marks to identify students at risk, the DTSMS refreshes data every 5 minutes to receive the most recent data updates from the LMS and other sources of student data that indicate the number of hands raised in the online class, and the attendance of students, thus being aware of performance concerns automatically.

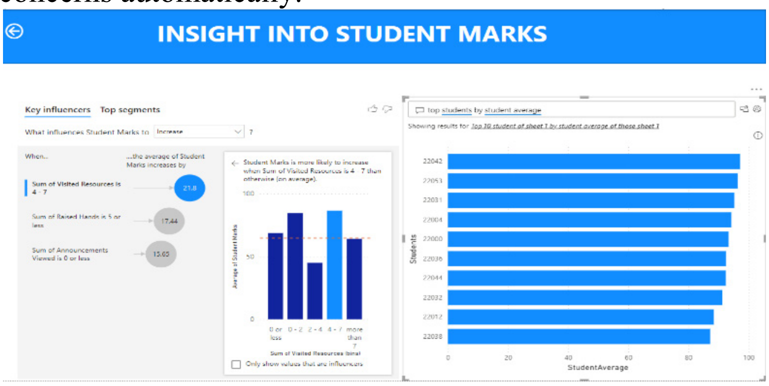

Figure 4: DTSMS Insights page

Its automatic alerts feature sends email alerts to students at risk and their educators after the first two assessments have been written. It then sends alerts after each assessment to keep students and educators up to date about students' academic performance. This feature is often absent in traditional monitoring and less often in conventional systems like the LMS [14] and systems like the PTAMA [7] mentioned earlier, which foster a proactive teaching environment, enhancing responsiveness. This feature also makes identifying at-risk students less tedious and allows educators to focus on more important tasks [7].

The DTSMS integrates key influencers and Q&A functionality on an insights page, shown in Figure 6, which traditional monitoring systems [7] and some of the systems and implementations discussed earlier [6, 19] do not consistently implement. Educators can leverage these features to understand diverse factors influencing student and class performance, as they would with insights from the EoS system [14], the system mentioned in [11], and educational data mining and learning analytics systems [2]. The DTSMS portrays the potential of digital twin technology to improve the education field, especially regarding student monitoring.

7. Business Benefits

The Digital Twin-based Student Monitoring System (DTSMS) offers several advantages for educational institutions that the traditional monitoring framework does not facilitate:

- Performance insights: DTSMS offers insights into student performance, facilitating interventions.
- User-friendly data visualisations: The visualisations in the system empower data-driven decision-making for academic staff, which also show a correlation between student performance and the attributes affecting student performance.
- Automated identification of at-risk students: The system identifies at-risk students after writing an assessment, with little human intervention, thus facilitating a somewhat prompt intervention.

  The DTSMS meets immediate monitoring needs and aligns with broader objectives in the education field, fostering data-driven decisions and real-time monitoring.

8. Conclusions

This research aimed to explore the application of digital twin technology in Education for dynamic and personalised student performance monitoring and the factors that influence it. The DTSMS showcased its potential, particularly in real-time monitoring of academic performance and automated alerts for at-risk students. This research underscores the importance of integrating innovative technologies in Education to track student performance more effectively.

The limitation of the research was that the system did not cater to instances of physical lessons, where the behaviour of students in the class could also have been monitored using IoT. Secondly, the system could not necessarily provide real-time alerts since these could only be provided after each test was written.

Recommendations to improve the DTSMS would be integrating educational data mining and learning analytics to make the system more robust. Second, the researcher could explore the integration of IoT devices in the classroom and a 3D representation of the class to monitor the physical behaviour of students in the classroom in real-time.

Future research in this domain could investigate the scalability of the DTSMS to accommodate diverse educational settings, and evaluating its long-term impact on student outcomes would contribute valuable insights. Lastly, virtual and augmented reality technologies can be leveraged to provide an immersive learning experience.

Declaration of Use of Content generated by Artificial Intelligence (AI) (including but not limited to Generative-AI) in the paper

The authors acknowledge the use of content generated by Artificial Intelligence (AI) in the paper entitled "***Digital Twin Monitoring of Classes and Students***" using quilbot, grammarly and chat got in the following limited ways:
- To paraphrase some paragraphs
- To improve grammar in the whole paper

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