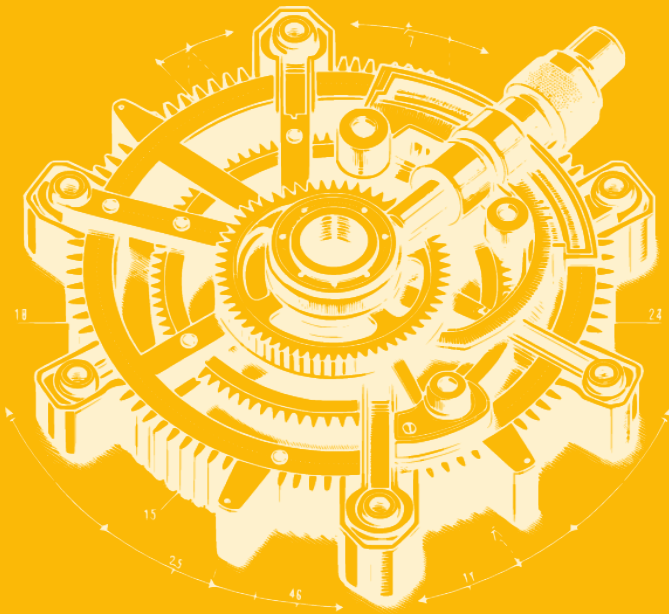


A. Goti, A. Guillén, J. Chiachío,
M. Chiachío

Digital Maintenance in the Digital Twin Era

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& Doctoral Workshop*



Aitor Goti

Department of Mechanics, Design and Industrial Management, Faculty of Engineering,
University of Deusto, 48007 Bilbao, Spain

Antonio J. Guillén

ICEI & Department of Management,
Complutense University of Madrid, 28040 Madrid, Spain
ajguillen@ucm.es

Juan Chiachío Ruano

Andalusian Research Institute in Data Science and Computational Intelligence (DaSCI),
University of Granada, 18071 Granada, Spain
jchiachio@go.ugr.es

Manuel Chiachío Ruano

Andalusian Research Institute in Data Science and Computational Intelligence (DaSCI),
University of Granada, 18071 Granada, Spain
mchiachio@go.ugr.es

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P.O. box 1 - 48080 Bilbao
e-mail: publicaciones@deusto.es

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EngageMate: Advancing Classroom Interaction with an Intelligent IoT Assistant driven by the Digital Twin Concept

Diego Casado-Mansilla^{1*}, Xavier Solé², Oihane Gómez-Carmona³, Joan Navarro²,
Diego López-de-Ipiña^{1*}

¹ Faculty of Engineering, University of Deusto

² GRITS, La Salle - Universitat Ramon Llull

³ Deustotech, University of Deusto

Abstract

The rapid evolution of educational technologies brings the Internet of Things (IoT) to the forefront as a transformative force, poised to reshape conventional teaching and learning methods through its network of interconnected devices and systems. This paper introduces an innovative IoT device enhanced by digital twin technology, aimed at improving teaching efficacy by enabling interactions with virtual replicas of physical objects for immersive, real-time learning simulations. The device goes beyond typical educational tools by monitoring classroom environmental conditions and assessing student engagement, supported by a web platform for educators to evaluate their teaching performances. A practical application involving two university teachers demonstrated the device's potential to significantly improve teaching strategies and student engagement, though it also revealed challenges in integrating such technologies into educational settings. These findings emphasize the need for ongoing research and development to overcome barriers and fully exploit IoT and digital twin technologies in education, thus facilitating a more interactive, effective, and personalized learning environment.

1. Introduction

In the rapidly evolving landscape of education, the Internet of Things (IoT) emerges as a transformative force, promising to redefine traditional teaching and learning paradigms through its interconnected devices and systems network. Integrating IoT into educational settings heralds a significant milestone in the journey towards more interactive, personalized, and accessible teaching and learning experiences for students of all ages, including those in higher education. Despite the potential, the body of literature exploring the full capabilities of IoT in education remains relatively underdeveloped, highlighting the need for novel proposals to enrich the academic discourse within the research community. This paper draws over two important concepts, engagement, and comfort. It introduces an innovative IoT device designed to enhance

* dcasado@deusto.es



teaching performance through the application of digital twin technology. By leveraging the concept of digital twins, this device offers a groundbreaking approach to education, enabling teachers and students to interact with virtual replicas of physical objects. This interaction enriches the learning experience with immersive, real-time simulations, providing a hands-on understanding of complex subjects.

The proposed IoT device goes beyond traditional educational tools by measuring environmental conditions within the classroom and sending alerts to teachers, thus optimizing the learning environment. Furthermore, it includes features to gauge student engagement and comfort, and offers a web platform where educators can review and reflect on their daily teaching performance to increase students uptake and engagement. A practical application of the IoT-digital twin approach was conducted in a university setting with two different teachers to assess its impact. The study provided valuable insights into the device's effectiveness, revealing its potential to significantly enhance both teaching strategies and student engagement. However, it also identified limitations and challenges, sparking a discussion on the integration of emerging technologies in education. The findings from this study contribute to the ongoing exploration of how IoT and digital twins can be harnessed to enrich the educational landscape. They underscore the necessity for continued research and development in this area, aiming to overcome current barriers and fully realize the potential of these technologies in creating a more engaging, effective, and personalized learning experience. Through such innovations, the future of education can be shaped to better meet the diverse needs of students and educators alike, paving the way for a more informed, interactive, and inspired educational environment.

2. State of the Art

As presented in the introduction section, the reviewed literature draws over to underpinning concepts: engagement and comfort.

2.1. Engagement

Student engagement in the classroom is a multifaceted parameter involving at least three dimensions [1]: behavioural (associated with participation), cognitive (associated with mental performance) and emotional (associated with positive or negative reactions to different stimuli). Given the wide range of parameters it covers, engagement can be considered a good indicator of the quality of students' learning process and their personal development in the classroom [2, 3, 4]. This has prompted research into what methods and objectively measurable parameters can and should be taken into account when quantifying the level of student engagement [5]. Typically, this work revolves around observation of students and their natural performance in the classroom [2]: how many times they raise their hands, how many times they interact with peers, what position they hold on the chair, what they have on the table, how much they yawn, how many interactions they have with devices outside the teaching context (e.g., mobile phones),

how much work they have handed in, what grades they have received, how much they have received, how many times they have been given a grade, how many times they have been given a grade, how many times they have been given a grade, how many times they have been given a grade, how many times they have been given a grade. Traditionally, this quantification of the level of student engagement is usually done subconsciously in a more or less informal way, and also depends on the experience and skills of the teacher.

Thus, engagement can be seen as one of the (multiple) connecting links between teacher and learners in the learning process [6]. Paradoxically, most of the studies that have been carried out to date look at this link in only one direction: from the learners to the teacher. However, it seems that teacher engagement in the classroom can also have a significant impact on the learning process of students [7]. In this case, it is evident that the aforementioned dimensions (behavioural, cognitive and emotional) cannot be directly and fully applied to quantify teacher engagement while delivering a classroom session [8].

2.2. *Comfort*

Typically, enhancing comfort in indoor environments aims to make individuals more relaxed within building interiors. Consequently, various methods to assess indoor conditions have been developed, such as the ANSI/ASHRAE Standard 55 [9] and the ISO 7730 [10]. In efforts to achieve a comfortable indoor atmosphere, numerous research projects have explored different approaches to evaluate comfort in educational spaces, offering recommendations to ensure classrooms are comfortable and establishing guidelines to maintain suitable conditions [11]. Commonly examined factors include thermal conditions [12], humidity levels [13], visual comfort, which involves appropriate lighting [14], acoustics [15], and air quality [16]. Additionally, some researchers have investigated the influence of design elements such as equipment availability or the spatial layout, which can evoke positive emotional responses [17]. Simultaneously, numerous studies have examined how indoor environmental conditions affect student performance and learning quality. For instance, Montiel *et al.* [18] discussed how inadequate acoustics or external noise disrupts learning and teaching activities. Likewise, factors like temperature and humidity significantly influence comfort levels. On this topic, Jiang *et al.* [19] discovered that optimal learning occurs when thermal comfort is balanced, while Fisk [20] reviewed ventilation issues in schools and their effects on student health and performance. This research highlights potential health issues arising from inadequate comfort measures, noting that high humidity can lead to increased fatigue and respiratory infections [21], and poor lighting may contribute to myopia [22]. Additionally, the COVID Emergency has prompted increased focus on air quality and its health implications [23]. However, a review of this research indicates that while these studies primarily focus on understanding educational comfort and its outcomes, there has been less emphasis on exploring students' subjective perceptions of the indoor environment in classrooms compared to ideal objective conditions. Nonetheless, Frabsson *et al.* [24] suggest that deeper understanding of the relationship between these subjective and objective factors could lead to more precise standards for designing indoor environments.

3. Technological framework

To assess indoor comfort, a custom-designed weather station has been employed to monitor the environmental conditions within the classroom. The starting point of this IoT tool was previously introduced by the authors in a former article [25]. This station is equipped with sensors to measure noise (in decibels dB), temperature (in Celsius degrees °C), humidity (as a percentage %), luminosity (in lux), and air quality (CO₂ concentration in parts per million ppm). Constructed using the Wio Terminal platform from Seed Studio, this prototype (referenced in fig. 1) displays sensor readings on its built-in screen.

Figure 1

Smart IoT device to monitor the classroom activities and environment



Additionally, it wirelessly transmits data using the MQTT protocol for real-time analysis to a cloud server that manages both the environmental monitoring system and data collection. This server archives the indoor monitoring data for subsequent analysis and showcases them on a web-based dashboard. The IoT devices also allow to track the lecture performance where the teacher will have to define the values according to his class, i.e. he will have to choose the type of class (lecture, interactive, exercises, laboratory...), the number of students, the time of the day (morning, afternoon...), the day of the week (Monday, Tuesday...) or the breaks he/she is doing during the lecture.

To measure the engagement of students, the platform is inherited from a previous work of the authors [5]. The starting point was the systematic identification of a set of

measurable digital characteristics that arise from the use of the inherent sensors (camera, microphone, and keyboard) in videoconferencing environments. This data is used to calculate the level of student engagement, and an analytical model is devised for its quantification. Ultimately, a system based on web technologies captures and monitors the digital characteristics, and through the repeated calculation of the analytical model is able to obtain the evolution of the level of engagement to make it (exclusively) available to the teacher. This information facilitates the deployment of adaptive teaching methodologies in synchronous virtual environments, reducing the difficulties presented by this type of environment compared to traditional face-to-face teaching models. The ten most relevant properties and dimensions of engagement are presented below.

Table 1
Characteristics of engagement

Digital Category (CD)	(Engagement dimension) Description
Assistance	(Behavioural / Emotional) Characteristics associated with the number of participants in the session and their variations.
Camera use	(Behavioural / Emotional) Camera status events and their variations.
Voice interactions	(Behavioural) Details (duration, number) concerning voice interventions, as well as the level of silence.
Hand raised	(Behavioural)
Screen sharing	Use of the survey options of the handheld and screen sharing respectively.
Chat interactions	(Behavioural / Emotional) Use of chat, such as the number of messages, number of questions and use of emoticons.
	(Behavioural)
Sound analysis	Sound quality, noise, volume and discontinuity.
Facial emotion	(Emotional) Identification of participants' emotions.
Lip movement	(Behavioural/Emotional) Detections of yawning or interactions with people outside of the training session. videoconferencing.
Eye-tracking	(Emotional) Characteristics that emerge from the participants' direction of vision.

These categories are fed into a formula called ENQUA(t) that calculates the engagement. The way each factor is obtained can be illustrated in figure 2.

Figure 2

Diagram of the architecture of the software system deployed on the teacher's computer (on the right, in blue). The software connects to a videoconferencing session (Zoom or Teams) and extracts the available information in real time (see table 1)



From this systematised collection of digital data, the analytical model is run repeatedly, making the calculated engagement level values available exclusively to the teacher on a dashboard. Note that, at the architectural level, this approach could be seen as a particular case in which principles of both edge computing (calculation of the engagement level on the border device) and cloud computing (extraction of the parameters associated with the Digital Categories from the cloud of the videoconferencing service provider) are combined. Although this tool was specifically designed to monitor student engagement in synchronous virtual environments, it could also be used to monitor teacher engagement, not only in synchronous virtual environments but also in face-to-face sessions (as intended in this paper). Thus, the teacher would have to (1) create a videoconference session in which he/she would be alone, (2) configure the software to connect to that session, and (3) adjust the parameters of the ENQUA(t) analytical model so that the data displayed on the dashboard would be adjusted to the new reality being monitored (teacher engagement instead of student engagement). In essence, some characteristics from Table 1 were removed to stick with Sound analysis, Facial emotion, Lip movement, Eye-Tracking and Voice interactions.

4. Experiments to measure engagement and comfort

Two sessions with two teachers have been carried out with the following characteristics:

- *Experiment 1.* This experiment is focused on observing whether there are relevant influences on the teacher's level of engagement associated with different body and eye behaviours. For this purpose, the teacher deliberately alternates various body postures, inside and outside the camera capture frame, as well as the fixation or withdrawal of the gaze directed at the materials being explained. This experiment aims to evaluate whether the software is able to measure the level of engagement when the teacher moves naturally or, on the contrary, the teacher must be looking at the laptop camera at all times.
- *Experiment 2.* This experiment is focused on observing the software's ability to measure the teacher's level of engagement. To this end, the teacher delivers the same session twice and deliberately changes his or her style, mood and emotional state (happy or joyful) from one session to the next in an attempt to present different levels of engagement. This experiment aims to evaluate the feasibility of using the software to measure the teacher's engagement, with the aim of providing a further tool to support teaching.

Both experiments were conducted using a laptop computer, connected to a Zoom session, which was monitored by the system [5] in real time. The results of the teacher's engagement level were accessible via the web interface from another computer so as not to influence the teacher's behaviour.

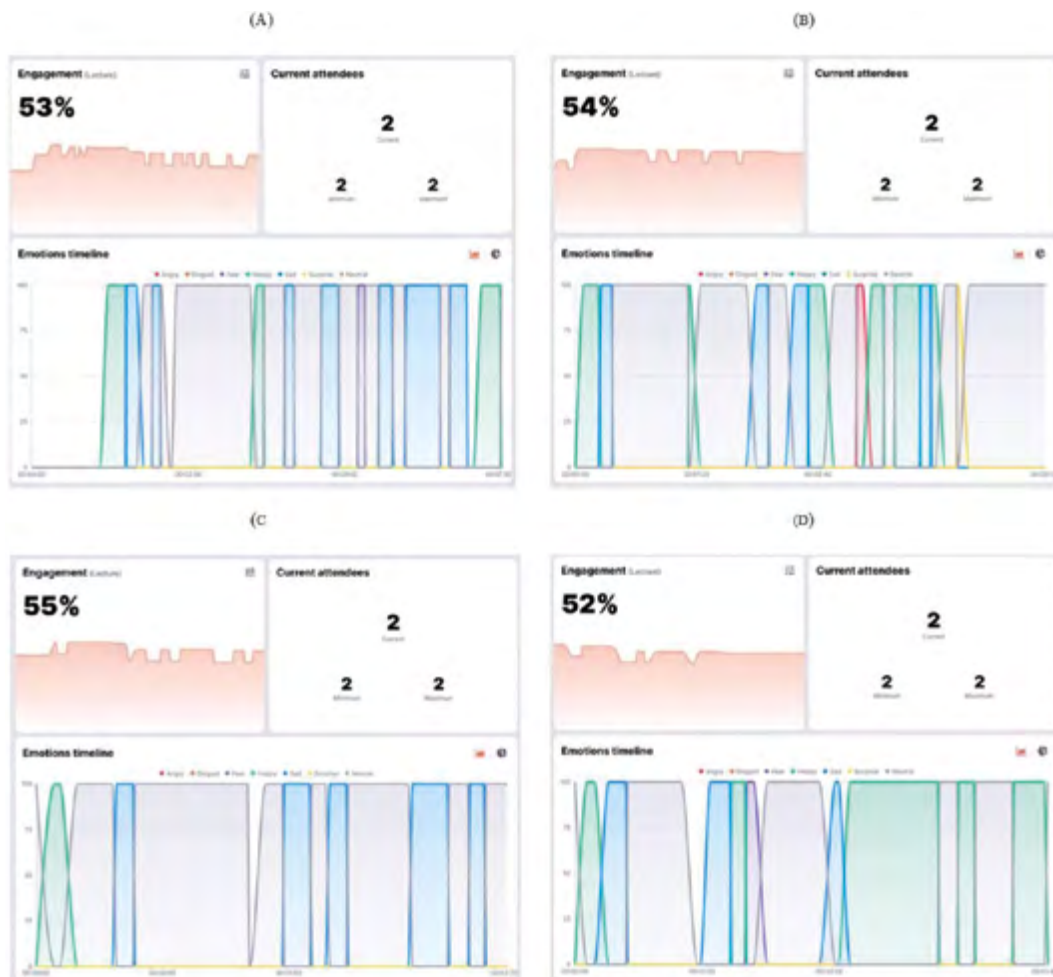
5. Results

For the 1st experiment, two professors from the University of Deusto in Bilbao, Spain, were chosen along with a third professor who facilitated the session. Both instructors were tasked with presenting a five-minute lecture on a well-known topic using identical slides to control for content differences. They delivered the lectures under two scenarios: one under ideal conditions where they sat facing the camera with consistent eye contact, and another under less controlled conditions where they stood, occasionally moved out of the camera's main focus, and did not maintain continuous eye contact. This was intended to mimic a more dynamic teaching environment. The objective was to maintain uniformity in the delivery across repetitions to ensure that any differences in engagement levels were attributable solely to their body language and eye dynamics. Figure 3 illustrates the engagement levels of each teacher during these conditions. Teacher 1 exhibited a neutral delivery style, while Teacher 2 displayed a more dynamic approach, generally eliciting positive emotions. However, despite these stylistic differences and scenarios, the observed variations did not significantly influence the measured engagement levels, suggesting the teacher engagement measurement software remained effective under varying conditions. This experiment underscores the system's versatility and reliability in different instructional contexts.

Figure 3

Evolution of the engagement level in experiment 1.

- (a) teacher 1 under ideal conditions,
- (b) teacher 2 under ideal conditions,
- (c) teacher 1 under non-ideal conditions,
- (d) teacher 2 under non-ideal conditions

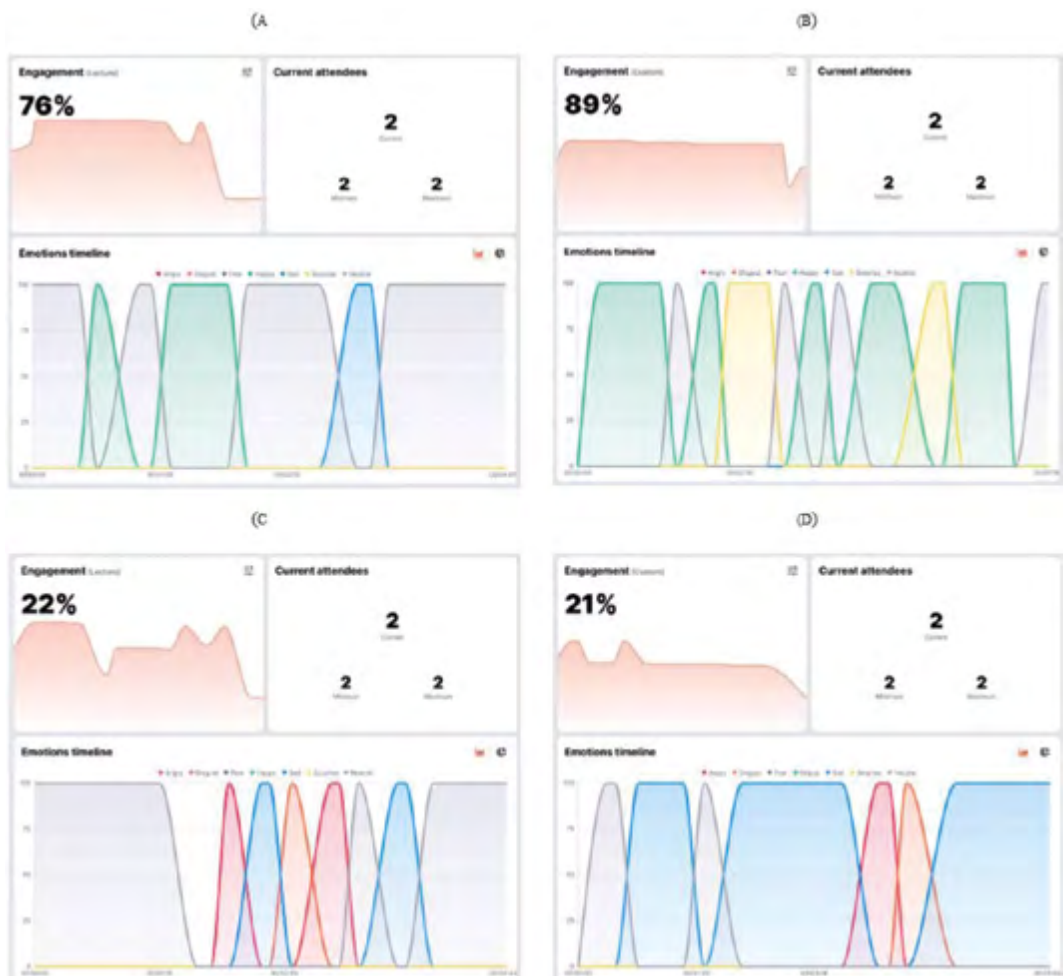


For the 2nd experiment, the same teachers were selected to deliver a five-minute lecture on a topic they were both well-versed in, under two distinct conditions: (1) Ideal conditions, where the teachers were enthusiastic, engaging through gestures, movement, and rhetorical questions to make the session lively, and (2) Non-ideal conditions, in which the teachers merely stared at the screen and read the content monotonously, simulating the effects of teacher fatigue or burnout. The aim was to keep the content delivery consistent across both scenarios to ensure any observed

differences in engagement were solely due to the delivery style. Figure 4 illustrates the engagement levels for each teacher under these conditions. Teacher 3 managed to maintain high engagement despite occasional sadness, which temporarily reduced engagement. Teacher 4, under ideal conditions, displayed high engagement facilitated by positive emotions but experienced a slight dip in engagement when out of camera focus. Under non-ideal conditions, the presence of negative emotions correlated with lower engagement levels. These results confirm the system’s ability to detect variations in teaching style and engagement. This experiment supports the system’s potential as a tool for teachers to self-assess and adjust their engagement levels during sessions.

Figure 4

Teacher 3 under ideal conditions,
 (b) teacher 4 under ideal conditions,
 (c) teacher 3 under non-ideal conditions,
 (d) teacher 4 under non-ideal conditions



6. Conclusions

This paper demonstrates the significant potential of integrating Internet of Things (IoT) and digital twin technologies in educational environments to enhance both teacher and student engagement and comfort in classrooms. The innovative IoT device discussed facilitates interactions with virtual replicas of physical objects, offering immersive, real-time learning experiences. By monitoring environmental conditions and student engagement, and providing a web platform for educator feedback, this tool goes beyond traditional educational approaches. The implementation of this technology in a university setting revealed its capability to significantly improve teaching strategies and increase student engagement, although it also highlighted the challenges of integrating such advanced technologies in current educational frameworks. The experiments conducted illustrated that the system could effectively measure and sustain teacher engagement under varying conditions, indicating its robustness and adaptability. Moreover, the study underscores the importance of continued research and development to fully harness the capabilities of IoT and digital twins in education. Such technological advancements can lead to more dynamic, effective, and personalized teaching and learning experiences, ultimately shaping the future of education to better meet diverse needs. Therefore, this research contributes valuable insights into the transformative potential of IoT and digital twin technologies in enhancing educational settings by providing a more interactive, informed, and comfortable learning environment for students and educators alike.

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University of Deusto, Bilbao, 30th May 2024
Diego Casado-Mansilla,
Xavier Solé, Oihane Gómez-Carmona, Joan Navarro, and Diego López-de-Ipiñá
dcasado@deusto.es
<http://paginaspersonales.deusto.es/dcasado>
<http://www.morelab.deusto.es>



[@dieguich](https://twitter.com/dieguich)



Overview

- IoT as a transformative force in education.
- Introduction of an innovative IoT device enhanced by digital twin technology.

Aim: Improve teaching efficacy through immersive real-time learning simulations.

Objectives of this talk

- Enhance teaching performance.
- Enable interactions with virtual replicas of physical objects.
- Monitor classroom environmental conditions.
- Assess student engagement.
- Provide a web platform for educators to evaluate their teaching performance

IoT and Digital Twin Technology

- IoT: Network of interconnected devices.
- Digital Twin: Virtual replicas of physical objects for simulation and interaction.
- Benefits: Real-time data, immersive learning, enhanced engagement.



Background

- **Engagement and Comfort - Direct impact on learning quality and student performance.**
 - **Engagement:** Behavioral, cognitive, and emotional dimensions.
 - **Comfort:** Thermal conditions, humidity, lighting, acoustics, air quality.



Technological Framework

- IoT Device



Engagement Measurement (I)



Engagement Measurement (II)

- Use of camera, microphone, and keyboard.
- Analytical model: **ENQUA(t)**.
- Dimensions: Assistance, camera use, voice interactions, hand raised, screen sharing, chat interactions, sound analysis, facial emotion, lip movement, eye-tracking.



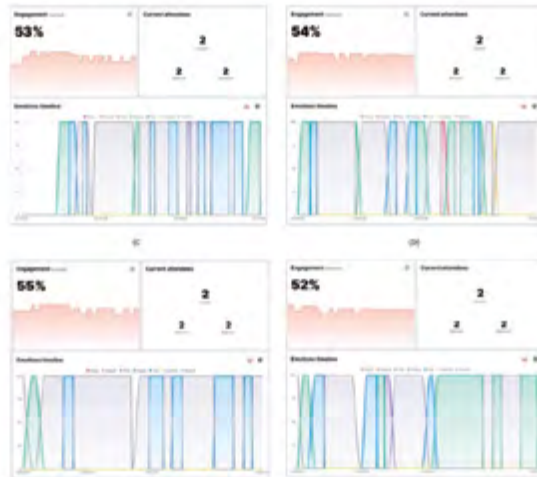
Experiment I

- Objective:
 - Evaluate software's ability to measure engagement with different body and eye behaviors.
- Method:
 - Two teachers, controlled and dynamic conditions.
- Results:
 - Software effectively measured engagement levels.

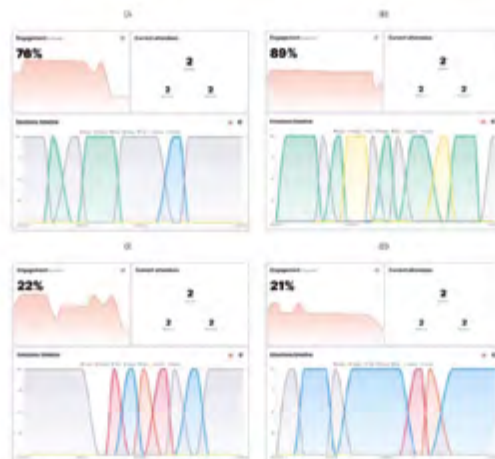
Experiment II

- Objective:
 - Observe software's ability to measure engagement under different emotional states.
- Method:
 - Same lecture delivered twice with varied engagement levels (enthusiastic vs. monotonous).
- Results:
 - System detected variations in teaching style and engagement.

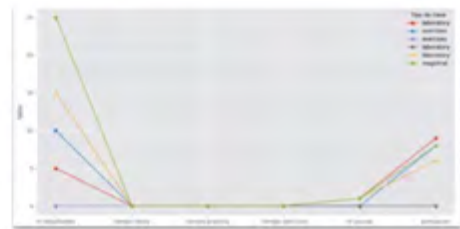
Results (Experiment I)



Results (Experiment II)



Teachers' reflection over data



Conclusions

- IoT and digital twin technologies hold great potential for enhancing educational environments.
- Need for continued research and development.
- Future of education: More interactive, effective, and personalized learning experiences.

Future Work

- Addressing integration challenges.
- Enhancing system features based on feedback.
- Expanding studies to diverse educational settings

