Unlocking the Potential of IoT for Interactive and Collaborative Learning: Case Studies in Higher Education

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Abstract. This paper presents two case studies that explore the integration of environmental awareness and IoT technology in interactive and collaborative learning environments. In the first case study, a comprehensive assessment was conducted to measure the digital data competence of university students in relation to their understanding of standards and regulations for healthy and energy efficient learning spaces. The assessment encompassed their knowledge of relevant variables for classroom health, such as temperature, humidity, CO_2 levels, and lighting, as well as their familiarity with recommended energy-saving thresholds. The results highlighted gaps in digital data competence among the participants, indicating a need for targeted interventions to enhance their understanding and awareness of these standards. The results of the second case study demonstrated the effectiveness of the serious game in promoting student engagement and facilitating their understanding of the importance of adhering to recommended thresholds. By integrating digital data competence, and IoT technology, universities can empower students to become active participants in creating healthy and energy-efficient classrooms. Furthermore, by utilizing data from IoT systems, students can enhance their skills in data management, machine learning, artificial intelligence, and other data processing techniques. This integration provides them with valuable hands-on experience in working with real-world data, analyzing patterns, and making data-driven decisions.

Keywords: Environmental awareness, Digital data competence, Higher education, Internet of Things, Learning analytics, Serious games, Smart Learning Environments.

1 Introduction

The Internet of Things (IoT) has emerged as a transformative technology with the potential to revolutionize various industries, including education. By connecting everyday objects to the internet, IoT enables the collection and analysis of vast amounts of data, thereby also providing valuable insights that can be used to enhance learning and teaching. In particular, IoT has the potential to foster environmental awareness in higher education, by enabling real-time monitoring and analysis of energy and resource consumption.

Environmental awareness has become a critical issue in higher education, with universities and colleges under increasing pressure to reduce their carbon footprint and promote sustainable practices. The impact of climate change is being felt across the globe, with rising temperatures, sea-levels, and extreme weather events posing significant challenges to human societies and ecosystems. Higher education institutions have a key role to play in addressing these challenges, by promoting environmental sustainability and educating the next generation of leaders and professionals.

IoT can provide valuable insights into energy usage, waste generation, and water consumption, enabling institutions to identify areas for improvement and implement more sustainable practices [1]. By installing sensors and devices throughout campus buildings and infrastructure, institutions can monitor energy and resource consumption in real-time, allowing them to identify trends and patterns, and implement targeted interventions. For example, institutions can identify areas of high energy consumption, such as computer labs or research facilities, and implement energy-efficient technologies or behavioral interventions to reduce energy usage [1].

Furthermore, IoT can facilitate experiential learning opportunities for students, by providing them with hands-on experience in monitoring and managing environmental resources. By incorporating IoT technologies into their curriculum, institutions can offer students a unique learning experience, where they can apply theoretical concepts to real-world scenarios. For example, students can learn about the principles of sustainable design and energy efficiency, and then use IoT technologies to design and implement their own sustainable solutions on campus.

2 Related work

The use of IoT technologies to support environmental awareness in education is a growing area of research. Numerous studies have explored the potential of IoT to promote energy efficiency, reduce carbon emissions, and support sustainable practices in educational settings. One area of focus has been the use of IoT to monitor and manage energy usage in buildings. Researchers have explored various approaches to monitoring energy usage, including the use of sensors, smart meters, and energy management systems [1, 2]. By providing real-time feedback on energy usage, these technologies can help users identify areas for improvement and implement targeted interventions to reduce energy consumption. Some studies have also explored the use of gamification to motivate behavior change and promote energy efficiency in educational settings [3, 4].

IoT has also been used to support healthy and smart learning environments [5]. Researchers have explored the use of sensors to monitor indoor air quality, noise, temperature, and humidity, enabling the creation of healthy and comfortable learning spaces [6–9]. Some studies have also explored the use of avatars or virtual assistants to provide personalized feedback on ambient conditions and suggest actions towards healthy and sustainable learning environments [10, 11].

Finally, the use of learning analytics in combination with IoT technologies is another promising area of research. Learning analytics can provide insights into student engagement, behavior, and performance, enabling institutions to identify areas for improvement and implement targeted interventions. IoT can complement learning analytics by providing additional data on environmental conditions, resource usage, and other factors that may impact learning outcomes.

This work is framed within a wider project[1] investigating learning paths to promote environmental awareness using IoT technology in learning spaces. Our approach builds on previous work piloting the tools implemented [12–14], while also incorporates elements of gamification and learning analytics to enhance student engagement and motivation [15, 16].

3 Methods

The importance of healthy workspaces has acquired special relevance in recent years due to the COVID pandemic and the increasing pressures for climate neutrality, where it has become necessary to balance variables such as CO_2 and temperature. Hence, health-related organizations and governments[2] have drawn up recommendations on the ideal CO_2 levels (CO_2<1000 ppm) and on how workspaces should be ventilated to minimize contagion (cross ventilation). In addition, the studies presented in this work were performed during winter (2022-2023) when energy costs rose drastically due to the impact of the war in Ukraine and other factors. In this context, some governments decreed measures to moderate energy consumption by establishing temperature limits for the use of heating (maximum 27ºC) and air conditioning (minimum 19ºC) in public settings[3]. Here students were tasked with monitoring these variables, and to identify suitable actions that might moderate within the recommended ranges.

4 Case study 1: Probing environmental awareness.

The first case study aimed to probe students' environmental awareness using the following indicators: 1) their knowledge about the international system units for the ambient variables affecting the classroom; 2) their knowledge on current recommendations for CO_2 and ventilation indoors in a post pandemic context; 3) their knowledge on current temperature regulations with regard to the responsible use of heating and air conditioning systems to save energy as a consequence of the war in

[1] TEASPILS Erasmus+ Project: https://www.teaspils.eu/

[2] Recommendations on the use of air conditioning and ventilation systems to prevent the spread of airborne transmission virus. https://short.upm.es/mya03

[3] Air conditioning energy saving and management plan to reduce consumption in the context of the war in Ukraine. https://short.upm.es/meifb

Ukraine. This case study involved 23 voluntary participants (Age: M(SD)=21.19(0.85); Gender: Male=20, female=3) who were enrolled in a higher education program of Computer Sciences. At the start of the session, students were informed that an IoT system installed on a planter [14] was collecting indoor ambient conditions so they could later on reflect on the values obtained. At the end of the session, participants were invited to complete a survey questionnaire to gather information about their knowledge and understanding on the topics.

4.1 Results

Indicator 1. International system units. Students (n=23) were prompted to answer in what unit CO_2, humidity, brightness, temperature, and noise are measured. They respectively answered correctly: parts-per-million (65.2%), percentage (73.9%), lux (83.6%), Celsius (100%), and decibels (100%). These results show that even after the pandemic, students are not familiar with the units used to alert when indoor places need to be ventilated. Students were more familiar with the rest of the units.

Indicator 2. Recommendations for indoor ventilation. Students were prompted to answer in which CO_2 levels should classrooms be ventilated following regional recommendations in a post pandemic context. The reported values in figure 1 show that their estimations ranged from 23 ppm (1^{st} quartile) to 115 ppm (3^{rd} quartile) with M(SD)= 239.6(451.3) ppm, maximum=2,000 ppm, and minimum 6 ppm. These results show that students were not familiar with the recommended threshold for ventilation.

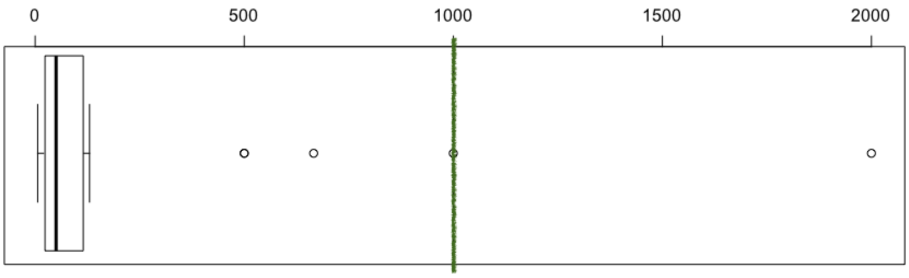

Fig. 1. X-axis CO_2 saturation in parts per million (ppm); Green line: Recommended threshold for indoor ventilation (>1000 ppm); Boxplot: Students' reports on recommended threshold.

In addition, students were prompted to estimate whether CO_2 measurements collected during the session would be committed with this recommendation in a 5-point-Likert scale. Students believed that the CO_2 samples collected during the session were likely M(SD)= 3.65(1.0) committed with the ventilation recommendation (n(%); 5.Extremely Likely: 4(17.4); 4.Likely: 11(47.8); 3.Neutral: 5(21.7); 2.Unlikely: 2(8.7); 1.Extremely Unlikely: 1(4.3)). However, the line chart in figure 2 shows that CO_2 values started exceeding 1,000 ppm after 15 minutes of starting the lecture, and reached 2,000 ppm after two hours.

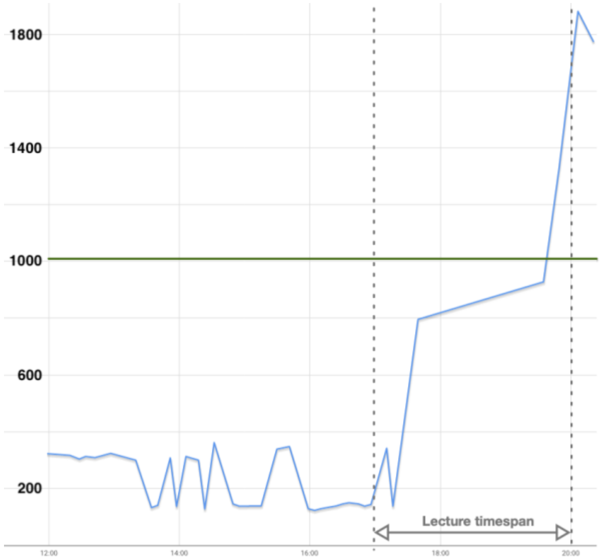

Fig. 2. X-axis timespan (12h-20h); Y-axis CO_2 saturation in parts per million (ppm); Green line: Recommended threshold for ventilation (>1000 ppm); Line chart illustrates real CO_2 samples collected during the lecture using the Spike.

Indicator 3. Regulations for energy saving and responsible use of heating and air-conditioning systems in public buildings. Students were prompted to answer in which temperature levels should AC and heating systems be adjusted considering the national regulations in an energy crisis context. The reported values show that their estimations with regard to the minimum temperature to adjust AC systems ranged from 18 ºC (1st quartile) to 24 ºC (3rd quartile) with M(SD)= 20.4(5.9) ºC, maximum=28 ºC, and minimum=0 ºC (See bottom boxplot in figure 3). When estimating the maximum temperature to adjust heating systems, students ranged from 21 ºC (1st quartile) to 26 ºC (3rd quartile) with M(SD)= 23.9(4.6) ºC, maximum=38 ºC, and minimum=18 ºC (See top boxplot in figure 3). Both means indicate that students' estimations were far from the real regulations (20.4ºC > 19ºC; 23.9ºC < 27ºC).

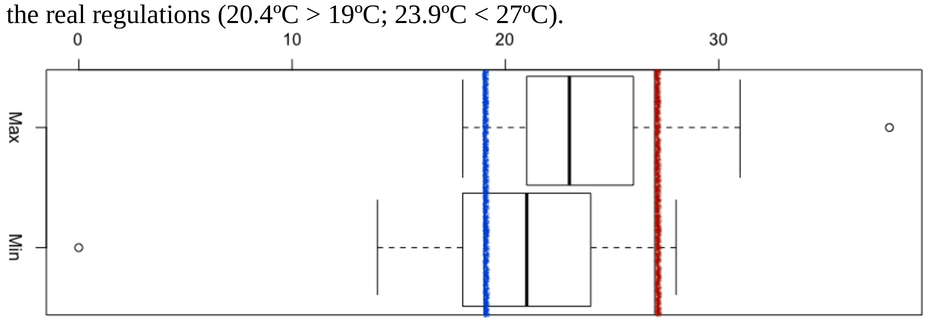

Fig. 3. X-axis Temperature in ºC (Celsius degrees); Blue line: Regulation for lower adjustment of air conditioning in summertime (19ºC); Red line: Regulation for upper adjustment of heating system in wintertime (27ºC).; Boxplot: Students' reports on temperature regulations (max, min).

In addition, students were prompted to estimate whether temperature measurements collected during the session would be committed with this recommendation in a 5-point-Likert scale. Students believed that the temperature samples collected during the session were extremely likely M(SD)= 3.78(1.0) committed with the ventilation recommendation (n(%); 5.Extremely Likely: 5(21.7); 4.Likely: 11(47.8); 3.Neutral: 5(21.7); 2.Unlikely: 1(4.3); 1.Extremely Unlikely: 1(4.3)). The line chart in figure 4 shows that students were right as temperature values went slightly beyond the upper threshold 26ºC when the lecture started and kept stable during the lecture in 27ºC.

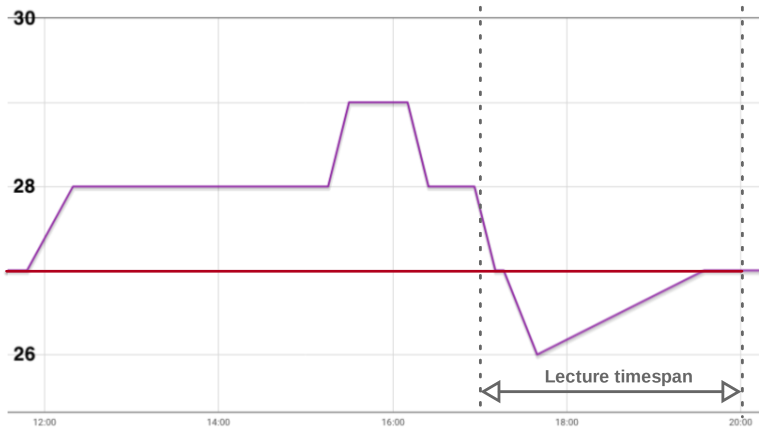

Fig. 4. X-axis timespan (12h-20h); Y-axis Temperature in ºC; Red line: Recommended threshold for heating adjustment in wintertime (27ºC); Line chart illustrates real temperature samples collected during the lecture using the Spike.

The data collected were analyzed to identify knowledge gaps and misconceptions among the participants, and to gain insights into their perceptions of the ideal learning metrics considering the existing recommendations and regulations. This information was used to inform the design of an IoT-based system for monitoring ambient conditions in learning spaces, which is the focus of the second case study.

5 Case study 2. A mobile serious game to monitor indoor spaces.

The second case study involved a group of 15 master's students specializing in web engineering, enrolled in a mobile application development course. The objective was to challenge these students to create a serious game leveraging data from an IoT system that captured environmental variables. The IoT system consisted of sensors that collected data on various parameters, stored the data in a cloud-based database, and presented in real time on the dashboard (See figure 5). The students were tasked with utilizing this data to provide actionable recommendations if the ventilation guidelines (based on the COVID times) or energy-saving recommendations were not being met.

The integration of IoT technology and mobile application development provided an innovative platform for students to apply their skills and knowledge in a real-world context. By utilizing the data collected from the IoT sensors (see Spike in figure 5), the students were able to visualize data in real time (see data panel in figure 5) and create a game that would not only entertain but also educate users on the importance of adhering to recommended ventilation and energy-saving practices.

The students were given access to the cloud-based database through the RESTful web service, enabling them to retrieve and analyze real-time environmental data. They focused on developing an interactive mobile application that would alert users when ventilation guidelines were not met, such as insufficient airflow or overcrowding in enclosed spaces. Additionally, the application would provide recommendations for appropriate actions to ensure a safe and healthy environment. Furthermore, the students were tasked with identifying instances of inappropriate heating usage that deviated from energy-saving recommendations. By analyzing temperature data and patterns obtained from the IoT system, the application would prompt users to adjust heating settings or adopt energy-efficient practices.

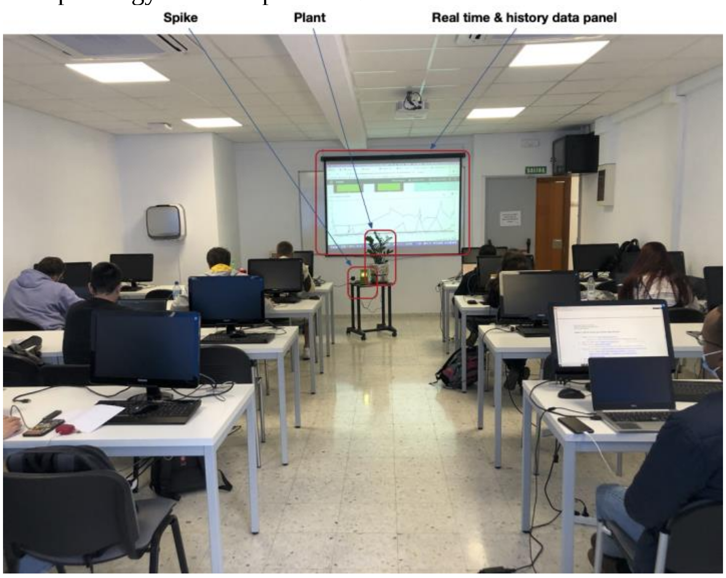

Fig. 5. Classroom setup. Plant, spike (IoT system), and data visualization dashboard

The activity suggested implementing an avatar that would analyze the data collected by the IoT system installed in the plant's planter and provide feedback based on compliance with recommended values. The students embraced this idea and developed various serious games, among which the following standout:

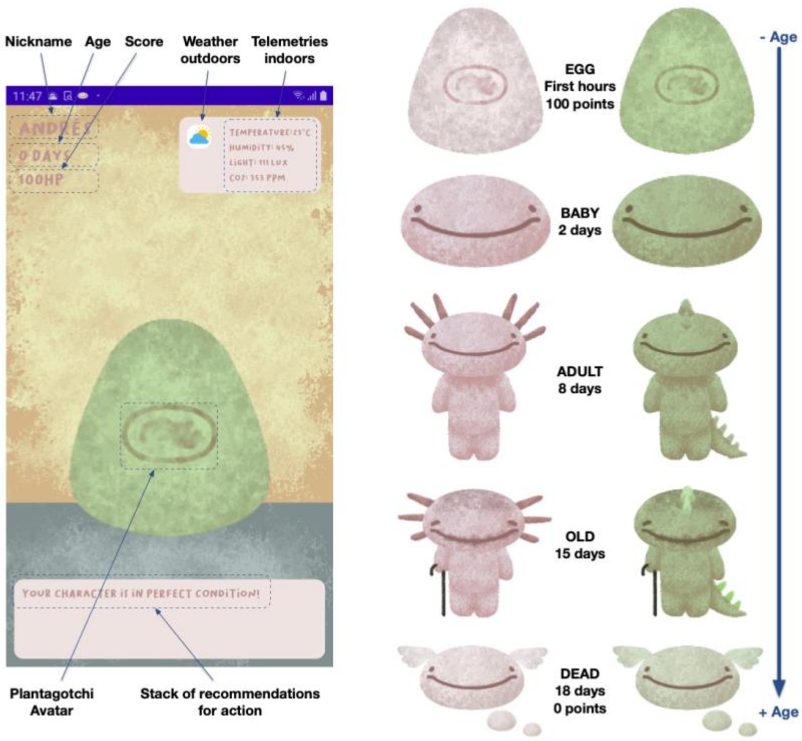

Fig. 6. Plantagotchi's dashboard and lifecycle

- <u>Plantagotchi lizard</u> (See figure 6). One student created an avatar based on a lizard. Its lifespan lasts 18 days, equivalent to 100 points, which are constantly deducted from the first day the avatar is born until its final day when the avatar "passes away". The points are decremented more rapidly when the thresholds are exceeded, indicating a failure to meet the recommended ventilation, temperature (maximum in winter; minimum in summer), and the guidelines listed in Table 1. The avatar provides actionable recommendations when the thresholds are surpassed, enabling the student to moderate these variables and achieve appropriate measurements. The objective of this serious game is to keep the avatar alive for the entire 18 days, and the player who successfully accomplishes this goal emerges as the winner. This implementation demonstrates a creative and engaging approach to fostering student participation and learning. The avatar, Plantagotchi, serves as a virtual representation of the plant's well-being, acting as a visual indicator of the impact of environmental conditions on its health. By associating the avatar's lifespan and point system with the adherence to recommended thresholds, students are motivated to make informed decisions and take appropriate actions to maintain the plant's vitality. Plantagotchi lifelike attributes and interactive nature enable students to form an emotional connection with the avatar. This emotional engagement enhances the learning experience by fostering a sense of responsibility and accountability for maintaining optimal classroom conditions. As the avatar's points decrease more rapidly when thresholds are exceeded, students are incentivized to actively monitor and control the environmental variables within the specified ranges.

Table 1. Draining rules and notifications for action towards environmental awareness.

Variable	Thresholds	Draining rule	Alert	Recommendation
Temperature	< 19ºC	-1 points/min	Ambient temperature is too low	Please turn the AC off
Temperature	> 27ºC	-1 points/min	Ambient temperature is too high	Please open the window, or turn the heater off
Humidity	< 30%	-0.1 points/min	Ambient humidity is too low	Please use a humidifier
Humidity	> 50%	-0.1 points/min	Ambient humidity is too high	
Light	> 1100 lux	-0.5	The light is too bright	Dim the lights or find a darker spot to stay
CO_2	> 1000ppm	-1.2	The density of CO_2 in the air is too high	Please open the window to ventilate the space

- <u>Save the canary</u>. One student took a unique approach and created the "Save the Canary" application, which aimed to raise awareness about the importance of monitoring CO_2 levels in the classroom. Drawing from the historical role of canaries as indicators of oxygen deficiency, the application utilized the canary avatar as a visual representation of the environmental conditions. The avatar, modeled after a canary, played a crucial role in delivering feedback and recommendations to the users. Through a combination of text-based prompts and emoticons reflecting the canary's emotions, the application aimed to evoke a sense of urgency and action in response to elevated CO_2 levels. As CO_2 levels increased, the canary avatar would display signs of discomfort, such as a frowning emoticon or distressed text-based messages. This visual representation aimed to create a connection between the user and the avatar, encouraging a proactive response to address the issue. The application's recommendations were tailored to guide users in taking appropriate measures to mitigate the high CO_2 levels. These recommendations included opening windows for ventilation, adjusting air conditioning or heating settings, or taking short breaks outside the classroom to refresh the air. The "Save the Canary" application effectively combined IoT data, historical symbolism, and gamification to promote sustainable practices and raise awareness about the significance of monitoring CO_2 levels. By leveraging the avatar's emotional cues and text-based recommendations, users were empowered to take timely actions to ensure a healthy and comfortable learning environment.
- <u>Personal trainer.</u> The "Personal Trainer" application offered a unique approach to assist individuals in making informed decisions regarding their exercise routines. By analyzing the telemetry data acquired from the Spike IoT system within the indoor environment and comparing it with the data obtained from the nearby weather station, the application determined the most favorable location for physical activities. The application incorporated various environmental parameters such as temperature, humidity, and air quality, along with other relevant factors, to evaluate the suitability of indoor and outdoor exercise settings. By considering the disparity between the indoor and outdoor conditions, the "Personal Trainer"

application provided tailored recommendations to users, suggesting whether it would be more beneficial to exercise inside or venture outdoors. When the telemetry data from the Spike indicated favorable conditions within the indoor environment, such as optimal temperature, air quality, and reduced humidity, the application would suggest engaging in physical activities indoors. On the other hand, if the external weather data from the weather station indicated pleasant weather conditions, the application would recommend outdoor exercises. By leveraging the IoT data from Spike and the external weather station, the "Personal Trainer" application offered users personalized guidance, ensuring that their exercise routines aligned with the prevailing environmental conditions.

6 Discussion and conclusions

Based on the results obtained from the two presented case studies, several important conclusions can be drawn regarding students' environmental awareness and the potential of IoT technology to promote it. In the first case study, a lack of environmental awareness among students was revealed. The findings showed that a significant percentage of participants were unfamiliar with basic concepts related to air quality, such as the international metric unit used to measure CO_2 saturation. Furthermore, students demonstrated a lack of knowledge regarding recommended thresholds for proper ventilation, despite global attention focused on the importance of ventilation during the pandemic. It was also observed that they lacked awareness of current regulations related to the efficient use of heating and air conditioning systems for energy conservation. These findings highlight the need for additional efforts to foster environmental awareness among higher education students.

In the second case study, the potential of IoT technology and the use of telemetry to address this lack of environmental awareness was demonstrated. Master's students were able to utilize the data collected by the sensor system to interpret and understand regulations related to ventilation and energy conservation. Serious games based on avatars were designed providing actionable recommendations to meet ventilation standards and established regulations. These serious games not only promoted practical learning and knowledge application but might also increase student motivation and engagement towards environmental practices. Overall, these results highlight the importance of integrating IoT technology into higher education to promote environmental awareness and foster sustainable practices. IoT technology offers opportunities for real-time data collection, personalized feedback, and the creation of more meaningful learning experiences. By combining the power of technology with innovative pedagogical approaches like serious games, significant advancements in environmental education can be achieved.

This work shows that IoT technology and serious games based on avatars can play a key role to study artificial intelligence (AI) and machine learning (ML) in higher education. Its importance lies in its ability to provide real-world data and create interconnected systems that facilitate hands-on learning experiences. By integrating IoT devices and sensors into educational settings, students can gather and analyze vast amounts of data, enabling them to explore AI and ML concepts in practical ways. IoT technology allows students to develop a deeper understanding of AI algorithms, data processing, and decision-making processes based on predictive models [17].

In conclusion, the results of the case studies focus attention on the need to strengthen environmental awareness among higher education students. IoT technology, along with innovative pedagogical approaches, has the potential to play a key role in this regard. By implementing IoT-based strategies such as real-time monitoring, gamification, and personalized feedback, we can foster greater environmental awareness and encourage sustainable practices among students.

However, it is important to recognize that challenges exist in implementing IoT technology in the educational context, such as privacy and security concerns, as well as the costs associated with infrastructure and ongoing maintenance. These challenges need to be adequately addressed to ensure the long-term success of IoT-based initiatives.

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