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Utilizing IoT Systems to Improve Students Digital Competency and Awareness of Environmental Issues*

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This research delves into the potential of Internet of Things (IoT) systems to cultivate environmental consciousness among university students across diverse engineering disciplines. The study unfolds in two distinct phases. In the initial phase, we assess students' (between 30–40 depending on the session) environmental awareness across four dimensions outlined in the existing literature: awareness of environmental issues, awareness of individual responsibility, general attitudes toward environmental solutions, and general attitudes toward environmental issues. Our observations reveal a moderate overall level of environmental consciousness among students, with some variability in responses based on the dimension assessed. Subsequently, in the second phase, with 18 students, the study employs a Likert scale pretest and posttest, comprising five levels, to gauge the impact of the IoT system on three dimensions: enhancement of students' digital competences, improvement of IoT skills, and cultivation of environmental awareness. Overall, our findings suggest that the IoT system utilized in the experiment positively influences the enhancement of students' digital competences and IoT skills. However, the perceived effectiveness in cultivating environmental awareness exhibits a more modest increase with less uniformity in the responses. These results underscore the nuanced influence of IoT systems on different facets of student learning and highlight the importance of considering multidimensional outcomes when integrating such technologies into educational settings. The study contributes valuable insights for educators seeking to leverage IoT applications to not only advance technical skills but also foster a holistic understanding of environmental issues among future engineering professionals.

Keywords: IoT; Environmental awareness; digital competences; IoT skills; educational technology

1. Introduction

Environmental awareness holds paramount significance in contemporary society, as it underscores the imperative to safeguard our environment and advocate for sustainable practices to conserve natural resources. Within the realms of computer engineering and agronomy, the significance of environmental awareness is heightened, given its profound impact on the environment [1].

The growing apprehension regarding environmental challenges, such as climate change, biodiversity loss, and pollution, has instigated a collective call to action across various sectors, including education [2–4]. Therefore, it is crucial to comprehend how to foster environmental awareness and sustainable practices within disciplines such as computer engineering and agronomy. Within this context, there is a pressing need to conduct research and evaluate the environmental awareness of students, while also identifying effective strategies to enhance it.

On the other hand, the progress of information technologies and the Internet of Things (IoT) presents novel opportunities to tackle environmental challenges and advocate for sustainability [5]. Leveraging sensors, data collection, and intelligent analysis can optimize resource utilization, decrease waste, and mitigate environmental impact [6]. Consequently, exploring students' competencies in IoT becomes essential in gauging their capacity to devise innovative and sustainable solutions that contribute to environmental conservation. Considering the swift evolution of this technology in society, there is an imperative to equip the new generations with digital competences and IoT-related skills [7], thereby furnishing them with a competitive edge.

Certain researchers have already implemented this methodology within the realm of higher education [8], tackling environmental concerns and IoT-related solutions through an interdisciplinary and collaborative framework. Examining environmental awareness and IoT-related competencies among students in computer engineering and agronomy fosters collaboration between these disciplines, culminating in more cohesive and efficacious solutions.

While there have been research endeavors concentrating on assessing students' environmental awareness, these studies predominantly seek to quantify students' environmental consciousness and juxtapose outcomes based on factors such as gender [9] or geographical location [10]. Conversely, it becomes imperative to gauge environmental awareness not at a singular time point but at

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various intervals to determine if a learning activity facilitates an augmentation in students' environmental consciousness. Considering this, coupled with the utilization of the previously mentioned technology, would advance effective classroom practices that not only cultivate environmental awareness but also endow students with essential digital competences and IoT skills.

This scientific article endeavors to scrutinize the environmental awareness of computer engineering students while introducing an IoT system to evaluate the perception of agronomy engineering students concerning their capacity to foster environmental awareness, IoT-related skills (IoT skills), and digital competences in the educational milieu. A mixed-method approach, integrating both quantitative and qualitative methods, will be employed to gather data through surveys and analyze qualitative data in conjunction with the system.

Precisely, this study centers on two primary objectives: firstly, comprehending the extent of environmental awareness among students; and secondly, investigating the potential of technology as a tool to propel environmental awareness and foster the cultivation of essential skills within the realms of digital competences and IoT-related skills. The paper had multiple objectives:

- Guide students in using the Telegram and Thingsboard APIs with the ESP32 for communication purposes.
- Demonstrate the educational potential of IoT systems in conveying concepts related to environmental awareness, showcased through the monitoring of various variables concerning plant life and its environment.
- Assess the perceived effectiveness of IoT systems in enhancing students' digital competences, IoT skills, and environmental awareness
- Encourage critical thinking by prompting students to analyse the agreements and discrepancies among guidelines for ventilation in scenarios such as COVID or flu, current regulations regarding cooling indoor spaces in Spain, considerations for individuals' well-being and efficiency, and the influence of plants in educational settings.

By gaining a more profound understanding of this correlation, more efficacious strategies can be formulated to advocate for sustainability in these disciplines and equip future professionals to address contemporary and impending environmental challenges.

2. Methods

2.1 Introduction

To fulfill the objectives outlined in the preceding section, the experiment was bifurcated into two segments. The initial part sought to gauge the environmental awareness of students enrolled in a computer engineering-related degree program. Following the measurement of environmental awareness among higher education students, which indicated a commendable but not outstanding level, the subsequent phase of the experiment was executed to investigate the potential of IoT systems in augmenting this metric. The second part of the experiment sought to assess the perceived effectiveness of an IoT system in imparting IoT skills, enhancing environmental awareness, and cultivating digital competences within the educational setting of an agronomy engineering-related degree program.

The following hypotheses have been proposed:

Hypothesis 1 (H1). Higher education students will perceive the effectiveness of an IoT system in promoting environmental awareness.

Hypothesis 2 (H2). Higher education students will perceive the effectiveness of an IoT system in developing digital competences.

Hypothesis 3 (H3). Higher education students will perceive the effectiveness of an IoT system in developing IoT skills.

2.2 Step 1: Environmental awareness

The initial phase of the experiment transpired at the Escuela Técnica Superior de Ingeniería de Sistemas Informáticos (School of Computer Systems Engineering -ETSISI-, UPM, Madrid) with students from the Computer-Based Systems (SBC) course of the Computer Engineering Degree and the double Degree in Computer Engineering and Technologies for Information Society. In this stage, the students' environmental awareness was evaluated employing a previously validated test [11]. This segment of the experiment comprised three sessions, each lasting approximately one hour, distributed over three weeks. 70 students, representing both morning and afternoon shifts, participated in this phase. However, not all students reached the end of the process.

Within this project-based course, students collaborate in groups of five to implement intricate solutions utilizing IoT systems. The primary goal is to tackle tangible needs associated with the Sustainable Development Goals outlined by the United Nations. Over the duration of the course, students gain expertise in computer science, embedded systems, and IoT, culminating in the creation and execution of a final project conceptualized and developed by the students themselves.

To engineer this IoT system, students utilize ESP32 microcontrollers, an array of sensors encompassing types such as humidity, pressure, temperature, or CO_2, among others). Additionally, they have access to IoT platforms such as Thingsboard and the Telegram Application Programming Interface (API). The Telegram API enables the programming of an interface with the microcontroller through commands and messages.

The sessions aimed to achieve various objectives at the course level:

- Instruct students on communicating with the Telegram and Thingsboard APIs using the ESP32.
- Illustrate how an IoT system can serve as an educational tool to impart concepts related to environmental awareness, demonstrated through the monitoring of variables concerning a plant and its surroundings.
- Promote critical reflection by encouraging students to contemplate the agreements and contradictions between recommendations on ventilation considering conditions like COVID or flu [12], prevailing legislation on cooling enclosed spaces in Spain [13], considerations for the well-being and efficiency of individuals [14], and the impact of plants in educational spaces [15–17].

To achieve these objectives, each of the three sessions featured a distinct setup. In the initial session, all doors and windows of the classroom were closed, and the cooling and air filtering systems were deactivated. Conversely, for the second session, the setup was reversed; doors and windows were opened, and the cooling and air filtering systems were activated. In the final session, considerations were given to the students' responses from the preceding sessions, leading to a setup like the first session (all closed), but with the addition of evenly distributed plants throughout the classroom. The only constant across all three setups was the presence of the IoT system, which monitored the plants and their environment, embedded in a pot with a plant for the duration of each session.

To motivate and engage students in the experiments during these three sessions, reference was made to an IoT system previously developed by students in the same course in collaboration between ETSISI and Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas (Agricultural Engineering School -ETSIAAB-, UPM, Madrid). This collaborative effort has persisted over the years due to the system's practical utility. Known as Spike, this mobile spike is positioned in a pot, collecting data on variables that impact the plant and its surroundings [18].

The system served as a motivating element for students, owing to the inherent nature of the device. Capitalizing on the open-source and open-data attributes of this system, its design and source code were employed to educate students on the communication components of the ESP32 microcontroller, Telegram, and Thingsboard. These three components were mandatory for implementation in their end-of-course projects, and in previous years, students encountered challenges in obtaining information and executing them. Consequently, during the sessions, students were given the opportunity to engage with the physical system, interact with the Telegram bot via a group on the application, and manipulate the Thingsboard dashboards.

The structure of each session remained consistent, following these steps: (1) positioning a pot in the classroom and activating the aforementioned IoT system for real-time data collection; (2) preparation of the setup, including adjustments to windows, doors, cooling systems, air filtering systems, and/or plants; (3) delivering a lecture on the IoT system and its components; (4) presenting the data collected by the IoT systems to the students during the session; (5) administering a questionnaire on environmental awareness and prompting reflection on the concordances and discrepancies among recommendations regarding ventilation amid the COVID situation, prevailing legislation on cooling enclosed spaces, considerations for the well-being and efficiency of individuals, the impact of plants in classrooms, and the amalgamation of all these elements, while considering the collected data.

Concerning the session content, each one focused on a specific technical aspect of the IoT system. In the inaugural session, the course professors introduced the two researchers leading the experiment, presenting them as experts – one in computer engineering and the other in agronomic engineering. Subsequently, the researchers addressed the students, providing an overview of the experiment's context and elucidating the various components essential for establishing communication between the ESP, Thingsboard, and Telegram. In the subsequent session, students were instructed on how to create the different elements previously introduced, and they were introduced to the concept of APIs. The third and concluding session involved teaching students how to interconnect all the created elements, ensuring that data sent to the APIs would trigger the transmission of messages and data to Thingsboard and Telegram.

Following the initial session, students were notified about the voluntary option to join a Telegram group. This group included the expert in computer engineering, the expert in agronomic engineering, all students willing to participate, and the Telegram bot programmed for the discussed IoT system. This setup aimed to offer personalized support to students based on their individual needs and facilitate communication throughout the learning process.

The purpose of establishing this group was for students to utilize it for educational purposes and to seek clarification from both their peers and the experts regarding any queries arising from the sessions. Moreover, students could engage with the Telegram bot, which maintained communication with the IoT system presented in class. This allowed them to assess its functionality, explore the capabilities of Telegram bots, and consider additional use cases.

2.3 Step 2: Perceived Effectiveness of IoT systems

The second phase took place at the ETSIAAB, involving students enrolled in the courses 'Irrigation and Drainage Systems and Technology' and 'Irrigation and Drainage Systems and Technology for Green Areas and Horticultural Exploitations' within the Agricultural Engineering Degree. During this stage, the objective was to assess the perceived effectiveness of IoT systems in enhancing students' digital competences, IoT skills, and environmental awareness (H1, H2, and H3).

The courses scrutinize diverse irrigation systems, drainage types, and the computation of irrigation parameters. Upon completion of the course, students are required to select a plot of land within the school grounds, cultivate a specific crop, and execute an irrigation project on the chosen plot. This practical exercise is complemented by the documentation of the entire process. Furthermore, students must submit a comprehensive report elucidating how they would integrate new technologies into the irrigation of this plot.

To inspire and stimulate student participation in this experiment, a dedicated three-hour teaching session centered on IoT applied to irrigation was organized. Throughout this session, students were familiarized with IoT technology, its architecture, and the typical components integrated into IoT systems. Moreover, they were encouraged to engage in critical thinking about general use cases of IoT and explore specific applications of IoT in the context of irrigation. During this session, the Spike system was presented, encompassing its hardware and software architecture. The session also covered the intricacies of bidirectional communication between the IoT system, users, and a Telegram bot, highlighting the significance of interdisciplinary engineering. Furthermore, students received an overview of Thingsboard, an IoT platform facilitating real-time data querying from IoT devices and historical data. The session concluded with the resolution of a specific problem focusing on the utilization of an IoT system for the irrigation of a woody crop.

During this session, the time was not utilized to prepare a setup demonstrating that plants serve as a natural filter for temperature and CO_2. Instead, the focus shifted to recounting the experience from the SBC course (ETSISI, step 1) and sharing the results observed by those students, along with the conclusions drawn. In contrast, the emphasis in this session was on assessing whether the use of the IoT system in class resulted in any perceived improvement among students in terms of digital competences, IoT skills, and environmental awareness. Additionally, open-ended questions about IoT systems were presented to the students for further exploration.

To measure these aspects, several tests were conducted, collaboratively prepared by the course teachers. The test preparation involved the following steps: (1) defining what was to be measured (the perceived capacity of IoT systems by students to foster digital competences, IoT skills, and environmental awareness); (2) discussing the relevance of each topic with an expert in educational technology; (3) presenting a set of questions related to each topic; (4) filtering the questions based on their relevance or connection to the intended measurements in the experiment.

The chosen test format was a Likert-type test with 5 levels (with scores from 1 to 5, where 1 corresponds to "Strongly disagree" and 5 corresponds to "Strongly agree"). Additionally, 20% of inverse questions were included to ensure the sincerity of the responses in each of the explored dimensions.

3. Results

3.1 Step 1: Environmental Awareness

Following the three sessions, the students participated in a questionnaire encompassing environmental awareness across four dimensions (D1–D4): (1) awareness of environmental issues; (2) awareness of individual responsibility; (3) general attitudes toward environmental solutions; (4) general attitudes toward environmental issues. The obtained results present the mean measures of environmental awareness and the corresponding standard deviations for each of the dimensions. Additionally, the overall mean and standard deviation are provided for the validated responses, encompassing a total of 29 students. The results are showed in Fig. 1.

Overall, the findings suggest that engineering students exhibit moderate levels of environmental awareness across all the specified dimensions. A summary of the results is provided below:

D1: A moderate level of awareness regarding environmental issues is obtained. The standard

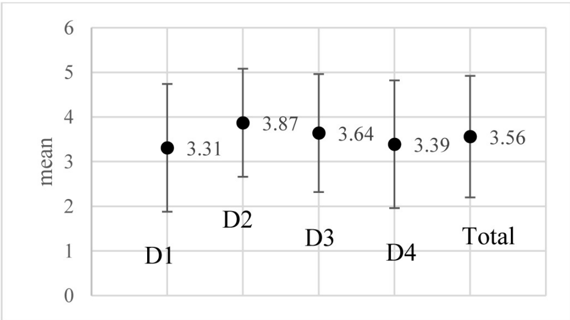

Fig. 1. Environmental awareness dimensions and their means and standard deviations. Dimension 1 (D1), dimension 2 (D2), dimension 3 (D3), dimension 4 (D4) and total.

deviation of 1.43 implies variability in the students' responses, indicating a discernible degree of knowledge and recognition of environmental problems. D2: The mean obtained indicates a moderately high level of awareness regarding individual responsibility concerning the environment. The standard deviation of 1.21 suggests less variability in responses compared to D1, indicating an awareness of their role and influence in environmental care and preservation. D3: A moderately positive attitude toward environmental solutions was found. The standard deviation of 1.32 suggests some variability in students' attitudes, indicating receptiveness and a favorable disposition toward seeking solutions to environmental problems. D4: A moderate attitude toward environmental issues was discovered. The standard deviation of 1.43 suggests some variability in students' responses, indicating recognition of the importance of environmental issues but perhaps not a solid stance or active commitment to their resolution.

Total mean and total standard deviation: The overall mean for all students is 3.56, suggesting a moderate level of environmental awareness.

The students utilized the Telegram group to communicate programming queries, while the experts leveraged the group to address uncertainties and share news and articles pertaining to plants and their properties.

By concentrating on the most frequently recurring responses provided by students in the tests conducted after each session, several observations can be discerned:

3.1.1 Session 1: Closed setup

The students responded to questions that: (1) required them to draw conclusions by observing the graphs presented in Thingsboard, (2) identified potential issues related to COVID recommendations, (3) identified potential challenges concerning indoor temperature regulations, (4) identified potential issues regarding optimal values necessary for plant growth, and (5) identified potential challenges related to optimal values required for human performance.

Regarding question 1, students observed that both measures had increased over time (32.43%); offered a positive explanation for the increase in CO_2 (29.73%); provided an affirmative explanation for the rise in temperature (29.73%); acknowledged the interdependence of temperature and CO_2 as dependent variables (21.62%); or noted the presence of numerous individuals in the classroom, with some specifying it as an enclosed space (21.62%).

Regarding question 2, students indicated that the classroom was inadequately or insufficiently ventilated (32.43%); expressed concerns about an elevated risk of contagion (24.32%); highlighted conflicts between temperature legislation and COVID recommendations (24.32%); emphasized the necessity to ventilate the rooms (13.51%); or mentioned the potential accumulation of COVID particles (10.81%).

Concerning question 3, students provided commentary on the conflict between COVID recommendations and legislation (13.51%); discussed potential increases in heating costs (13.51%); mentioned potential decreases in heating costs with greater savings (13.51%); or considered the cooling effect of ventilating with open windows (13.51%).

Concerning question 4, students pointed out that if there are suboptimal values (regarding temperature and/or CO_2), the plant will not grow as intended (32.43%); acknowledged the adverse impact on plant growth (10.81%); recognized the dependency on the specific plant (10.81%); suggested that elevated CO_2 levels have a positive effect on plant growth (8.11%); or noted potential issues with the plant if temperature has an impact (8.11%).

Regarding question 5, students commented that it has a negative impact on performance (56.76%); attributed performance issues to temperature (27.03%); attributed performance issues to CO_2 levels (27.03%); mentioned negative effects on concentration (10.81%); mentioned negative effects on well-being (10.81%); emphasized the necessity of optimal CO_2 values for performance (10.81%); or highlighted the necessity of optimal temperature values for performance (10.81%).

3.1.2 Session 2: Open setup

The students responded to questions that: (1) required them to draw conclusions by observing the graphs presented in Thingsboard, (2) prompted them to explain any differences noticed compared to session 1, (3) elicited their preference for the setup, (4) inquired about potential issues they might encounter concerning COVID recommendations, (5) inquired about potential issues they might encounter concerning indoor temperature legislation, (6) inquired about potential issues they might encounter concerning the optimal values required for plant growth, and (7) inquired about potential issues they might encounter concerning the optimal values needed for individuals to perform adequately.

Concerning question 1, students noted that both measures decreased (62.50%); observed that CO_2 decreased when ventilating by opening the windows (47.50%); mentioned the action of opening the windows (47.50%); indicated that temperature decreased when ventilating by opening the windows (47.50%); or specified that both measures decreased when ventilating by opening the windows (42.50%).

Regarding question 2, students responded that: they felt colder (37.50%); they felt much colder (22.50%); they noticed a less stuffy atmosphere (12.50%); they experienced a clearer/fresher head (5.00%); they observed a change in thermal sensation (temperature) (5.00%); they breathed better (5.00%).

Regarding question 3, the students responded that with this setup, they felt less comfortable (55.00%) and expressed a preference for a setup where everything was closed (62.50%).

Regarding question 4, the students answered that: they didn't find any problems (17.50%); COVID recommendations were being followed (15.00%); there was increased ventilation (12.50%); there would be fewer COVID contagions (12.50%); having more ventilation meant fewer COVID contagions (10.00%).

Regarding question 5, the students answered that: there were higher heating costs (15.00%); there was more energy wastage (12.50%); there was inefficient heating (10.00%); having the windows open made it difficult to control the temperature (10.00%); legislation was not being complied with (7.50%).

Regarding question 6, the students commented: it all depends on the type of plant (25.00%); cold can affect the plant and its development (22.50%); too much cold can lead to the death of the plant (17.50%); the plant lacks suitable conditions to grow properly (15.00%); low temperature may not be suitable for the plant (7.50%); or they don't foresee any problems (7.50%).

Regarding question 7, the students responded that: a middle ground should be sought between the first setup and the second (10.00%); they feel more discomfort due to the cold (7.50%); they notice they act slower because of the cold (7.50%); they don't perform well (7.50%); their performance decreases (5.00%); CO_2 is fine, but the temperature is low (5.00%); the cold affects their performance (5.00%); their concentration worsens (5.00%).

3.1.3 Session 3: Closed setup with plants

The students responded to a set of inquiries, encompassing: (1) tasks prompting them to draw conclusions by observing graphs presented in Thingsboard; (2) tasks soliciting them to articulate disparities noted in comparison to Session 1; (3) their preferences regarding setup; (4) potential benefits/problems related to adherence to COVID recommendations; (5) potential benefits/problems associated with indoor temperature regulations; (6) potential benefits/problems linked to the optimal values requisite for plant growth; (7) potential benefits/problems tied to the optimal values necessary for human performance; (8) their consideration of plants as regulators of temperature; (9) the rationale behind their belief in plants regulating temperature; (10) their stance on whether plants filter CO_2; (11) the processes plants undergo for CO_2 filtration; (12) the extent to which these sessions have heightened their awareness of the significance of indoor plants; (13) the extent to which these sessions have prompted reflection on the interplay between legislation, COVID recommendations, and the needs of both plants and humans; (14) strategies they would employ to regulate CO_2 and temperature within a classroom setting; (15) the incorporation of information disseminated via Telegram in formulating their responses.

In response to question 1, the students provided the following insights: both measures exhibit an upward trend over time (45.45%); plants contribute to temperature regulation (21.21%); plants play a role in regulating both measures (18.18%); plants aid in the regulation of CO_2 (18.18%); there is a slower increase in CO_2 compared to Session 1 (9.09%); there is a slower increase in temperature compared to Session 1 (9.09%); and the temperature remains stable (9.09%).

Regarding question 2, the students articulated the following observations: they perceived a decrease in CO_2 levels (18.18%); there was a lesser increase in CO_2 (15.15%); they experienced greater comfort within the classroom (12.12%); they observed a decrease in temperature (9.09%); the presence of plants contributed to a more relaxed atmosphere (6.06%); they noted a more constant temperature (6.06%); there was an increase in temperature (6.06%); CO_2 regulation was evident (6.06%); the rise in temperature was more gradual (6.06%); and the temperature was described as more pleasant (6.06%).

In response to question 3, the students conveyed the following sentiments: they experienced heightened comfort compared to preceding sessions

(72.73%), reported an equivalent level of comfort to Session 1 (12.12%), perceived diminished comfort compared to previous sessions (9.09%), and reported an equivalent level of comfort to Session 2 (6.06%). Furthermore, they expressed a preference for the room filled with plants (63.64%), an inclination towards an open configuration (30.30%), and a preference for a fully closed setting (6.06%).

Concerning question 4, the students provided the following responses: they associated indoor plants with better air quality (12.12%), a cleaner air ambiance (6.06%), and a fresher environment (6.06%). Additionally, they acknowledged the positive aspect of plants in helping to regulate temperature (6.06%). However, they also acknowledged potential drawbacks, including concerns that a fully closed environment could lead to increased contagion (9.09%) or result in inadequate ventilation, potentially worsening the overall air quality (6.06%).

In response to question 5, the students articulated the following positive aspects: temperature regulation (18.18%), improved energy consumption (9.09%), enhanced temperature conditions (9.09%), and the elimination of the necessity to use heating or air conditioning (6.06%), leading to more stable temperatures (6.06%). However, they also acknowledged potential drawbacks, including the limitation of not being able to use the classroom during the summer due to the ongoing regulation of temperature (3.03%).

Concerning question 6, the students responded that the presence of plants would contribute to the regulation of temperature (9.09%), maintain the plants in optimal conditions (6.06%), and aid in the regulation of CO_2 (6.06%). Nevertheless, they also noted a disadvantage, highlighting the insufficient light present in the classroom (12.12%).

In response to question 7, the students indicated positive outcomes, including improved performance (15.15%), heightened comfort (12.12%), enhanced concentration (9.09%), reduced CO_2 levels (9.09%), a more cheerful atmosphere (6.06%), and the belief that plants could serve as a viable solution for achieving optimal temperature and CO_2 levels in the classroom (6.06%). However, they also acknowledged potential drawbacks, such as a limitation in space (6.06%).

Concerning question 8, the students expressed a unified belief that plants play a role in regulating the temperature of the environment (100%).

In response to question 9, the students provided varied explanations for their belief that plants regulate the environment. These include through photosynthesis (12.12%), transforming CO_2 into O_2 (12.12%), aiding in thermoregulation of the environment (9.09%), lowering CO_2 levels leading to a decrease in temperature (6.06%), the cooling effect due to transpiration (6.06%), and through the operation of stomata (6.06%).

Concerning question 10, the students expressed a consensus in believing that plants have the capacity to filter CO_2 (100%).

In response to question 11, the students provided the following explanations for the process plants follow to filter CO_2: photosynthesis (72.73%), converting CO_2 into O_2 (21.21%), absorbing CO_2 (6.06%), converting CO_2 into O_2 in the daytime cycle (6.06%), and converting O_2 into CO_2 in the nighttime cycle (6.06%).

Concerning question 12, the students expressed a shared perspective that the sessions have indeed heightened their awareness of the importance of indoor plants (90.91%).

In response to question 13, the students indicated a consensus that the sessions have prompted reflection on the interplay between legislation, COVID recommendations, and the needs of both plants and humans (87.88%).

Concerning question 14, the students outlined various strategies they would employ to regulate CO_2 and temperature in a classroom setting. These include adding more plants (72.73%), ventilating the classroom (21.21%), opening windows (18.18%), utilizing thermal regulation systems such as air conditioning or heating (9.09%), incorporating CO_2 filters (6.06%), employing air purifiers (6.06%), and integrating the use of sensors (6.06%).

In response to question 15, the students indicated that they did not utilize Telegram to find the answers (69.70%).

3.2 Step 2: Perceived Effectiveness

The students provided feedback on questions pertaining to their perceived IoT systems' capability to: (1) cultivate digital competences in students; (2) foster IoT skills in students; (3) promote environmental awareness. Initially, 15 students participated in the session. However, due to its duration, a 20-minute break was implemented midway, resulting in the departure of 9 students. Consequently, only 6 students attended the second half of the session. Following the validation of the students' responses, 10 valid pre-tests and 6 valid post-tests were accounted for, with only 3 of them containing accepted responses in both the pre-test and post-test. The experiment's outcomes are presented using means, standard deviations, and Student's t-test for each of the assessed dimensions. The results are depicted in the Figs. 2–4.

In dimension 1, there is an observed increase in perceived effectiveness for developing digital com-

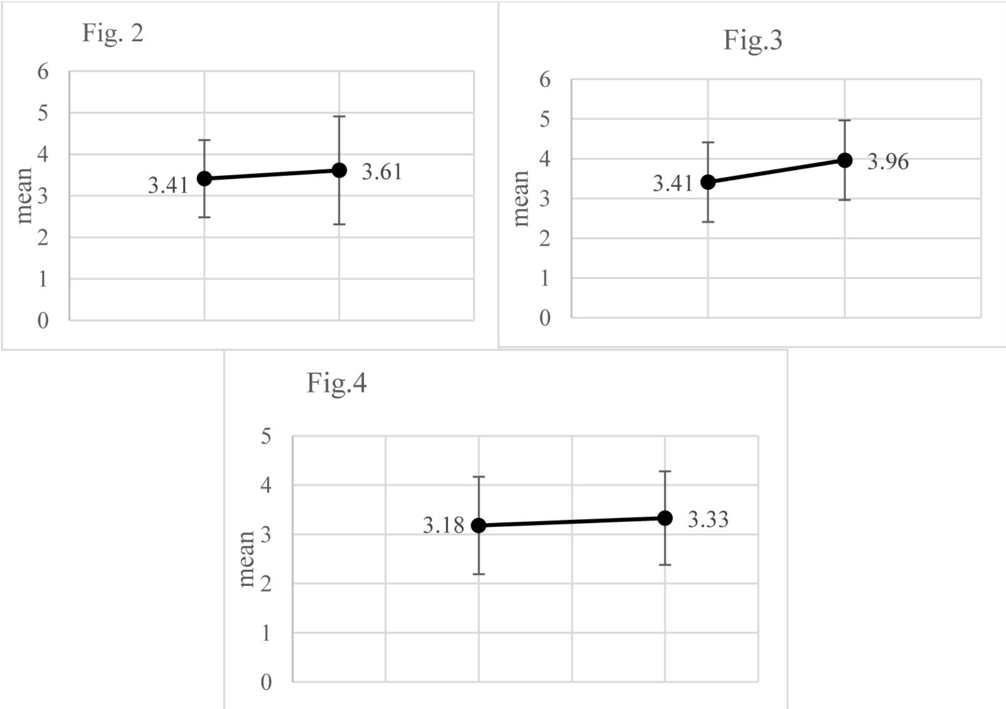

Fig. 2, 3 and 4. Perceived effectiveness for developing digital competences in students using IoT systems, for developing IoT skills (Fig. 3) and for fostering environmental awareness in students (Fig. 4). Means and standard deviations of pre-test (left) and post-test (right).

petences in students. The mean in the post-test (3.61) is slightly higher than in the pre-test (3.41), indicating improvement. However, the standard deviation in the post-test (1.3) is higher than in the pre-test (0.93), suggesting greater variability in responses. This may indicate a lack of consensus in the perception of effectiveness. Nevertheless, the Student's t-test for this dimension yields a value of 4.67E-03, suggesting a significant difference between the pre-test and the post-test. This indicates that the IoT systems used in the experiment have indeed contributed to the development of digital competences in the evaluated students.

In dimension 2, there is a notable increase in perceived effectiveness for developing IoT skills. The mean in the post-test (3.96) is significantly higher than in the pre-test (3.41), indicating substantial improvement. Additionally, the standard deviation in the post-test (0.95) is comparable to that of the pre-test (0.81), suggesting greater consistency in responses. Furthermore, the Student's t-test for this dimension yields a value of 1.23E-4, indicating a significant difference between the pre-test and the post-test. This implies that the students have undergone significant development in their IoT-related skills because of the experiment's intervention.

In dimension 3, a marginal increase in perceived effectiveness for fostering environmental awareness is observed. The mean in the post-test (3.33) is slightly higher than in the pre-test (3.18), indicating a modest improvement. The standard deviation in the post-test (0.95) is like that of the pre-test (0.99), signifying consistent responses. The Student's t-test for this dimension yields a value of 1, indicating that there is no significant difference between the pre-test and the post-test concerning environmental awareness. This suggests that the experiment did not have a significant impact on fostering environmental awareness among the students.

In the complete questionnaire, the pre-test yielded a mean of 3.30 with a standard deviation of 0.80. This suggests that, on average, the students held a moderate perception across the three evaluated dimensions. In the post-test, the mean increased to 3.85, indicating that following the intervention with IoT systems, students exhibited a slightly more positive perception in the mentioned three dimensions. However, it is noteworthy that the standard deviation also increased to 1.12, implying greater variability in students' responses compared to the pre-test.

Overall, it can be concluded that the intervention with IoT systems had a positive impact on students' perception in the three evaluated dimensions. However, the higher variability in post-test responses suggests that while some students experienced a significant change in perception, others did not. Additionally, the Student's t-test yielded a value of 6.29E-06, indicating a significant difference between the pre-test and the post-test overall. This implies that the intervention with IoT systems has had a positive effect on the perceived capacity of students in the three mentioned dimensions collectively.

In summary, the IoT system employed in the experiment has demonstrated a positive impact on the development of digital competences and IoT skills among the students. However, the perceived effectiveness in fostering environmental awareness exhibits a smaller increase and less consistency in the responses.

It is crucial to acknowledge that these findings are rooted in the subjective perceptions of the students and may not necessarily signify an objective change in their acquired competencies or skills. To obtain a more comprehensive understanding of the impact of IoT systems on these aspects, it would be beneficial to complement this study with additional objective and longitudinal evaluations. Such assessments could provide a more nuanced and thorough assessment of the sustained effects of IoT interventions on students' skills and awareness over time.

Five open-ended questions were formulated for the students, centering on their beliefs regarding the use of the IoT system in the classroom: (1) Do you believe the IoT system has yielded any benefits for you or the community? If so, what specific benefits have you observed? (2) In your opinion, has the IoT system introduced any challenges for you or the community? If yes, what issues have arisen? (3) Do you perceive the IoT system as having the potential to address environmental concerns? If so, what aspects contribute to this belief? (4) What, in your view, are the obstacles associated with the implementation of this IoT system? (5) How do you think the IoT system could be enhanced to be more accessible to a broader range of users?

In response to question 1, students highlighted several benefits offered by the IoT system, including: gaining more knowledge, access to more readily available information, the ability to manage a significant amount of data from any location, and precision in data collection.

In relation to question 2, three students expressed the belief that the IoT system did not bring about any problems. Conversely, other students raised concerns about potential issues, including challenges with battery life, maintenance requirements, the generation of overwhelming data, and security concerns given the system's interconnection to the internet.

In response to question 3, students expressed that the IoT system can contribute to solving environmental problems by providing information, enabling the generation of a database for predictions, offering more real-time data, and optimizing resources. However, one student noted a different perspective, stating that the system itself cannot solve problems; instead, it provides data for humans to make decisions based on the information collected by the IoT system.

In relation to question 4, students identified various barriers associated with the IoT system, including concerns about battery limitations, maintenance requirements, computer security issues, the necessity for a human filter, and the need for regulatory considerations.

In response to question 5, students suggested that the accessibility of the IoT system could be improved if it featured a simple interface, conducted training sessions for users, was made available for free, or if it was designed to be intuitive.

4. Discussion

The subsequent sections will delve into the analysis and discussion of the results obtained in each of the stages. Additionally, the study's limitations will be addressed.

4.1 Stage 1: Environmental Awareness

Environmental awareness is a multifaceted concept that encompasses cognitive, affective, conative, and active dimensions [19]. Previous studies, such as the work by Gomera Martínez et al., [20], have adopted a comprehensive approach by measuring environmental awareness across these four dimensions through questionnaires, specifically among university students. Additionally, Khoiri et al., [21] explored the environmental awareness of high school students in Indonesia, employing a non-test questionnaire as their measurement tool.

In a related study by López and Palacios [22], environmental awareness was assessed in a secondary school setting. The researchers utilized a Likert-type test focused on environmental conservation, open-ended questions addressing environmental problems and potential solutions, and a final test gauging students' perception of the environment. Notably, this study concentrated on the city of Granada, offering insights specific to that locality. The current research seeks to contribute to the broader understanding of environmental awareness by adopting a more generalized approach, not limited to a single city. While acknowledging the relevance of city-specific studies, the aim is to provide insights that can be applicable to diverse environments and urban contexts.

The examples provided align with the perspective discussed in the work by Ham et al. [23], emphasizing the significance of research on environmental awareness and the necessity for effective measurement tools in this domain. The authors stress the importance of standardizing the assessment of environmental awareness in students. In line with this principle, our study adopts the test introduced by Özden [24], which places a greater emphasis on individuals' perception of environmental awareness. This choice reflects a commitment to employing a standardized and widely applicable measure to assess environmental awareness among students.

During the initial phase of the study, the environmental awareness of computer engineering students was assessed through multiple sessions employing distinct setups within the same classroom. To achieve this, agronomic variables of a plant and its surrounding environment were consistently monitored using an IoT system previously developed by students enrolled in the course in prior years. The assessment encompassed four dimensions as evaluated by tests: (1) awareness of environmental issues; (2) recognition of individual responsibility; (3) overall attitudes toward environmental solutions; and (4) general attitudes toward environmental challenges.

In general, the findings indicate that engineering students exhibit a moderate level of environmental awareness across all assessed dimensions, with heightened awareness observed in dimension 2 (awareness of individual responsibility). Notably, responses in this dimension displayed less variability. While students demonstrate some level of awareness and concern regarding environmental issues, there is room for improvement in cultivating more proactive and dedicated attitudes toward seeking solutions. This enhancement might be facilitated through the incorporation of additional practical activities, enabling students to conduct independent investigations. Similarly, efforts could be directed towards activities aligned with students' interests, where environmental awareness serves as a central theme surrounding their areas of interest.

Moreover, it is noteworthy that across various sessions, students presented diverse conclusions regarding the occurrences in the classroom with two distinct setups. This underscores the observation that some students have discerned the correlation between inadequate ventilation in the classroom and an elevated risk of COVID infections. Additionally, they recognized that insufficient ventilation contributes to heightened CO_2 levels, impacting both energy consumption and plant growth. Students also noted the influence of variables such as temperature and CO_2 on plant growth, as well as the impact of indoor temperature and CO_2 levels on human comfort. They identified inconsistencies between COVID recommendations, indoor temperature regulations, and the well-being of both plants and humans.

Furthermore, students discussed the role of plants in regulating indoor temperature and CO_2 levels, highlighting their capacity to function as CO_2 filters. Notably, they mentioned the significance of photosynthesis in facilitating CO_2 filtering. Students reported a heightened sense of comfort in classrooms adorned with plants and underscored the importance of incorporating indoor plants for improved well-being.

4.2 Stage 2: Perceived Effectiveness of IoT systems

In education, conventional evaluation practices often rely on objective metrics, such as student grades, to assess various aspects such as the effectiveness of a teaching model or the utility of a tool in the classroom. Nevertheless, some scholars also emphasize the significance of studying students' perceptions to glean insights into their academic experiences. An illustrative instance is the work of Slavin [25], which delves into the self-assessed mental health status of medical students. Another example is the study conducted by Lowerison et al., [26], where in they explored, among other factors, the correlation between overall course grades and students' perceived effectiveness in computer usage. It is noteworthy, however, that this study, conducted in the 2000s, primarily focused on secondary school students and exclusively considered the use of computers, thereby overlooking other prevalent technologies of that era. Furthermore, the scope of technology employed in the investigation was limited to computers, disregarding the broader landscape of available technologies at the time.

In the study conducted by Van De Bogart and Wichadee [27], they established a technological learning environment and assessed students' perceived effectiveness of educational technologies, learner motivation, participation, and learning outcomes within the context of a smart classroom.

While our familiarity often centers on educational settings in developed countries, there are studies that extend their measurements to underdeveloped or developing nations. The aim is to evaluate how educational environments in these countries either currently adapt or could potentially adapt to new technologies. Consequently, the work by Chasubuta and Ndibalema, [28] is dedicated to investigating the adoption of new technologies for online assessment within educational environments. This study explores the impact of these technologies on both students and teachers, examining their perceptions following the utilization of such tools.

Consistent with the approach taken in the papers, the authors of this article deem it pertinent to investigate students' perceptions regarding any facet that directly influences their education, given that they are the primary recipients of such knowledge. Consequently, the second phase of this study concentrates on evaluating the perceived capabilities of students in IoT systems, specifically in their capacity to: (1) cultivate digital competences (H2); (2) enhance IoT skills (H3); and (3) promote environmental awareness (H1). The evaluation of these dimensions utilized the same IoT system employed in the initial stage, which was introduced to the participants alongside another IoT system currently under development, specifically focused on irrigation.

To gauge these three dimensions, a Likert scale pretest and posttest, comprising 5 levels, were employed. Overall, it can be deduced that the IoT system utilized in the experiment has yielded a positive influence on the enhancement of students' digital competences and IoT skills. Nevertheless, the perceived effectiveness in cultivating environmental awareness exhibits a more modest increase with less uniformity in the responses.

Furthermore, it is noteworthy that students provided responses to open-ended questions regarding the advantages and challenges associated with the IoT system. They shared insights on how the IoT system could address environmental issues, identified potential barriers it may face, and proposed ways to enhance its accessibility. Students highlighted that the system facilitates more accessible information, although concerns were raised about battery life and security issues stemming from the device's internet connectivity.

Moreover, students emphasized that data acquisition allows for the creation of a database yet underscored that the raw data alone lack inherent value, emphasizing the importance of human interpretation for decision-making. They pointed out barriers arising from the device's dependency on external factors, such as battery life and cybersecurity, and highlighted the necessity for human involvement in data filtering.

The authors of this paper believe that there are multiple pathways to enhance students' awareness of environmental issues further using IoT systems.

- Promote other Interactive Learning Activities (like the one conducted with the Teaspike in this paper): Develop engaging and interactive tasks that utilize IoT devices to track environmental factors like air quality, temperature, and humidity. These activities can offer real-time data and insights into environmental conditions, promoting a deeper comprehension of environmental issues.
- Project-Based Learning: Implement learning experiences focused on projects where students utilize IoT systems to address environmental challenges. For example, students might create and deploy sensors to monitor pollution levels or other parameters in their local area or design smart irrigation systems for sustainable farming.
- Hands-On Experiments: practical experiments and demonstrations using IoT devices. For instance, students could construct and test models of energy-efficient devices or investigate the effects of various environmental interventions on IoT sensor data.

In conclusion, students suggested that an intuitive interface or training sessions could contribute to making the system more accessible. Research and environmental education thus need to reach closer cooperation and more involvement in expanding their combined effect [29].

4.3 Limitations of the Study

The study is subjected to several limitations. Firstly, there is a potential for bias in the results. It is crucial to acknowledge that these findings are confined to the engineering students who were part of the study and may not be extrapolated to other populations or settings. Nonetheless, these results offer a comprehensive snapshot of the environmental awareness, IoT skills, and digital competences within the scope of this group of students.

Secondly, as these are university degree courses, administrative procedures necessitated the conclusion of participation in the courses approximately one academic year in advance. This precaution was taken to prevent any disruption to the regular teaching activities within these courses.

Thirdly, the quantity of student responses to the questionnaires was contingent on the courses in which the study could be carried out and the enrollments within those specific courses.

Fourthly, a notable limitation pertains to the insufficient interest or motivation among students. The inability to secure more responses can be attributed to a lack of enthusiasm on the part of students for the topic addressed in the sessions. This diminished interest might stem from the students' perceived lack of relevance to their respective degree programs or the researcher's challenges in fostering motivation [30]. Consequently, only one half of the students in the 70-member group participated in the questionnaires, and in the 15-member class, half of the students left during a 20-minute break in the middle of the session.

Finally, another limitation arises from the potential lack of honesty among students. As a measure to authenticate the test results, 20% of the questions were formulated in a negative manner, aiming to identify incoherent responses and subsequently eliminate them. However, the combination of this strategy with students leaving during the break led to only 3 out of 15 students, who initially responded to the questionnaires correctly at the beginning and end of the session, being retained for the second stage of the study.

5. Conclusions

This paper outlines two experiments conducted with engineering students, aiming to assess and examine: (1) the environmental awareness of the students, and (2) the perceived effectiveness (as perceived by students) of IoT systems in cultivating digital competences, IoT skills, and environmental awareness. The findings from the first experiment indicate that students possess moderate levels of environmental awareness, with some variability evident in their responses. Regarding the second experiment, using a Likert scale pre-test and post-test, the study found that the introduction of IoT systems positively influenced students' digital competences and IoT skills. However, the impact on environmental awareness was more modest, indicating room for improvement in this area. Furthermore, students provided valuable insights into the advantages and challenges associated with IoT systems. While they recognized the benefits of IoT technology in facilitating access to information, concerns were raised regarding issues such as battery life and security. This suggests a need to explore alternative methods for effectively conveying environmental awareness. In conclusion, the study emphasizes the need for ongoing research and development to enhance the accessibility and effectiveness of IoT systems in educational settings. Pedagogical approaches that actively promote this form of awareness should be explored to ensure that students genuinely recognize the significance of environmental awareness.

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References

1. A. B. Ramos-Gavilán, M. A. Rodríguez-Esteban, M. A. Frechilla-Alonso, A. C. Raposeiras, D. Movilla-Quesada and A. B. González-Rogado, Raising awareness of the important role of engineering in sustainable development, *Heliyon*, **10**(1), 2024.
2. A. Amran, M. Perkasa, M. Satriawan, I. Jasin and M. Irwansyah, Assessing students 21st century attitude and environmental awareness: promoting education for sustainable development through science education, *Journal of Physics: Conference Series*, **1157**(2), IOP Publishing, 2019.
3. D. Dimante, T. Tambovceva and D. Atstaja, Raising environmental awareness through education, *International Journal of Continuing Engineering Education and Life Long Learning*, **26**(3), pp. 259–272, 2016.
4. E. P. Marpa, Navigating Environmental Education Practices to Promote Environmental Awareness and Education, *Online Submission*, **2**(1), 2020.
5. A. Leo-Ramírez, J. Alvarez, M. Pérez, W. Greller and B. Tabuenca, Learning Activities with Plants and Technology: A Systematic Literature Review, *Applied Sciences*, **13**(6), 2023.
6. R. Ramanathan, Y. Duan, T. Ajmal, K. Pelc, J. Gillespie, S. Ahmadzadeh and U. Ramanathan. Motivations and challenges for food companies in using IoT sensors for reducing food waste: some insights and a road map for the future, *Sustainability*, **15**(2), 2023.
7. R. Vuorikari, Y. Punie, S. Carretero and L. Van den Brande. *DigComp 2.0: The Digital Competence Framework for Citizens. Update Phase 1: the Conceptual Reference Model*, 2016
8. B. Tabuenca, W. Greller and D. Verpoorten, Mind the gap: smoothing the transition to higher education fostering time management skills, *Universal Access in the Information Society*, **21**(2), pp. 367–379, 2022.
9. M. Sivamoorthy, R. Nalini and C. Kumar, Environmental awareness, and practices among college students. *International Journal of Humanities and Social Science Invention*, **2**(8), pp. 11–15, 2013.
10. S. M. Shobeyri, B. Omidvar and N. N Prahallada, A comparative study of environmental awareness among secondary school students in Iran and India, *International Journal of Environmental Research*,**1**(1), pp. 28–34, 2007.
11. M. Özden, Environmental awareness and attitudes of student teachers: An empirical research, *International research in geographical and environmental education*, **17**(1), pp. 40–55, 2008.
12. S. Park, Y. Choi, D. Song and E. K. Kim, Natural ventilation strategy and related issues to prevent coronavirus disease 2019 (COVID-19) airborne transmission in a school building, *The Science of the total environment*, 789, 2021.
13. Boletín Oficial del Estado (Spanish Federal Gazette), https://www.boe.es/eli/es/rd/2021/03/23/178, Accessed 9 May 2024.
14. P. Strøm-Tejsen, D. Zukowska, P. Wargocki and D. P. Wyon, The effects of bedroom air quality on sleep and next-day performance, *Indoor air*, **26**(5), pp. 679–686, 2016.
15. T. Bringslimark, T. Hartig and G. G. Patil, The psychological benefits of indoor plants: A critical review of the experimental literature, *Journal of Environmental Psychology*, **29**(4), pp. 422–433, 2009.
16. B. Daly, C. Buchanan, K. Dasch, D. Eichen and C. Lenhart. Promoting school connectedness among urban youth of color: Reducing risk factors while promoting protective factors, *The Prevention Researcher*, **17**(3), pp.18–20, 2010.
17. K. T. Han, Influence of limitedly visible leafy indoor plants on the psychology, behavior, and health of students at a junior high school in Taiwan, *Environment and Behavior*, **41**(5), pp. 658–692, 2009.
18. B. Tabuenca, J. L. Moreno-Sancho, J. Arquero-Gallego, W. Greller and D. Hernández-Leo. Generating an environmental awareness system for learning using IoT technology, *Internet of Things*, **22**, 2023.
19. E. Chuliá, La conciencia medioambiental de los españoles en los noventa, *Energy and Environment*, 1995.

20. A. Gomera Martínez, F. Villamandos and M. Vaquero Abellán, Medición y categorización de la conciencia ambiental del alumnado universitario: contribución de la universidad a su fortalecimiento, *Profesorado*, **16**(2), 2012.
21. A. Khoiri, W. Sunarno, S. Sajidan and S. Sukarmin, Analysing students' environmental awareness profile using strategic environmental assessment, *F1000Research*, **10**, 2021.
22. J. A. López and F. J. P. Palacios, Effects of a project-based learning methodology on environmental awareness of secondary school students, *International Journal of Instruction*, **17**(1), pp. 1–22, 2024.
23. M. Ham, D. Mrčela and M. Horvat, Insights for measuring environmental awareness, *Ekonomski vjesnik: Review of Contemporary Entrepreneurship, Business, and Economic Issues*, **29**(1), pp. 159–176, 2016.
24. M. Özden, Environmental awareness and attitudes of student teachers: An empirical research, *International Research in Geographical and Environmental Education*, **17**(1), pp. 40–55, 2008.
25. R. E. Slavin, Cooperative Learning and Academic Achievement: Why Does Groupwork Work?, *Annals of Psychology*, **30**(3), pp. 785–791, 2014.
26. G. Lowerison, J. Sclater, R. F. Schmid and P. C. Abrami, Student perceived effectiveness of computer technology use in post-secondary classrooms, *Computers & Education*, **47**(4), pp. 465–489, 2006.
27. W. Van De Bogart and S. Wichadee, Students' perceived effectiveness of educational technologies and motivation in smart classroom, *TEM Journal*, **5**(4), p. 566, 2016.
28. A. Chasubuta and P. Ndibalema, Barriers hindering Effective Engagement in Online Assessment for Teacher Education in Tanzania: Perspectives from two Teachers' Colleges, *Journal of Issues and Practice in Education*, **16**, 2024.
29. J. K. Staniskis and Z. Stasiskiene, An integrated approach to environmental education and research: a case study, *Clean Technologies and Environmental Policy*, **8**, pp. 49–58, 2006.
30. E. K. L Tam, Developing a sustainability course for graduate engineering students and professionals, *The International Journal of Engineering Education*, **23**(6), pp. 1133–1140, 2007.

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