

Teaching Environmental Awareness with Smart IoT Planters in Learning Spaces [TEASPILS]

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Journal articles

Publication 1

[Tabuenca, B., Moreno-Sancho, J. L., Arguero-Gallego, J., Greller, W., & Hernández-Leo, D. \(2023\). Generating an environmental awareness system for learning using IoT technology. *Internet of Things*, 22, 100756.](#)

Plants have numerous beneficial effects on mental health, well-being, and indoor air quality. Nonetheless, these effects are not sufficiently well addressed in educational contexts. The increasing availability of sensors, networks, and cloud services can facilitate real-time measurements to perform data analysis on plants and the environment in which they coexist with students and teachers. This article addresses the use of plants and Internet-of-Things (IoT) technology to educate students (and teachers) on the benefits of using plants in indoor learning contexts (i.e., classrooms, study rooms, offices, libraries). The contribution of this research is threefold: first, a theoretical framework to design learning activities targeting environmental awareness is presented; second, an IoT system (Spike) specifically designed to monitor plants in learning spaces is described and evaluated; third, alternative learning activities and paths for learning using plants and IoT technology are described from a teachers' and students' perspective. These results show the potential of IoT technology to teach and to promote environmental awareness.

Publication 2

[Tabuenca, B., Serrano-Iglesias, S., Martín, A. C., Villa-Torrano, C., Dimitriadis, Y., Asensio-Pérez, J. I., ... & Kloos, C. D. \(2021\). Affordances and core functions of smart learning environments: A systematic literature review. *IEEE Transactions on Learning Technologies*, 14\(2\), 129-145.](#)

Smart learning environments (SLEs) have gained considerable momentum in the last 20 years. The term SLE has emerged to encompass a set of recent trends in the field of educational technology, heavily influenced by the growing impact of technologies, such as cloud services, mobile devices, and interconnected objects. However, the term SLE has been used inconsistently by the technology-enhanced learning (TEL) community since different research works employ the adjective "smart" to refer to different aspects of novel learning environments. Previous surveys on SLEs are narrowly focused on specific technologies or remain at a theoretical level that does not discuss practical implications found in empirical studies. To address this inconsistency and also to contribute to a common understanding of the SLE concept, this article presents a systematic literature review of papers published between 2000 and 2019 discussing SLEs in empirical studies. Sixty-eight papers out of an initial list of 1341 papers were analyzed to identify the following: 1) what affordances make a learning environment smart; 2) which technologies are used in SLEs; and 3) in what pedagogical contexts are SLEs used. Considering the limitations of previous surveys, and the inconsistent use of the SLE concept in the TEL community, this article presents a comprehensive characterization to describe SLEs through their affordances, the technologies used, and pedagogical approaches considered in the selected papers. As a result, specific core functions of SLEs are identified and explained. This work aims at ensuring a relevant knowledge base and reference toward the implementation of future SLEs.

Publication 3

[Leo-Ramírez, A., Alvarez, J., Pérez, M., Greller, W., & Tabuenca, B. \(2023\). Learning Activities with Plants and Technology: A Systematic Literature Review. *Applied Sciences*, 13\(6\), 3377.](#)

The increase in remote work and study modalities in recent years has changed our indoor physical spaces. Key variables such as air quality, temperature, or well-being in general have acquired special relevance when designing workspaces. In this context, plants can play an active role in moderating these variables and providing well-being to the people who live in these spaces. UNESCO, when framing its 2030 agenda, highlighted the importance

of promoting environmental awareness at the educational level (Sustainable Development Goals 3, 4, and 11). The scientific literature shows that the potential of plants is not sufficiently well addressed in educational contexts. Therefore, this review explores activities in which plants are used as a deliberate object of attention in learning contexts. The results show what learning activities have been carried out, what kind of plants have been used in the activities, and what technologies have supported those activities. The results provide a clear vision of the potential of plants to naturalize indoor learning spaces and to promote environmental awareness. This work aims to provide cues for further research on green education towards a sustainable society.

Publication 4

[Tabuenca, B., Greller, W., & Verpoorten, D. \(2022\). Mind the gap: smoothing the transition to higher education fostering time management skills. *Universal Access in the Information Society*, 21\(2\), 367-379.](#)

Freshmen in Higher Education are required to exhibit a strong inclination to taking ownership of their own learning. It entails well-developed self-regulated learning competences. This demand is further exacerbated in purely online settings such as open distant learning, MOOCs, or disruptive circumstances like the COVID pandemic. Time management skills are an essential component in this process and the target of this study, wherein 348 students covered a course through two conditions: the control group attended the semester in an unchanged way, while students in the experimental group were weekly invited to estimate and log their workload and time allocations, via “reflection amplifiers” provided on their mobile devices. While no major difference in time management and learning performance was observable, data reveals that perceived time allocation and prescribed study-time differ substantially. These results raise questions, on the students’ side, about the potential of qualitative (self-inputted) learning analytics to raise awareness on where time investments go. On the teachers’ side, the results highlight the need to better plan the curricula workload specifically for first-year students.

Publication 5

Tabuenca, B., Uche-Soria, M., Greller, W., & Hernández-Leo, D. Balcells-Falgueras, P., Gloor, P., Garbajosa-Sopeña, J. (Submitted August 23). Greening the Future of Smart Learning Environments: AIoT Case Studies with Plants. Under revision in Q1 journal.

Conference articles

Publication 6

[Tovar, E., Tabuenca, B., Greller, W., Piedra, N., & Friesel, A. \(2023, May\). Recognizing lifelong learning competences: a report of two cases. In 2023 IEEE Global Engineering Education Conference \(EDUCON\) \(pp. 1-6\). IEEE.](#)

The importance of microcredentials has grown in recent years. The gap between study programs offered by Higher Education Institutions and the industry job demands gave rise to more open and bitesize modules in the shape of Open Educational Resources, MOOCs and microcredentials. This article shows two novel cases bridging this gap based on the recognition of the competences learning units. In addition, the article elaborates on how these competences were selected and what approaches are appropriate for the recognition of these competences. Therefore, we describe how learning outcomes are mapped to competences in two disparate lifelong learning contexts. Finally, lessons learned and cues for further research are discussed.

Publication 7

[Rodosthenous, C., Mavrotheris, E., Greller, W., & Tabuenca, B. \(2022, September\). Creating environmental awareness in education through IoT and gamification. In International Conference on Interactive Collaborative Learning \(pp. 657-668\). Cham: Springer I \[Open article available here\]](#) **Best paper award at ICL conference 2022.**

In this paper, we present our efforts and plans for creating environmental awareness towards plants and greenery, while educating children and their teachers in ecological learning spaces. Our approach aims to stimulate knowledge and appreciation of plants and the effects of plants in classrooms, offices, homes and open learning spaces, which have hitherto been undervalued. By promoting plant appreciation at young ages and the use of plants for learning, we aim to lay the foundations for wider environmental awareness and positive attitudes towards nature. In parallel, we enhance the learning experience with advanced sensor and Internet of Things (IoT) technologies, stimulating interactive learning via gamification. Utilising this technology-enhanced approach with gamified data sets, pupils will not only learn basic facts about plants, but also learn about the needed care and responsibilities towards them, in order to establish a wide-ranging plant supported school climate. Towards that goal, we describe a number of gamification elements in the context of smart IoT planters and an accompanying visualisation dashboard.

Publication 8

[Tabuenca, B., García-Alcántara, V., Gilarranz-Casado, C., Leo-Ramírez, A., Arquero-Gallego, J., & Tovar, E. \(2022, March\). Engineering IoT systems in the convergence between agronomic and computer sciences. In 2022 IEEE Global Engineering Education Conference \(EDUCON\) \(pp. 2084-2087\). IEEE.](#)

The association between agronomy and computer engineering can facilitate a collaborative scenario between teachers and groups of students from different disciplines towards investigating smart technologies to track objects, plants, or soils. Nonetheless, the combination of these disciplines is rarely integrated in curricula. This work addresses this challenge presenting a case study in the context of Higher Education studies. Therefore, a project-based learning approach is presented in which students from both disciplines contribute to create and optimize IoT systems designed to track and monitor plants, soil, and environmental variables towards promoting environmental awareness in the future engineers. This research suggests at integrating these disciplines in a jigsaw classroom using specific sustainable development goals as a mediator. The presented methodology leads to scaffold multidisciplinary learning initiatives combining agronomic and computer sciences by engineering IoT systems.

Publication 9

[Leo-Ramírez, A., Tabuenca, B., García-Alcántara, V., Tovar, E., Greller, W., & Gilarranz-Casado, C. \(2021, July\). Solutions to ventilate learning spaces: a review of current CO2 sensors for IoT systems. In 2021 IEEE 45th Annual Computers, Software, and Applications Conference \(COMPSAC\) \(pp. 1544-1551\). IEEE.](#)

Over the past year, the implementation of IoT systems for monitoring CO2 in learning spaces has accelerated. The urgency caused by the pandemic has motivated the creation of multiple maker communities made up of teachers, researchers, students, parents, and volunteers in general to act together on the implementation of IoT systems monitoring CO2 in learning spaces. This article explores this topic contributing in three key aspects: First, the results of a review of scientific articles presenting IoT systems to ventilate learning spaces are described. Their CO2 sensors are characterized and classified considering their main features. Second, a European project is presented that aims at promoting environmental awareness exploring the effects of plants in learning spaces measuring CO2 with IoT systems installed in smart pots. Third, the main lessons learned are summarized and suggestions for future implementations are suggested. These results imply a relevant base knowledge towards facilitating the implementation of effective IoT systems to fulfill ventilation protocols in learning spaces.

Publication 10

[Tabuenca, B., Greller, W., Hernández Leo, D., Gilarranz Casado, C., García Alcántara, V., & Tovar, E. \(2021\). Talking to plants: an IoT system supporting human-plant interactions and learning. In LAS4SLE @ EC-TEL 2021: Learning Analytics for Smart Learning Environments, September 21, 2021, Bolzano, Italy](#)

The presence of plants in learning spaces can substantially improve well-being among students and teachers. Plants can positively influence environmental parameters such as air quality, temperature, or reverberation, but they also have an impact on parameters such as concentration, collaboration, and learning performance. This study aims to use plants as a learning object to promote ecological learning spaces. The paper presents an IoT system (Smart Spike) designed to collect data, and to provide real-time feedback on the state of the plant, soil, and environment variables. Moreover, this prototype was evaluated by 62 students of Agronomics and Computer Engineering to explore what measurements they considered most relevant, and how they would communicate with the plant using a mobile chatbot. The results aim to establish a better understanding of potential interactions between plants, learners, teachers, and the microclimate with a view to scaffolding learning activities supported by IoT technology and artificial intelligence.

Publication 11

[Rodosthenous, C., & Mavrotheris, E. \(2022\). Applying Gamification Mechanics in an Environmental Education SPOC. In Proceeding of 14th International Conference on Education and New Learning Technologies \(EDULEARN22\) \(pp. 9818-9825\). IATED. 10.21125/edulearn.2022.2370](#)

In this paper we present our work for applying gamification mechanics for an environmental Education Small Private Online Course (SPOC) in the framework of the Erasmus+ project titled "Teaching Environmental Awareness with Smart IoT Planters in Learning Spaces". The TEASPILS project focuses on creating environmental awareness towards plants and greenery, educating young people and their teachers towards ecological learning spaces. The project's actions will promote and foster awareness of environmental issues in an educational context. The project team designed a SPOC for 30 learners to introduce the project goals and strengthen environmental awareness, build responsibility among students, show connections in the natural sciences, and improve the social and indoor climate through plants in classrooms. The SPOC is delivered in 5 online sessions of 2 hours each and a final session in physical presence. These sessions cover a

range of topics such as Planters, the connection of plants with Humans and society in general actions research, and sensors and visualization technology. The SPOC is delivered using the Moodle Learning Management System and includes multimodal content and activities. In particular, the course includes content in the form of video presentations, reading material, links to relevant websites, discussion forums for learners to introduce themselves and promote collaboration on topics related to the project. Moreover, the course introduces a self-evaluation quiz for each session and activities, such as to prepare a learning scenario for a plant education course.

A practice that finds increasing usage in the educational domain is Gamification, which refers to the application of game design elements in non-game contexts (e.g., classroom, training, marketing, fitness apps). Gamification is used to engage and motivate users, provide the element of fun, challenge, competition, and provide meaningful feedback to learners. To increase participation and engagement for the SPOC, we proposed certain gamification mechanics, including badges, leaderboards, a level up system and certificates which were implemented and fully integrated in the LMS and applied in the specific group of learners. We present these gamification elements and how these are applied in the aforementioned SPOC. A badge system is incorporated in the course and connected to the self-evaluation quizzes and collaboration activities. In addition, a number of badges are designed in that context and manually assigned to learners when they complete a certain task. Since the group of learners is diverse, we also proposed other gamification mechanics to accommodate the needs of different types of learners, such as leaderboards which are more suitable for learners who are antagonistic.

Our work also includes statistics on how the learners interacted with the course and a mapping of our learners with the corresponding player type, based on Marczewki's user type hexad, which is used to identify proper gamification mechanics for each user type. To conclude, we also provide pointers to our future work for designing a gamification approach for the different activities and components of the TEASPILS project.

Publication 11

[Tabuenca, B. \(2022\) Teaching Environmental Awareness with Smart IoT Planters in Learning Spaces: an open approach. Presentation at OER 2022 Conference, 26th April, London, United Kingdom](#)

Publication 12

Tabuenca, B., Leo-Ramirez, A., Uche-Soria, M., Tovar, E., Greller, W., Rodosthenous, C., Mavrotheris, E., (2023). Unlocking the potential of IoT for interactive and collaborative learning: Case studies in higher education, In: International Conference on Interactive Collaborative Learning 2023, Springer. In Press.

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, CO2 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.

Workshops

Publication 13

Hernández-Leo, D., Ortiz-Beltrán, A., Balcells, P., (2022) TEASPILS: Plantes i tecnologia. Creació d'activitats d'aprenentatge. Presentation at Maker Faire Barcelona, on July 2, 2022, Barcelona, Spain.

<https://docs.google.com/presentation/d/1wpr6tN-jOcBkYitUXOrWgtmYRomYaWWi1W9MKaAZLmk/edit#slide=id.p>

Publication 14

Hernández-Leo, D., Ortiz-Beltrán, A., Balcells, P., (2022) Sensors, IoT per l'aprenentatge STEAM i el desenvolupament de consciència mediambiental. Presentation at Maker Faire Barcelona, on July 1, 2022, Barcelona, Spain.

https://docs.google.com/presentation/d/15n6vSIPsCt7RiwRjxpn4nP70nlagriBiMb4fO8Ib0_s/edit#slide=id.p