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

Intellectual Output 2

Final report

Smart IoT planters to collect data in learning spaces

Teaspils

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Project information

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Project coordinator organisation:	Universidad Politécnica de Madrid (UPM)
Consortium Partners	Doukas school (DOU) Hochschule für Agrar und Umweltpädagogik (HAUP) Open University of Cyprus (OUC) Pädagogische Hochschule Wien (PHW) Universidad Pompeu Fabra (UPF)
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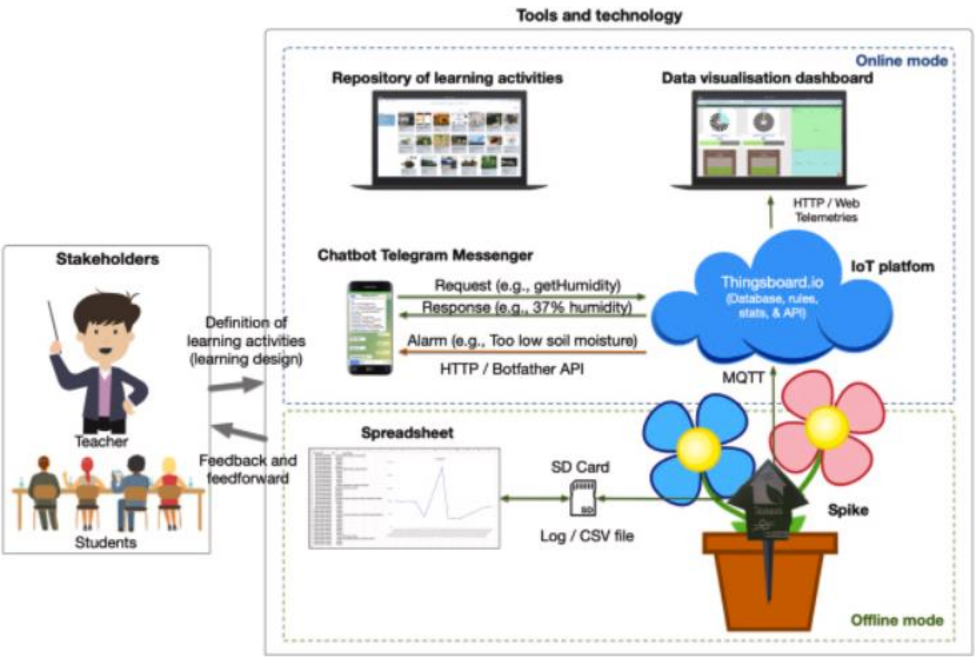
Intellectual output (IO2) of the TEASPILS project has been expertly overseen by Bernardo Tabuenca Archilla from the Universidad Politécnica de Madrid. You can reach out to him at bernardo.tabuenca@upm.es for any inquiries related to this specific outcome. These smart planters are designed to collect data within learning spaces, enhancing digital green competences while raising environmental consciousness among students. Our commitment to open access extends to IO2, ensuring the accessibility and utility of our findings for educators, learners, and all stakeholders interested in the intersection of technology and environmental awareness. Please feel free to contact Bernardo Tabuenca Archilla with any questions regarding this result.

Smart IoT planters to collect data in learning spaces

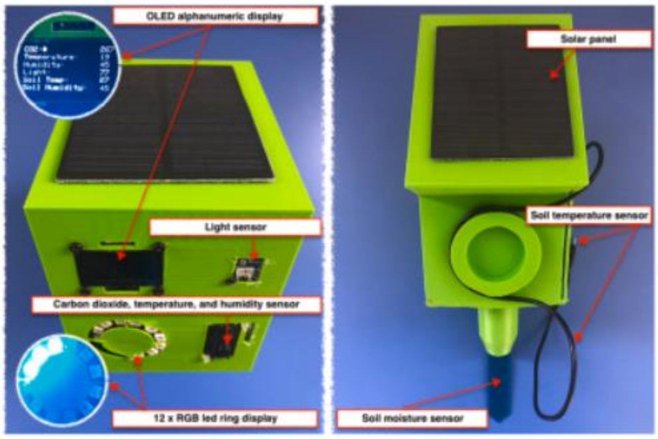
The IoT system implemented in this IO has been designed to explore variables affecting plants and the environment in which they are located. It intends to support teachers in the creation of learning activities (i.e., learning designs) using IoT technology and indoor plants to train the digital green competences mentioned above. The interaction between stakeholders and the IoT system aims to inspire authentic learning experiences (i.e., feedback and feedforward) to promote awareness on the benefits of using plants in learning spaces. The overall setup if the IoT system comprises the following tools:



Spike

The Spike is the core of the system. It is responsible for collecting data (sensors), storing it (internal and remote), and offering real-time feedback on it (actuators). All system components are orchestrated by an ESP32 micro-controller with Wi-Fi and Bluetooth connectivity. The case of the Spike was designed with a 3D printer. The upper part is shaped like a house and the microelectronics are isolated inside. The lower part is shaped like a stake to be able to insert it into a planter and obtain measurements about the soil of the plant. As illustrated in Fig. 3b, the roof is divided into two sides: the first side has a solar panel installed to recharge the batteries (inside the casing) that operate the entire system. Alternatively, the Spike can be powered using a micro-usb cable (5 V) if there is not enough charge. The other side of the roof is equipped with sensors and actuators. Here we describe the variables measured by these sensors and the arguments considered to install them in the Spike:

- Carbon dioxide. As students and teachers exhale carbon dioxide (CO_2) when they breathe, the concentration of this gas is an objective measure to determine if the air in the classroom is clean. High CO_2 levels increase the chances to breathe air that was previously exhaled by another person. Therefore, the system makes it possible to observe how plants moderate CO_2 levels and consequently apply the existing recommendations/regulations to ventilate classrooms.
- Light. Plants need light to carry out photosynthesis. Natural photosynthesis is the process of capturing CO_2 in the form of carbohydrate and releasing O_2 using light as the energy source.
- Ambient temperature. Humans and plants carry out their vital functions in a more efficient way within certain ambient temperature ranges. The Sensirion-SCD30 sensor of the Spike monitors ambient temperature levels in Celsius degrees (°C) to optimise the well-being of plants and stakeholders in the classroom.
- Ambient humidity. Humidity is a key variable to consider for obtaining a healthy environment for humans and plants. The Sensirion-SCD30 sensor of the Spike monitors relative humidity levels in percentage (%) to optimise the well-being of plants and stakeholders.
- Soil moisture. This variable must be optimised considering the composition, the texture of the soil (clay, sandy) and the type of plant. Soil texture determines water filtration. The seed-studio capacitive soil moisture sensor of the Spike monitors soil humidity to automatise plant watering and to optimise plant growth. The capacitive soil moisture sensor, compared with resistive sensors, does not require direct exposure of the metal electrodes which can significantly reduce the erosion of the electrodes.
- Soil temperature. Based on the scientific literature, the researchers of this work considered it interesting to empirically explore how soil temperature is correlated with the rest of the variables measured by the Spike (C02, humidity, etc.) in a learning context.



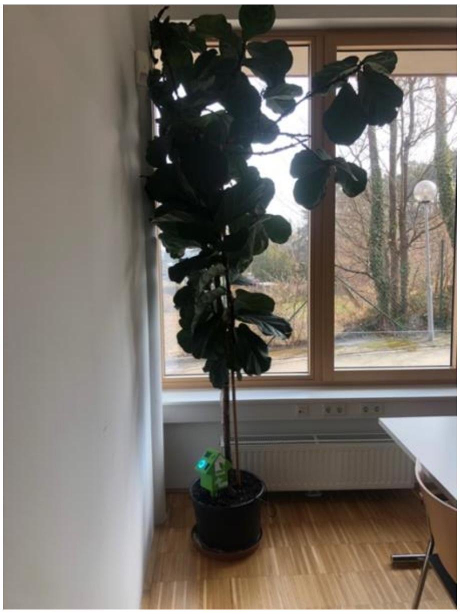
The system allows to configure how often the data is read from the sensors. The Spike stores the data collected from sensors on a memory SD-card in spreadsheet format (i.e., Excel and CSV file). The SD-card can be ejected from the Spike to insert in a computer to analyse the data. When working in online mode, the Spike also uploads the data to the cloud. The system is equipped with two displays (actuators) to present the data. The 1.3-inch OLED is used to display alphanumeric data with the measurements collected by the sensors in real-time. In addition, the 12 multicoloured LED ring is using a traffic light metaphor to indicate the gradient for the monitored variable. The system represents a moment in which the CO_2 variable is monitored (see asterisk on the OLED display). Three blue leds indicate optimum levels in the variable. Table 1 shows the correspondence between the configured thresholds and the feedback colour on the ring for the variables measured.

You can see a short video description of the Spike here:

Video:
https://drive.google.com/file/d/12Nkq6oZAXGft9fTI18R3WEXDU5LV4p_A/view?usp=sharing

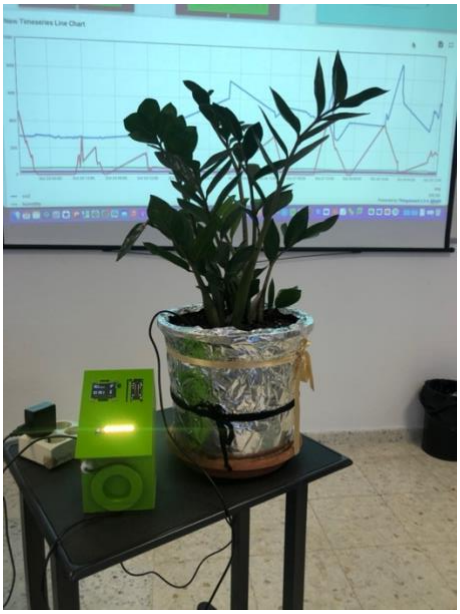
The system has evolved throughout the project in three different versions:

Spike version 1
This IoT system contains all the elements described above and was designed to be embedded in the soil of the planter itself.



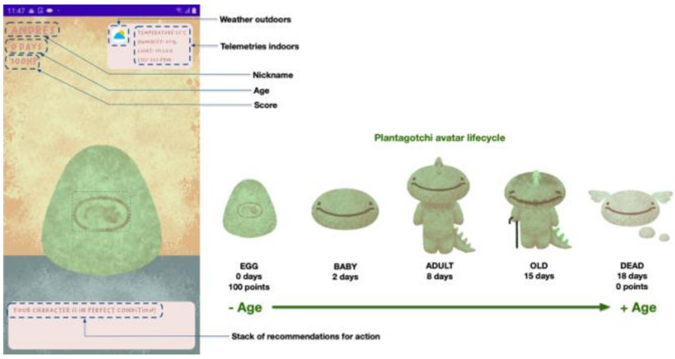
Spike version 2
This IoT system improves the previous version by incorporating actuators (OLED RGB progressive bar) adapted to improve feedback usability in colorblind people. In addition, two

temperature probes have been incorporated to be able to compare/contrast the measurements between two different plants. The system includes a chatbot to interact with the plant via text messages via Telegram. Unlike the previous version, this system was designed to be physically installed next to the pot as the dimensions of the spike could damage small potted plants.



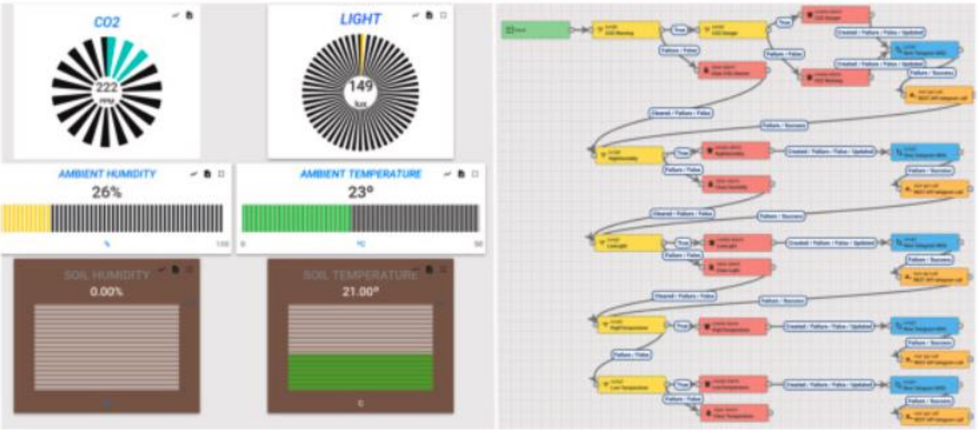
Spike version 3

This IoT system includes functionalities that allow exploring learning activities related to the Internet of Things and artificial intelligence. These functionalities are: 1) a voice assistant that allows you to interact with the system through voice dialogues; 2) a mobile avatar (Plantagotchi) that allows the gardener to be given a virtual entity that allows illustrating how the plant reacts to different environmental conditions that may occur in the classroom; 3) an electrical differential meter that allows exploring how the plant reacts to different stimuli (for example: presence of people, music, noise, irrigation of the plant, or extreme variations of light or temperature).

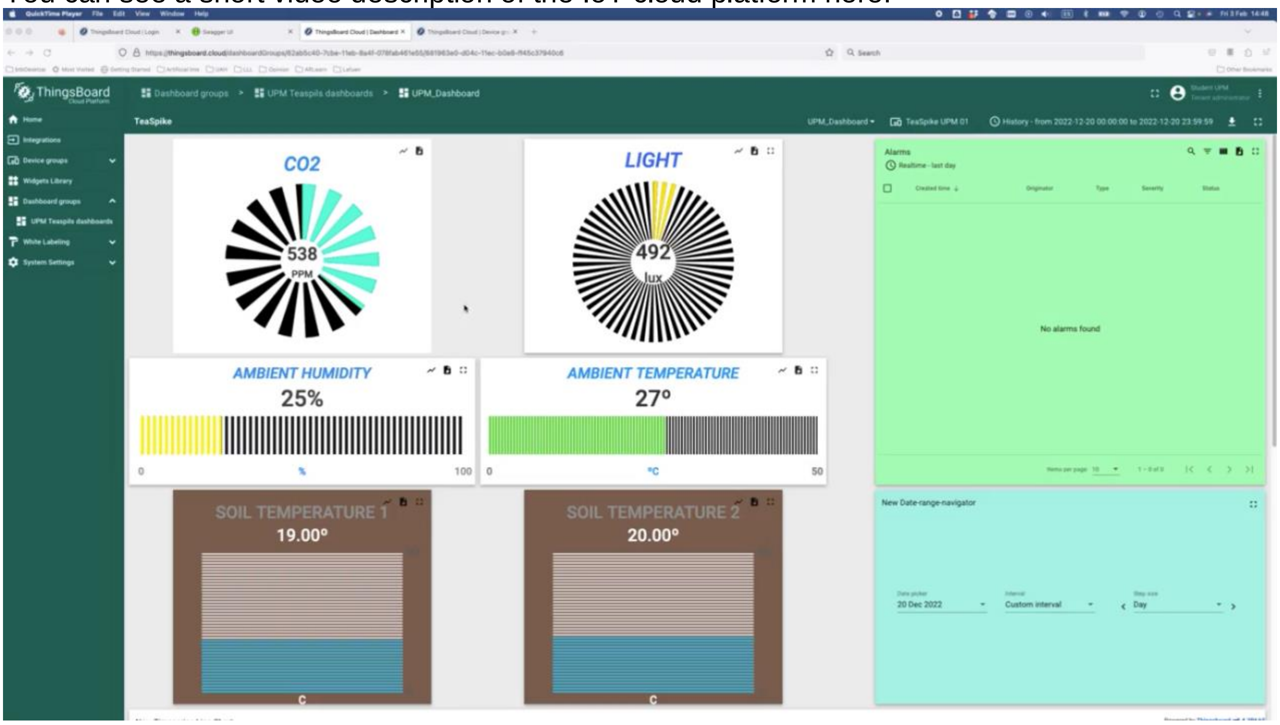


IoT cloud platform

The platform is an online service that allows hosting the data collected by the Spike when working in online mode. This service includes a data panel to remotely display the information collected by the sensors. The visualisation includes an individual panel for each variable collected in real-time, and also a representation of historical data with a line chart. The timeline representation allows stakeholders to download the database for a given time/date range in a spreadsheet for exhaustive analysis. The platform includes a web service that facilitates the programming of additional applications to access and represent data. In addition, the platform features rules configuration to identify specific scenarios and to activate additional alarms (e.g., the need for watering the plant in case of extremely low soil moisture). The system is configured to trigger alerts whenever the red thresholds are reached. The figure illustrates alarm messages due to extremely low ambient light.



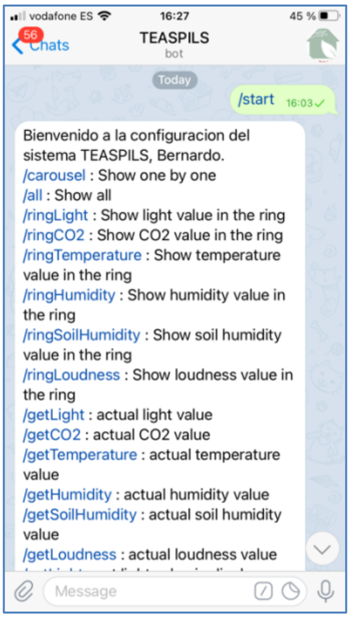
You can see a short video description of the IoT cloud platform here:



Video:
https://drive.google.com/file/d/1nGXIAYcijiJvDD3m8kg3YKU4oh8HuACi/view?usp=sharing

Mobile messaging application

Interactions between humans and plants are highly complex and are to a large extent based on an intrinsic intuition toward nature. Many aspects of plants are hidden from fact-based measurements with technical instruments and rely on observation and experiential estimation, such as judging the state of health of a plant organism, or when a plant is about to bloom. Similarly, the effects plants have on humans are equally difficult to evidence with hard data. However, in our approach, we aim to use technology as a mediator between these to agents to arrive at a better understanding of what the interrelationship entails. From this combination, we investigate two research questions: 1) We have investigated what measurements are relevant to explore in the care for a plant towards promoting awareness about the impact of nature on healthy learning environments.SLEs collect data, analyze data, and react considering the results of analyzing the data, for example with machine learning algorithms or natural language processing; 2) We have investigated what kind of plant-human interactions might help to scaffold learning activities towards promoting awareness about the impact of nature on healthy learning environments. These questions call for innovative solutions that bind IoT technologies and pedagogies using learning analytics. In this paper, we present a prototype system called Smart Spike as a key enabler to scaffold learning activities in SLEs.



The system architecture includes a mobile chatbot which is based on the Telegram instant messenger. This system has been configured with a series of commands that allow interaction between stakeholders and the system. The application features two types of interactions considering the actor initiating the communication:

- Stakeholder-initiated interactions. Teachers and students can use the chatbot to find the last measurement made by any of the sensors installed in the system.
- System-initiated interactions. Teacher and students remotely receive alerts when specific scenarios occur (See configured rules in previous section). These notifications can be configured to be sent to one person or to a group.

This feature was designed to refine the developments and perceived usefulness of the Spike to enhance human-2-plant interaction in smart learning environments, and to stimulate environmental awareness using plants and IoT technology. One insight we took from the bulk of feedback was that there are a complex number of potential variables involved. It may prove to be difficult to prioritize various indicators delivered by the sensors over others. For some parameters very little is known regarding their impact on plant life, e.g., noise level.

A further challenge was the triangulation of different ambient measurements that are mutually reinforcing: air quality, state of soil, and internal plant health. Since the aim of the study is learner-focused, a simple gathering of environmental data will not be comprehensive enough to fully fathom the impact on students' well-being and productivity. The responses we received in the evaluation exercise partly suggest to combine physical measurements with immeasurable subjective input by individuals (e.g., what do you feel when looking at me?). This can be achieved via the "plant diary" as envisaged in part (c) of our learning analytics lens. However, this might require the development of a shared vocabulary.

These forthcoming challenges aside, the results obtained indicate that the data that can be automatically collected by the sensors encapsulated in the Spike may be relevant and valid to support interesting learning activities. Results also show that the potential of the Smart Spike device goes beyond its current design, as additional sensors have been proposed by participants to extend the device. Moreover, the responses stressed the role of human annotations as complementary data to extend the depth and breadth of the learning opportunities that can be envisaged. Among the independent variables are threshold levels arising from the analysis of the data and the reactions they trigger. Different plant species operate under different conditions. Therefore, critical conditions arise under different circumstances. Learning activities will be created to define user control mechanisms to configure thresholds for warning levels to take care of the plant. These mechanisms will be combined with botanical advice to customize the initial plant-specific settings of the Spike. Interaction triggers can then be introduced on the basis of LA interaction patterns collected in learning activities.

The general idea and objective of the Spike was received very positively by the participants, as they see great opportunity and potential for integration into classroom life and teaching. The active engagement of students is perceived to lead to experiential learning with options for some inquiry-based learning activities. It will be an interesting experiment to evaluate the individual relationships emerging between plant and student caretaker. Our learning analytics approach will monitor this relationship and detect potential changes in behavior and attitude. A variety of mutual attachment levels are foreseeable, but it can be hoped that all students will benefit and internalize a higher appreciation and awareness of plant surroundings.

The current state of the art of plant-supported pedagogy is still rudimentary. Involving technology as a mediator in a participatory learning design, could meet objections by some people or contravene health and safety policies. Using mobile interfaces for interaction, for example, could be prevented by school policies restricting mobile phone use.

In future work, we intend to investigate suitable machine learning algorithms to chat with plants with the aim to support specific dialogues for improved well-being of plants, students, and teachers in learning spaces.

You can see a short video description of the Mobile messaging platform here:

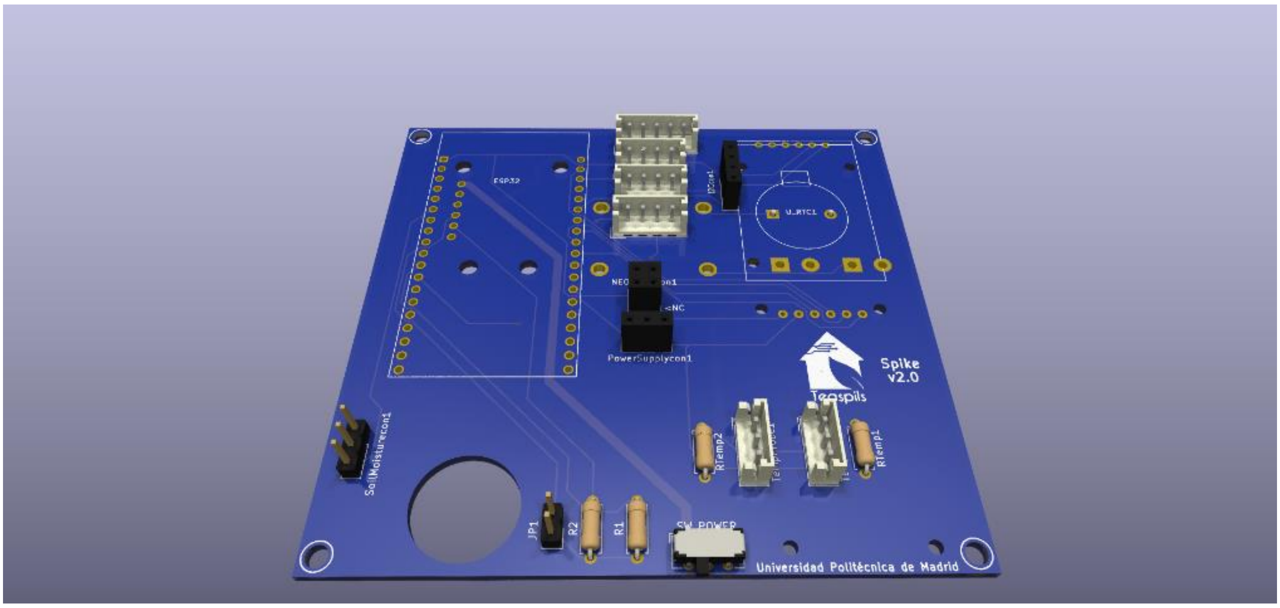
Video:
https://drive.google.com/file/d/14cdI9zg3kBfdA9l84Rg6e-dTsfXbNKk6/view?usp=sharing

Generated available outputs

Here you have instructions and resources to replicate the Sike:

- Printed Circuit Board (PCB) design.

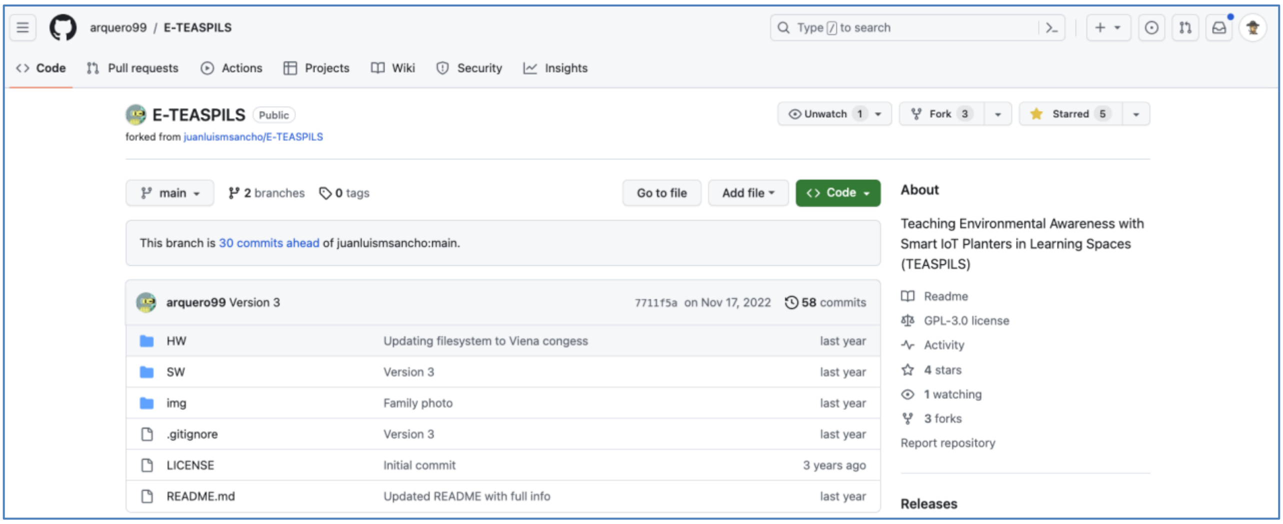
Download PCB files available here:
https://drive.google.com/file/d/1XRJqCgwo9O8lwYh2nnhNIP5G24eXSuTH/view?usp=sharing



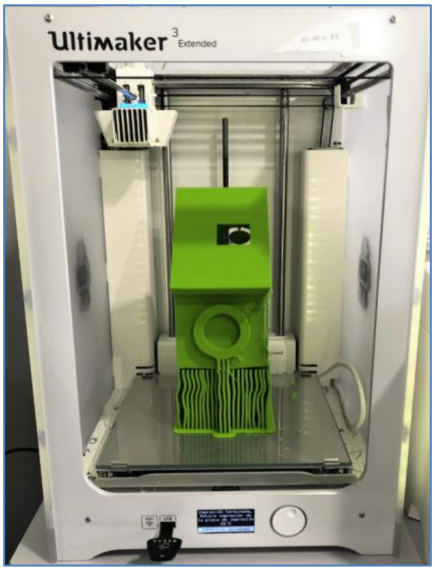
You can order 5 x replicas for 10€ e.g. here: https://3d.jlcpcb.com/

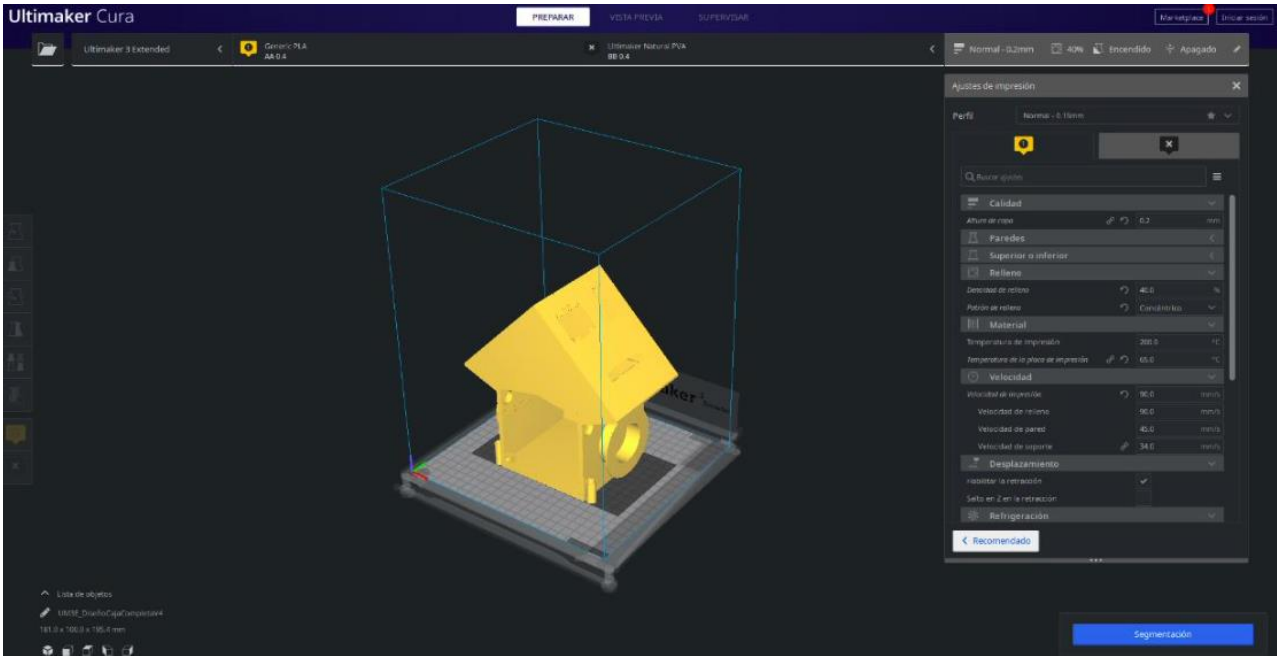
- Open source code running in the Spike. Available here: https://github.com/arquero99/E-TEASPILS (Github by Juan Arquero Gallego)

Developed for ESP32 microcontroller with Arduino IDE.



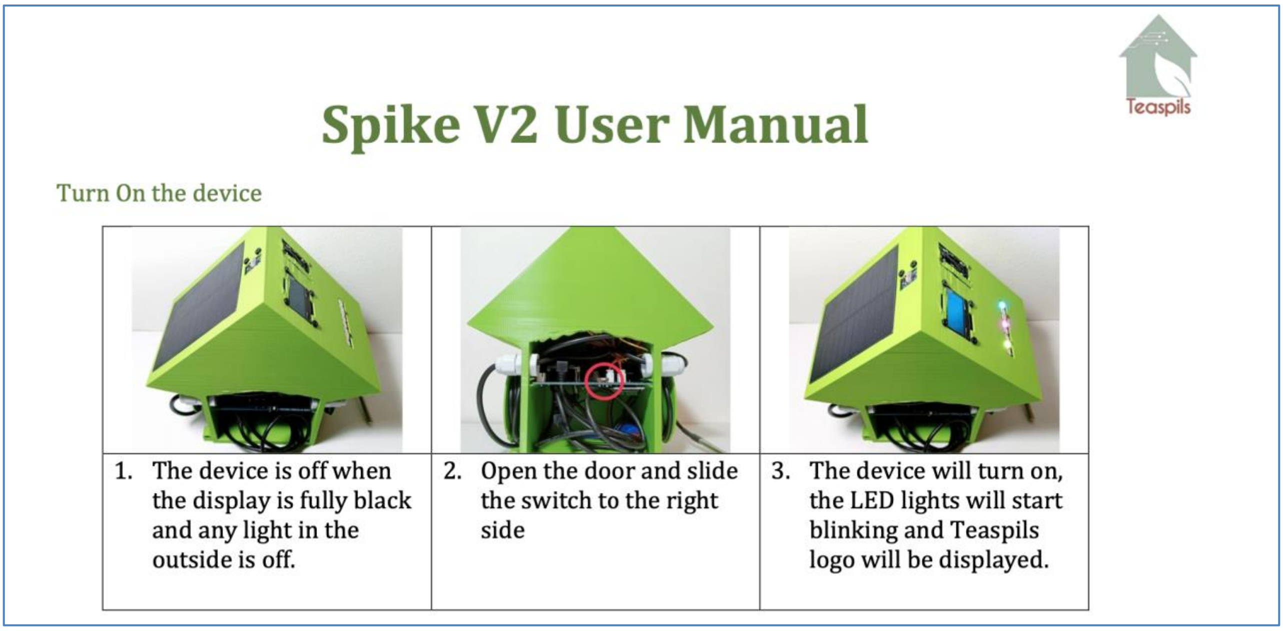
- 3D house-formatted case design. Designed with FreeCAD and printed with Ultimaker 3D printer:



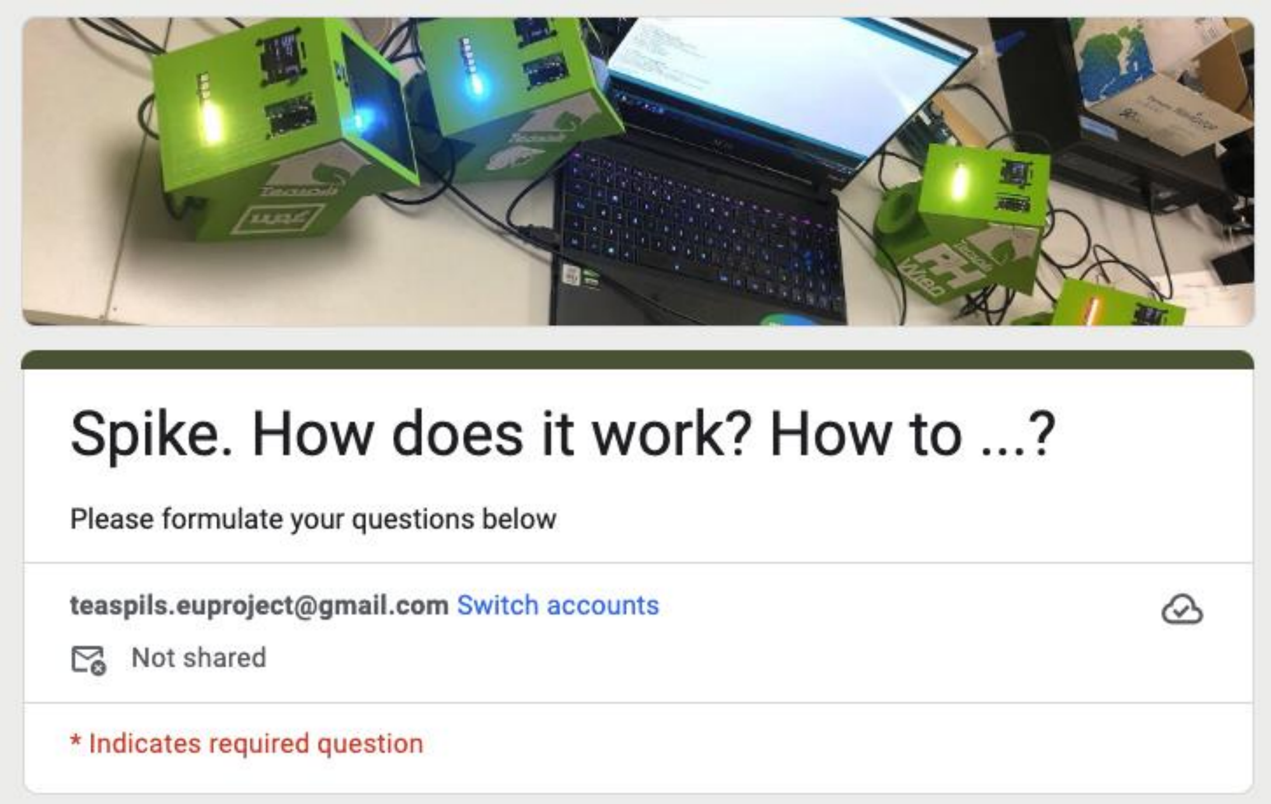


Moreno Sancho, Juan Luis (2023). *Spike: Sistema IOT para fomentar conciencia medioambiental en espacios de estudio*. Thesis (Master thesis), E.T.S.I. de Sistemas Informáticos (UPM)
Freecad design files for 3D printer available here (See page 27 onwards: https://oa.upm.es/76164/)

- Spike user manual. How to use the Spike?. Available here: https://drive.google.com/file/d/1vg30S2c52OvdgxEBmN2GEcXFNcLBN2vd/view?usp=sharing



- Troubleshooting Any issue/problem with the spike? Write here you question via this form and we will contact you.



Alternatively, you can write an email to **teaspils.euproject@gmail.com**

Dissemination and academic results

The success of this IO is contrasted with the following tangible results:

- 4 final degree projects, 2 final master's projects, and 1 doctoral thesis (in progress) involved/finished throughout the project.
- Articles in international impact journals
- Articles in international conferences.

Available academic publications reporting this on this Intellectual Output available here:

Tabuenca, B., Moreno-Sancho, J. L., Arquero-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.

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 tow disparate lifelong learning contexts. Finally, lessons learned and cues for further research are discussed.

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.

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.

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.

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

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.