Talking to plants: an IoT system supporting human-plant interactions and learning

Bernardo Tabuenca[1], Wolfgang Greller[2], Davinia Hernández-Leo[3], Carlos Gilarranz-Casado[1], Vicente García-Alcántara[1] and Edmundo Tovar[1]

[1] Universidad Politécnica de Madrid, Calle Ramiro de Maeztu 7, 28040 Madrid, Spain
[2] Pädagogische Hochschule Wien, Grenzackerstraße 18, 1100 Wien, Austria
[3] Universidad Pompeu Fabra, Plaça de la Mercè, 10-12, 08002 Barcelona, Spain

Abstract

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.

Keywords

Artificial intelligence, environmental awareness, chatbots, internet of things, plants, sensors, smart learning environments, well-being

1. Introduction

Plants have always played a vital natural part of human life and surroundings. Far from merely being an essential source of food, the value of plants as part of human working and living environments have long been recognized. In the present era of environmental awareness and the recognition of the importance to protect natural environments and species from decline and even extinction, plants (especially trees) are increasingly playing a pivotal role in the discussion over climate change. Most of this public debate focuses on natural wilderness environments, but plants are also omnipresent in our everyday urban lives. However, understanding their role and effects on humans has yet to enter our thinking [1]. The effect of greenery in the home and in the workplace serves to stimulate both the senses and the mind, improving mental cognition and performance [2]–[4]. This study aims not only to further our general understanding of what plants in urban indoor working and learning environments mean to us and what impact they have on our physical and mental well-being, our social interactions, our cultural identity, and our productivity. It also intends to raise awareness in schools of the importance of any surrounding greenery. Hence, it aims to advance children's ecological knowledge through "green pedagogies" and exposure to plant care, thereby developing an integrated linkage between the presence of healthy plants and the microclimate in the classroom in support for social coherence and learning [5], [6].

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EMAIL: bernardo.tabuenca@upm.es (A.1); wolfgang.greller@phwien.ac.at (A.2); davinia.hernandez-leo@upf.edu (A.3); carlosandres.gilarranz@upm.es (A.4)); vicente.garcia@upm.es (A.5)); edmundo.tovar@upm.es (A.6)
ORCID: 0000-0002-1093-4187 (A.1); 0000-0003-0548-7455 (A.3) ; 0000-0002-2712-0702 (A.4); 0000-0001-6770-4115 (A.5); 0000-0003-2929-659X (A.6)

1.1. Plants in smart learning environments

The presence of plants in the classroom still is a rather rare feature. School policies, health concerns, or similar hesitations might have prevented this from happening. However, our knowledge about the human-plant interrelationship increases steadily, which identifies that plants can play a calming and soothing role in our everyday lives, and, thereby, positively affect our general well-being, our productivity, concentration, and social interactions [5]. Using plants not only as an aesthetic decorative feature, but as a pedagogic asset in classrooms, school corridors, and halls might help scaffolding technology-enhanced learning activities in so called Smart Learning Environments (SLE) [7]–[10]. A recent review [11] concludes that SLEs are ecologies comprising four key components:

1. Stakeholders. Students and teachers that generally perform learning activities. Teachers can play a key role organizing learning activities where plants are the main focus of attention.
2. Space. Physical or virtual environment where learning occurs. The classroom, or the desktop where the stakeholder normally performs learning activities. In this research, we explore the role of plants for well-being in physical learning spaces.
3. System. The system collects data from the learning context, processes the data collected, and coherently suggests actions to ease learning constraints towards improved learning performance [11]. These core functions (sense-analyze-react) provide smartness to the SLE with the help of technology. In this research, we investigate how plants can add value to these core functions supported by technology.
4. Technology. In SLEs, technology is configured to assist stakeholders. Data processing techniques, or IoT systems are examples of technologies included in SLEs to assist stakeholders. In this study, we explore IoT technologies that might help to enhance learning using plants and learning analytics (LA).

LA are driven by the collection and analysis of traces that learners leave behind [12]. With an IoT approach using sensors and visualizations, students can not only learn basic facts about plants, but also about care and responsibility towards them. LA can support students and teachers to monitor, scaffold and customize activities in smart learning environments.

1.2. Related work and research questions

Related previous research put an emphasis on the environmental improvements that plants bring to the atmosphere in classrooms, such as improving air quality [13], [14]. Nieuwenhuis et al. [15], on the other hand, reflect on the landscaping potential that plants offer for working spaces, a function that is also picked up in some frameworks by education authorities as part of their furnishing and design recommendations for classroom spaces involving planters. Moreover, previous research investigates the pedagogic and psychological benefits plants bring to students and teachers. Among them are higher attention spans [4], [14], well-being [4], [5], and even study performance [16], [17]. Despite these attempts to justify and promote the presence of potted plants in indoor learning spaces, there is a perceived lack in the literature investigating social aspects involving plants, such as their impact on the classroom community, or the interaction patterns between humans and plants sharing the same space. This gap neglects, in our mind, the findings by Elsner & Wertz [18] that plants are instrumental for human existence and evolution. The authors found that infants up to one year and a half exhibit more social attention involving plants than other object types. In a survey study from 2005, Lohr & Pearson-Mims reported on the influence that children's interactions with plants have on their later attitudes towards trees and gardening as adults [19]. Likewise, previous research in the area of applied technology has used sensors and IoT technology to measure and control the microclimate in learning spaces [20]–[23].

In this study, we integrate IoT technology with plants in order to make them "smart". This is to say, we collect various types of sensor data from plants to communicate with stakeholders in learning activities. In this way, plants engage in an ongoing "conversation" with their human caretakers (teachers and students), which we could call a technology-supported "plant-human dialogue". This approach also allows to generate interactive learning patterns that can be integrated into curricular activities. These learning activities do not focus solely on developing some simple botanical knowledge, but are aimed at a cross-subject theme developing higher levels of digital and data literacy or understanding graphical representations and models [24]. Our approach triangulates plants, stakeholders, and learning analytics to provide for a higher appreciation of indoor greenery and its connection to the plant world around us.

Learning analytics is described as *"the application of analytic techniques to analyse educational data, including data about learner and teacher activities, to identify patterns of behavior and provide actionable information to improve learning and learning-related activities"* [27]. In our application, we collect and combine interaction patterns between students and plants in three ways: (a) caring actions of students on plants as seen in sensor data, e.g. watering, fertilizing, etc.; (b) communication activities with the plant via the chatbot, including responses of students to plant notifications – e.g. the plant notifies the user for water. This will allow us to find out whether students are proactive, reactive, or indifferent towards plants, and whether this relationship changes over time; (c) using a digital plant diary, students record their observations and attitude towards plants on a weekly basis. This manual input data can be analyzed independently or in relation to their other performances and interactions. Additionally, LA offers opportunities to gamify interaction patterns: e.g. a "green thumb competition" for the best caretaker in class. This gamification will be explored in a separate strand of the project at a later stage.

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:

In RQ1, we investigate 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. Therefore, in RQ2 we investigate 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.

2. Smart Spike: an IoT system to promote environmental awareness

The Smart Spike was conceived to be installed in a planter in indoor learning spaces (e.g., classroom, library, hall, office). The sensors ("sense" core function of SLE framework [11]) report measurements of plants, soil and environment. The current version of the system includes sensors to measure ambient variables (carbon dioxide, temperature, humidity, light, and noise) and soil variables (soil moisture sensor) which is embedded in the ground. A non-volatile memory card is used to store sensor data when WIFI connection is not working, and consequently data cannot be stored in the cloud. The system incorporates a 0,96 inches OLED display with 128 x 64 pixels resolution to show alphanumeric representations of the data collected by the sensors, and a 12-led ring to report visual feedback combining different colors. These displays perform actions (e.g., show visual effects or present information) depending on the interpretation of the data collected from the sensors and the reactions of stakeholders ("react" core function of SLE framework [11]). An ESP-32 microcontroller [25] orchestrates all components capturing data from sensors, processing the data ("analyze" core function of SLE framework [11]), and presenting the data on the displays.

Additionally, the Smart Spike features a chatbot interface based on Telegram that enables a personal communication channel with the plant. Stakeholders can start a dialogue to ask the system for the humidity of the soil towards watering the plant. Reciprocally, the system can be configured to proactively alert stakeholders under specific circumstances, e.g., when CO_2 levels exceed 800 parts per million (ppm) and consequently the classroom should be ventilated. Likewise, the chatbot features commands to define the feedback displayed when the pre-configured thresholds in the rules are exceeded (e.g., show green in led ring when CO_2 is below 800 ppm). The Smart Spike thresholds can be configured to reflect what's considered to be the optimal state for individual plants (e.g., cactus vs. leafy plants). The objective of this research is to define learning activities in which students make decisions based on the values reported by the sensors about the plant, soil, and environmental variables. These traces (LA) will support stakeholders to identify behavior patterns in plant care towards providing customized queues for learning.

3. Concept Evaluation

This section presents the results of a concept evaluation towards answering RQ1 and RQ2, where the first prototype of the Smart Spike was presented.

3.1. Method

The system was presented to 62 (gender: 53 male; 9 female) students (age M=22.7; SD=4) in their last year of the degree in computer engineering (n=38), and the degree in agronomic engineering (n=24). Two different sessions of 2 hours each were organized where the components of the system and its functionality were described. The researchers argued the potential of the Smart Spike as a suitable tool to promote healthy learning environments using plants in classrooms in future courses.

In the first half of the session, the researchers made a demo of the system and students were able to manipulate the components. In the session organized with agronomy students (n=24) there was more focus on digital aspects, whereas in the session organized with computer science students (n=38), there was more focus on plants and the soil. In the second half of the session, the researchers kindly asked students for their contribution on how to better configure the system considering their collective feedback. Participants documented their reports using an online form.

3.2. Results

In RQ1, we aimed at exploring which variables might be relevant to measure and explore to promote healthy learning environments using plants and the IoT system installed in a planter. Therefore, in the first question, participants were asked to rate the current list of measurements performed by the system to rate how important these variables are to promote healthy learning environments. Table 1 summarizes the results of the reports.

Table 1

How important do you consider these measurements to promote healthy learning environments?

	Not at all important	Low importance	Neutral	Important	Very important	M(SD)
Soil moisture	0(0%)	0(0%)	2(3.2%)	12(19.4%)	48(77.4%)	4.7(.5)
Light	0(0%)	1(1.6%)	6(9.7%)	15(24.2%)	40(64.5%)	4.5(.7)
Temperature	1(1.6%)	0(0%)	6(9.7%)	20(32.3%)	35(56.5%)	4.4(.8)
Humidity	1(1.6%)	0(0%)	7(11.3%)	32(51.6%)	22(35.5%)	4.2(.7)
CO_2	3(4.8%)	3(4.8%)	5(8.1%)	20(32.3%)	31(50%)	4.2(1)
Noise	12(19.4%)	15(24.2%)	26(41.9%)	8(12.9%)	1(1.6%)	2.5(1)

The second question invited participants to pinpoint measurements they considered important to promote environmental awareness in learning spaces, but that were not included in the current version of the Smart Spike. One participant suggested integrating an IMU (Inertial measurement unit) sensor in the system to trace when the planter is moved from one place to another (e.g., close to the window, or to a different classroom). Some participants highlighted the importance of evenly distributing the light (considering the direction) impacting on the plant e.g., by measuring the inclination of the plant (phototropism). Additional suggested measurements were height of the plant (growth), the root growth within the pot, vapor pressure in the leaves or changing color.

Different participants put their focus on the soil and suggested investigating organics like salinity, PH, nitrogen, nutrients, and fertilizers in the soil. These variables are important to trace the health of the plant. Likewise, different students highlighted the importance to measure the quality and quantity of the water "... measure the electrical conductivity to check if salts are accumulating by the irrigation water or by the fertilizers used. You should also take into account if the pot is draining well or on the contrary water is accumulating at the bottom which could lead to root suffocation and fungal growth".

With regard to additional environmental variables, participants suggested including pollen and micro-dust sensors for allergic people, and ultraviolet radiation to explore the potential impact on plants. Additionally, some students suggested exploring the color of the walls considering how they absorb the radiation (clear color reflect, dark colors absorb).

In RQ2 we aimed at exploring which dialogues might be configured to facilitate the communication between plant and the stakeholders. The current version of the Smart Spike includes a Telegram chatbot that answers to questions when introducing inquiries with specific keywords. The aim of the project is to improve the chatbot to answer complex inquiries with artificial intelligence and natural language processing features. Therefore, students were invited to report what they would ask the planter, and what the planter might ask them using the bot. The main prompts are listed in Table 2.

Table 2

Potential dialogues to be implemented

Human to plant
Do you need a bigger pot? How can I help you? Do you have bugs? How old are you? Do you want me to move you closer to light? Is there enough light in the classroom? Is it too sunny/shady for you? How much did you grow in the last week? How many new leaves do you have? How do you feel today? Do you need anything? Do you have an injury or internal problem that shows no symptoms, and yet causes you to suffer and not grow as you should? How was your night/weekend? Who is taking care of you this week? Are you happy with your new caretaker? Who was your best caretaker so far? Do you need music? Are you hot (cold)? Are you 'thirsty'? Do you need more water? How are you eating (nutrients) and how can you get them from the soil? Is it too noisy for you? Do you think we are too noisy? How many hours of light did you have today? Would you be able to survive if I go on holidays for a week?
Plant to human
Can you provide me with some more light? How many leaves have I lost? Do I look healthy? Do you like how I look? How focused are you today? How do I influence you? Do you like having me around? I feel like suffocating, could you help me? (hint: check CO2 levels) I am thirsty. When have you watered me last? What do you feel when looking at me? How do I make you feel today? How are you? Are you happy with me? Have the daylight hours decreased? Do I have any parasites? What do I look like? What color do I have? Have I dropped any leaves? Am I leaning towards the light? Can you water me? Do you also notice the quality of the air? Can you transplant me to a bigger pot? Do you know the amount of oxygen I provide to the environment?

4. Discussion and conclusions

The above-described student evaluation was designed to refine the developments and perceived usefulness of the Smart 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 (see 1.2 above). 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 Smart 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 Smart 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 Smart 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 [26]. Future steps also include the development of a dashboard visualizing sensor data, designing learning tasks and resources, involving teachers in co-design workshops, and the implementation of pilots in educational centers.

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