Creating Environmental Awareness in Education Through IoT and Gamification

Christos Rodosthenous[1(✉)], Efstathios Mavrotheris[1], Wolfgang Greller[2], and Bernardo Tabuenca[3]

[1] Open University of Cyprus, Nicosia, Cyprus
{christos.rodosthenous,stathis.mavrotheris}@ouc.ac.cy
[2] University College of Teacher Education Vienna, Vienna, Austria
wolfgang.greller@phwien.ac.at
[3] Universidad Politécnica de Madrid, Madrid, Spain
bernardo.tabuenca@upm.es

Abstract. 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.

Keywords: Environmental education · Gamification · IoT

1 Introduction

In this paper, we present our efforts and plans for creating environmental awareness towards plants and greenery, educating young children and their teachers in ecological learning spaces. The work presented in this paper is based on the Erasmus+ project "Teaching Environmental Awareness with Smart Internet of Things (IoT) Planters in Learning Spaces" (TEASPILS)[1]. The project's ambition is to foster awareness of environmental issues in an educational context, e.g.,

[1] https://teaspils.eu.

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the Sustainable Development Goals (SDGs) of the UN Agenda 2030. Unlike the wider agenda of protecting natural habitats like global rainforests, our approach aims to stimulate knowledge and appreciation of plants close to the people concerned, i.e. in urban indoor environments, especially given that the effects of plants in classrooms, offices, homes and open learning spaces have hitherto been undervalued (cf. [2]).

In our work, we target young students mainly from primary and secondary education levels, and facilitate their learning about plants in their immediate vicinity. Typically, plants are seldomly placed in classrooms or seminar rooms, and, even if, they usually just have a passive role as decorative items. By contrast, it is our objective to put these plants into active use as live learning objects that support a variety of learning activities. With this promotion of plant appreciation at a young age, our intention is to lay the foundations of much wider protective attitudes of natural and artificial flora (and fauna) (cf. [9,20]). Furthermore, we enhance the learning experience with live indoor plants by involving up-to-date sensor and IoT technologies to stimulate new ways of interactive environmental learning [17,18] and gamification.

Utilising this technology-enhanced approach with a variety of IoT sensors and visualisations, young students will not only learn basic facts about plants, but also about the needed caring towards them. We use the cascading approach via educational leaders, lecturers, primary and secondary school teachers and support staff to establish a wide-ranging plant supported school climate. Towards that goal, we apply innovative pedagogical techniques and learning scenarios, while, at the same time, we aim to increase the learners' engagement with a number of gamification elements that can be applied both in the context of the smart IoT planters and of the accompanying online visualisation dashboard. Furthermore, we also propose a gamification approach for the teachers' training, which is realised through a Learning Management System (LMS) implemented in Moodle.

In the sections below, we describe the current state of the project outputs and how our pedagogical approach utilizes gamification elements along with digital sensor measurements, for increasing environmental awareness purposes. Gamification [3] is the process of applying game design elements in non-game contexts (e.g., classroom, training, marketing, fitness apps) with the purpose to engage and motivate users towards a task, by integrating elements of fun, challenge, and competition. The main research question we are exploring is how we can use gamification to promote and foster awareness of environmental issues in an educational context and fit this into the TEASPILS pedagogic model.

To facilitate plant specific insights on a number of indicators, we developed a specific sensor instrument, called "Spike" (Smart IoT planter), which measures continuously a number of parameters of the indoor plants and room environment. This internet connected device collects data in real time about the room climate, such as CO_2 levels, light and soil temperature. These data are stored locally as well as in the cloud, and are available for presentation via dashboard visualisations in real time. This IoT technology allows for interesting gamification

settings to be explored. In this paper, we specifically discuss how plant related data has the potential for pupils to reflect on their surrounding air quality and social climate in a learning space that is shared by plants and humans. We implement game mechanics as a motivating stimulant and scaffold for learning related to environmental concerns and topics, helping to trigger wider discussions and learning activities on the effects of plants on human health and well-being, while, at the same time, fostering digital skills and green competences.

An example of such an approach is the mapping of sensor data, like light and temperature to plant feelings/needs, such as whether the plant is thirsty, happy or suffocating. This approach will allow pupils to explore and receive feedback from the plant directly and will lead to a number of innovative learning scenarios.

2 The TEASPILS Ecosystem

To develop environmental awareness among teachers and pupils, we focus on three main tools which are part of the core outputs of the TEASPILS project: 1) the design and piloting of Smart IoT planters in the classroom, 2) the creation of a visualisation dashboard to present sensor data, and, 3) the training of educators in the utilisation of indoor plants and sensor equipment in teaching and learning activities, using a Small Private Online Course (SPOC). Furthermore, we are designing a gamification framework to enhance the use of these tools, by applying gamification elements to increase the engagement and interest of learners.

2.1 The Spike

A systematic design process that took into consideration a great number of pedagogic and usability issues, such as health and safety aspects of sensitive electrical equipment, connectivity and timing of sensor measurements, reproduction cost, error reporting, and suitability for use in primary, secondary, and tertiary classrooms, led to the first prototype of the Spike instrument being released for evaluation.

This IoT system (cf. Fig. 1) includes different sensors that measure the state of the soil and the environment in which they are installed. The data is saved on an SD-CARD and is also uploaded to a cloud platform. There are different channels to access the sensor data: 1) extracting the data from the SD-CARD and interpreting it in a spreadsheet (e.g., csv file); 2) importing the data into a dashboard that provides visualisation of trends; 3) using a chat to obtain instant sensor measurements (Telegram bot for mobile or desktop). The system includes a ring of LEDs that represents the different variables collected by the sensors by means of color codes. In addition, the system includes an OLED display that numerically represents the latest measurements collected by the sensors on a single screen.

The system design phase was accompanied by the first implementation of the gamification framework that enhances the train-the-educators experience in a TEASPILS led environmental training course (SPOC), during the winter

Fig. 1. Spike's controls and sensors on the "roof", and the Telegram bot screen (left).

term of 2021. The next step in this process will include the creation of game-based learning experiences and learning activities involving indoor plants and ambient sensor technologies. This is further enhanced with IoT support to enable interaction and dialogue between human learners and plants [19]. Subject specific learning activities are being developed as inspirations and transferable learning designs, suited for different pupil ages and at different levels of complexity. It is anticipated that these combined strategies of real live plants, sensor technology and gamification in cross-disciplinary learning will foster greater interest and awareness of environmental topics at all levels of education. The system will be pilot tested in schools in different European countries from the autumn 2022 onwards.

2.2 The Online Course

One of the outcomes of the TEASPILS project is a Small Private Online Course (SPOC) which is used for training the teachers who will use the tools and methods delivered by the project in their own teaching. The SPOC was offered to 30 participants between September 2021 and February 2022. The participants of the SPOC had the chance to attend 5 synchronous sessions of approximately 2 h each, including topics such as plant care requirements, the intrinsic relationship between plants humans and society, pedagogic action research, the utilisation of IoT sensors and visualisation technologies, and more.

During the SPOC, we applied a number of gamification mechanisms such as badges, points, levels, leaderboards and certificates to engage teachers while attending the course. These game mechanics where connected to activities and tasks in the elearning platform based on the Moodle LMS with the addition of specialised plugins. The content of the SPOC and the gamification mechanisms applied are presented in the previous work of [14].

The SPOC will be used as the base for developing an Open Online Course where everyone will be welcome to join and learn about the tools developed and how these tools can be incorporated in the educational process.

2.3 The Dashboard

The visualisation dashboard presents analytics and raw data collected by the "smart IoT planters" to support learning activities that promote understanding of environmental variables. The dashboard is a web application which is connected with the smart IoT planters and receives data from them. These data can then be presented in intuitive graphical formats (e.g., graphs, thermometers, etc.).

2.4 Learning Analytics

Learning Analytics (LA) is by now an established approach to use learning traces that users leave behind in electronic learning environments to infer knowledge and insights into a learner's progression along various learning paths for the purpose of improving learning (cf. [4,15,23]). In our context, it offers the possibility to triangulate learning with plant data and environmental measurements (e.g., air quality), so as to provide a more holistic picture on the interplay between plants and humans in a shared indoor learning space. From this approach, certain insights on pupil and teacher well-being can be obtained (cf. [6]), and more importantly, can be used in teaching.

3 Towards a Gamification Framework

In this section, we present our approach for providing the mechanism to increase user engagement and make learning more interesting and fun. We present a gamification framework which focuses on the TEASPLIS ecosystem presented in Sect. 2 of this work and the user type model presented by [22]. The idea is to propose actions targeted to specific user types based on the developed tools, i.e., the Spike, the dashboard, and the gamification elements aiming to increase the engagement of learners.

In particular, the gamification framework utilises the three main outputs of the TEASPILS ecosystem, using the collected datasets from the various ambient technologies and sensors as they offer themselves for devising quantitative gaming strategies, such as leaderboards, points, levels and other competitions between pupils caring for their plants. The idea behind this work is to make sensor data and the use of IoT and data visualisation technologies in plant care interesting and engaging also to younger pupils (primary level). Gaming theory will be used to create a framework of pedagogic models that can be used in environmental teaching activities. The approach taken by the research team is two-fold: At the implementation level, a virtual training course for educators was created and hosted the materials developed in the form of a SPOC, which

will eventually lead to a self-study Open Online Course. In the SPOC, a number of gamification elements were integrated and piloted with the participants. The second phase aims to generate a theoretical gamification framework for environmental learning based on the analysis of the data from the IoT devices used in the classroom. This framework will also be consolidated into the professional development course as a sustainable pedagogic model including assessment patterns to inform future adoption and application in ordinary teaching scenarios, from primary to tertiary levels.

The User Type Model. In the work of [22], six user types are identified based on their motivation: `Socialisers` are motivated by Relatedness, `Free Spirits` who are motivated by Autonomy and self-expression, `Achievers` who are motivated by Mastery, `Philanthropists` who are motivated by Purpose and Meaning (Altruism), `Players` who are motivated by Rewards, and `Disruptors` who are motivated by Change. These user types can be identified using a standardised questionnaire and based on the type, specific gamification elements can be applied which will be more beneficial for that specific user type.

An this point, it is also important to clarify that gamification does not always bring the desired results [1,21]. There are cases where learners are discouraged when they cannot achieve the desired targets, which could lead to demotivated learners.

3.1 Gamification Mechanics

Gamification has been widely used in various domains for increasing engagement and interest towards a non-game environment/system. In the educational context it has been used in courses for teaching programming languages [12], medical education [7], and in higher education [24]. The work of [10] which is relevant to our work, explores the use of gamification and how it affects pro-environmental behavioral change. They conclude that "...gamification approaches have the potential to educate and encourage pro-environmental behavioral change, as long as they combine in their design extrinsic and intrinsic motivational elements, short-term and long-term drivers, and game attributes that encourage taking action in real life". Our aim is to develop a gamification framework which will be applied on all aspects of the project, i.e., the SPOC, the Dashboard, and the Spike, and provide a holistic approach which can be utilised by teachers.

Gamifying the Spike. A major aspect of the project is the use of the Spike in a classroom setup where pupils will use it to take measurements and interact with the plant(s). The gamification framework can find application either by directly integrating with the Spike, the accompanying Telegram bot or in a physical classroom modality (tech-less). As we presented in Sect. 2.1, the Spike is one of the tools used to record sensor data and use them in a learning scenario. This leaves the door open to a number of gamification mechanisms, such as badges, leaderboards, quests, certificates, gifts, etc.

Moreover one could also suggest an approach which is more exploratory, where pupils (individually or in small groups) are assigned a plant in a pot and need to identify the values in the Spike and the dashboard where their plant is happy, unhappy, thirsty, etc. Table 1 presents an example of plant feelings mapping with the monitoring of Spike sensor values, visual observations by pupils and possible tasks for them to undertake. This is just an example where teachers are free to expand and connect with other learning activities suitable for their teaching.

Table 1. This table maps plant feeling with sensor values, observations made by pupils and the respective messages or graphics and possible tasks pupils can perform.

Plant feeling	Spike sensor values	Pupil observations	Message/ graphic	Task for pupils
Happy	Temperature, CO_2, Light	Green leaves with no signs of illness	Happy face	Spray the leaves with water
Unhappy	Temperature, CO_2, Light	Dropping leaves	Sad face	Check moisture in the pot, Check for pests, Check leaves' colour
Thirsty	Temperature	The pot is completely dry	Thirsty face	Assess the moisture in the pot by finger test, Water the plant
...	...	...	...	...

To guide teachers on appropriate gamification elements for each user type, we present in Table 2 a list of tasks and connect them with a game mechanic and a user type. These actions are just indicative and are associated with learning scenarios which where explored during the TEASPILS project workshop performed with primary and secondary school teachers from Cyprus, Greece and Spain. The examples presented can be applied with or without any technological means and can be combined in different learning scenarios.

Additional gamification mechanics can be applied directly to the Spike platform and the dashboard. The Spike can be gamified directly using the Telegram bot which currently is used for issuing commands. This will require the addition of a command to report the plant status (cf. Table 1), by featuring emojis to provide feedback on the plant's feelings to the pupil. The interface could also be used for setting the sensor threshold values for each plant feeling. Alternatively, the plant feeling can be displayed on the Spike's OLED screen or presented via colour metaphors (traffic lights: green-yellow-red) on the LED ring.

To promote competition, one can use badges, points and levels and award them to pupils who completed a task using the Telegram bot. This can work both

Table 2. In this table we describe actions and tasks undertaken by pupils and use a specific game mechanic and map them to the recommended user type.

Action/Task		Game element	User type
P1	Add the title of "Group Coordinator" to the pupil that helps other pupils in monitoring the Spike sensor values	Administrative role	Philanthropist
P2	Keep the plant diary up to date and share it with the rest of the class as a good example for others	Knowledge sharing	Philanthropist
P3	Pupils can give a "thumbs up" card to another pupil who is identified as the one that provided the best care for their plant	Gifting	Philanthropist
S1	Allow pupils to form teams and take care of a plant of their choice in the classroom while monitoring the temperature. Pupils compare the soil temperature from the Spike and dashboard with other teams plants and try to identify the differences and why these differences occur (e.g., sun exposure, type of plant)	Teams	Socialiser
S2	In a team of pupils, vote for the pupil who was the expert in a specific task such as watering the plant, spraying leaves, etc	Competition	Socialiser
F1	Ask pupils to find ways to check if pollution affects the health of a plant by asking them to place it on different places in their school and use the Spike to measure the CO_2. The pupil who demonstrates their methodology is rewarded with the badge of "Scientific Explorer"	Exploration	Free spirit
A1	In a scenario where pupils take care of a plant, we record each week the plant state (height, number of leaves, etc.) and award badges to the pupil whose plant had the best measurements each week. When a badge is awarded, the pupil levels up and this is presented in a time line depicting its progression. At the end of the month a certificate is awarded to the pupil who reached the highest level	Certificates & Levels	Achiever
P1	Award a badge to a pupil who successfully completes a specific task on the plant. For the duration of the school year, award points for each task to the pupil and record them on a leaderboard	Reward & Leaderboards & Levels	Player
P2	Create a virtual plant coin to "pay" pupils for their service towards taking care of a plant that produces fruits. When the fruits are ready then these can be used as physical "coins" for trading	Virtual Economy	Player
D1	Present pupils with a setup for measuring the CO_2 of a plant. Ask pupils to propose and implement new ideas to perform the measurement using the Spike and the Dashboard	Innovation Platform	Disruptor

in an individual mode where a pupil uses their phone as their personal log or in group-based setup where a pupil is responsible for coordinating a group of pupils and for recording their findings. The Telegram bot can also be used to present a leaderboard and update it based on the completed tasks of the individual or the group. Badges might be rewarded to pupils who take the most care of the plant.

These rewards might be accounted considering the frequency of pupils' requests to the plant, or considering the depth of the analysis of the datasets. In the work of [13] a similar gamified approach is presented for vocabulary training using a Telegram bot. In particular, the bot allows the award of badges, trophies, points and displays them in a leaderboard.

Gamifying Learning Analytics. Learning Analytics data can be used as a stimulant and motivator for learning using gamification tactics [11]. By showing pupils their interaction patterns not only with each other and the learning materials provided, but also with "their" plants, engagement with them on a regular basis can be enhanced (e.g., watering, checking, data readout). The Spike's IoT chatbot feature can initiate reflections about the well-being of pupils and plants in the same environment. They could feel hot or cold, dry or wet, lacking fresh air, etc. In this playful way, it is possible that learners identify more directly with living plants in their immediate surroundings. Rather than creating a serious game simulation [16], we are using live plants as the learning object for discovery learning.

Moreover, pupils can be given challenges and can be asked to compete against other pupils by comparing the visualisations of the plant-related data in the dashboard tool, which displays the graphs showing the changes and states of the respective indoor climate and soil. Naturally, each plant species requires certain conditions to thrive and grow. To find the optimal settings and thresholds can be one competitive task for pupils, and can be awarded with badges or points. Furthermore, the consistency in delivering optimal conditions to the selected plant over a longer period of time, can result in further incentives being handed out. Thus, the utilisation of Learning Analytics engagement patterns paired with gamification is a good way to bring learners to reflect on their own knowledge and competences regarding plants (their "green thumb" level) and study natural causal effects (like high CO_2 levels leading to fatigue). Additionally, they are benefiting from enhancing their interpretation of visualisations and graphs, structure discovery, relationship mining, and prediction [11].

Taking care of and responsibility for plants is another objective of our work. The collected plant datasets and the interactive IoT elements of our Spike tool lend themselves well for gamification. This roughly follows the "Tamagotchi" approach [8] were players willingly dedicated time, attention, and emotions to a virtual pet - in our case a real potted plant. The higher the level of interaction and care each pupil provides for their plant, the more this will be reflected in their respective learning analytics datasets. It is our expectation that this also leads to higher levels of appreciation of natural flora in general (cf. [5,9]).

Gamifying the Dashboard. Gamification elements can also find application in the dashboard. Figure 2 illustrates a suggested approach for gamifying the dashboard with simple game elements such as a leaderboard, points, progress bar and graphics to promote aesthetics.

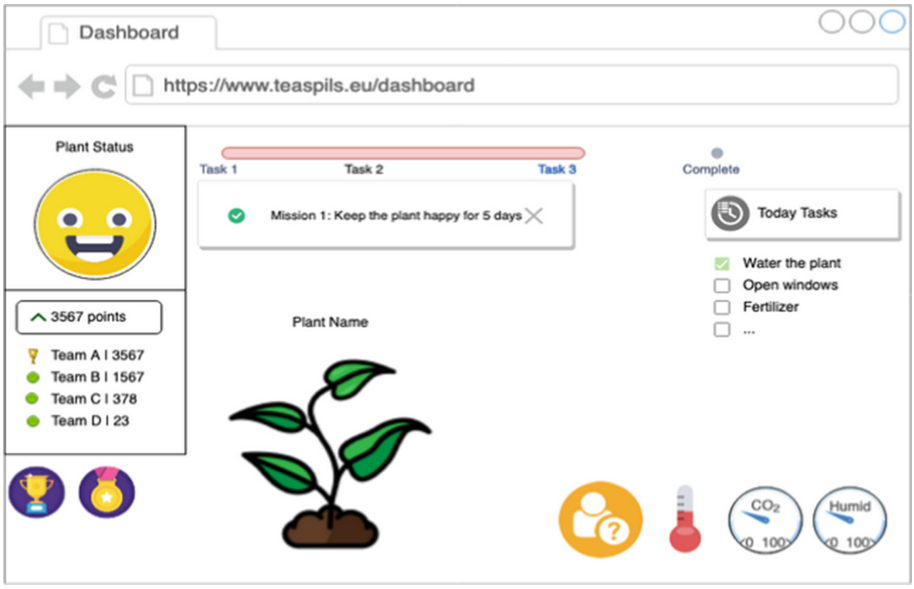

Fig. 2. A demo of a featured gamified version of the Dashboard where the plant status and the leaderboard are depicted on the left, the progress bar and the current mission are depicted in the centre and the task list is shown on the right.

Gamification does not only need to be applied using technological means, but it can be used successfully without any. Based on the learning activities provided, a set of game mechanics can be used to promote engagement towards a learning activity.

4 Conclusion

In this paper we describe our efforts for delivering an innovative educational program to increase environmental awareness through IoT and Gamification, in the context of the Erasmus+ Project TEASPILS. The approach followed involves both the use of IoT technologies and a pedagogic framework which includes a gamification approach in order to increase the engagement and interest of learners to the program. This first version of the gamification framework was originally presented in the Project's Teachers' Training Workshop and subsequently teachers were invited to design new learning activities using gamification mechanics. These activities were uploaded to the ILDE+ platform[2] which is accessible to everyone interested. The platform is part of the TEASPILS ecosystem and provides a collection of short learning designs on how to use plants in teaching.

Future versions of the gamification framework will include more actions and activities and their corresponding game mechanics, based on the feedback we

[2] https://ildeplus.upf.edu/teaspils/.

will get from the pilot period at schools. The gamification framework presented in this work is limited to the IoT smart planter and the dashboard and does not refer to game mechanics that could be included in the Open Online Course scheduled for release at the end of the project.

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References

1. Andrade, F.R., Mizoguchi, R., Isotani, S.: The bright and dark sides of gamification. In: Proceedings of the 13th International Conference on Intelligent Tutoring Systems, ITS 2016, vol. 9684, pp. 176–186. Springer, Heidelberg (2016). https://doi.org/10.1007/978-3-319-39583-8_17
2. Cetin, M., Sevik, H.: Measuring the impact of selected plants on indoor CO_2 concentrations. Polish J. Environ. Stud. **25**(3), 973–979 (2016)
3. Deterding, S., Dixon, D., Khaled, R., Nacke, L.: From game design elements to gamefulness: defining "Gamification". In: Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, pp. 9-15. ACM (2011)
4. Greller, W., Drachsler, H.: Translating learning into numbers: a generic framework for learning analytics. J. Educ. Technol. Soc. **15**(3), 42–57 (2012)
5. Grinde, B., Patil, G.G.: Biophilia: does visual contact with nature impact on health and well-being? Int. J. Environ. Res. Public Health **6**(9), 2332–2343 (2009)
6. Han, K.T.: Influence of limitedly visible leafy indoor plants on the psychology, behavior, and health of students at a junior high school in Taiwan. Environ. Behav. **41**(5), 658–692 (2009)
7. Krishnamurthy, K., et al.: Benefits of gamification in medical education. Clin. Anat. **35**, 795–807 (2022)
8. Lawton, L.: Taken by the tamagotchi: how a toy changed the perspective on mobile technology. iJournal **2**(2) (2017)
9. Lohr, V.I., Pearson-Mims, C.H.: Children's active and passive interactions with plants influence their attitudes and actions toward trees and gardening as adults. HortTechnol. Horttech **15**(3), 472–476 (2005)
10. Ouariachi, T., Li, C.Y., Elving, W.J.L.: Gamification approaches for education and engagement on pro-environmental behaviors: searching for best practices. Sustainability **12**(11), 4565 (2020)
11. Owen, V.E., Baker, R.S.: Learning analytics for games. In: Handbook of Game-based Learning, pp. 513–535 (2019)
12. Papadakis, S., Kalogiannakis, M.: Using gamification for supporting an introductory programming course. the case of classcraft in a secondary education classroom. In: Brooks, A.L., Brooks, E., Vidakis, N. (eds.) Interactivity, Game Creation, Design, Learning, and Innovation, pp. 366–375. Springer, Heidelberg (2018). https://doi.org/10.1007/978-3-319-76908-0_35
13. Rodosthenous, C., et al.: Using crowdsourced exercises for vocabulary training to expand conceptnet. In: Proceedings of the 12th Language Resources and Evaluation Conference, pp. 307–316. European Language Resources Association (2020)

14. Rodosthenous, C., Mavrotheris, S.: Applying gamification mechanics in an environmental education SPOC. In: Proceedings of the 14th annual International Conference on Education and New Learning Technologies (2022)
15. Schmitz, M., van Limbeek, E., Greller, W., Sloep, P., Drachsler, H.: Opportunities and challenges in using learning analytics in learning design. In: Lavoué, É., Drachsler, H., Verbert, K., Broisin, J., Pérez-Sanagustín, M. (eds.) Data Driven Approaches in Digital Education, pp. 209–223. Springer, Heidelberg (2017). https://doi.org/10.1007/978-3-319-66610-5_16
16. Shoukry, L., Göbel, S., Steinmetz, R.: Learning analytics and serious games: trends and considerations. In: Proceedings of the 2014 ACM International Workshop on Serious Games, SeriousGames 2014, pp. 21–26. ACM (2014)
17. Tabuenca, B., Börner, D., Kalz, M.: Effects of an ambient learning display on noise levels and perceived learning in a secondary school. IEEE Trans. Learn. Technol. **14**(1), 69–80 (2021)
18. Tabuenca, B., García-Alcántara, V., Gilarranz-Casado, C., Barrado-Aguirre, S.: Fostering environmental awareness with smart IoT planters in campuses. Sensors (Basel, Switzerland) **20**, 2227 (2020)
19. Tabuenca, B., Greller, W., Leo, D.H., Casado, C.G., Alcántara, V.G., Caro, E.T.: Talking to plants: an IoT system supporting human-plant interactions and learning. In: Proceedings of the LA4SLE 2021 Workshop: Learning Analytics for Smart Learning Environments (2021)
20. Thor, D., Karlsudd, P.: Teaching and fostering an active environmental awareness design, validation and planning for action-oriented environmental education. Sustainability **12**(8), 3209 (2020)
21. Toda, A.M., Valle, P.H.D., Isotani, S.: The dark side of gamification: an overview of negative effects of gamification in education. In: Cristea, A.I., Bittencourt, I.I., Lima, F. (eds.) Higher Education for All. From Challenges to Novel Technology-Enhanced Solutions, pp. 143–156. Springer, Heidelberg (2018). https://doi.org/10.1007/978-3-319-97934-2_9
22. Tondello, G.F., Wehbe, R.R., Diamond, L., Busch, M., Marczewski, A., Nacke, L.E.: The gamification user types hexad scale. In: Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play, p. 229-243. ACM (2016)
23. Van Harmelen, M., Workman, D.: Analytics for learning and teaching. CETIS Anal. Ser. **1**(3), 1–40 (2012)
24. Wiggins, B.E.: An overview and study on the use of games, simulations, and gamification in higher education. Int. J. Game-Based Learn. **6**(1), 18–29 (2016)