Master thesis on Cognitive Systems and Interactive Media

Universitat Pompeu Fabra

Dashboard for Environmental Awareness Education

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Abstract

An educational dashboard can provide opportunities for new methodologies and learning activities aligned with the 21st-century skills and the challenges of our society, such as the fight against climate change. In the context of the TEASPILS project, a dashboard has been developed as part of an IoT system to monitor the environmental conditions of plants, with the aim to promote environmental awareness among students and their teachers. The adoption of such a learning technology enables experience-based activities, but can also arise multiple questions about its impact on students. While dashboard tools for teachers in formal education have been extensively covered in the literature, fewer studies have focused on students, and even lesser on environmental dashboards for education. This research has addressed the implementation of a dashboard for environmental awareness education from different points of view, by designing learning activities based on the TEASPILS dashboard and by implementing and analysing the impact of different dashboard systems -mirroring, alerting, and advising- on the problem-solving skills of primary school students. For these purposes, a workshop around the topic of data analysis to understand the best conditions for a plant was conducted with primary and high school students, bringing the concept of the TEASPILS IoT system into real classrooms for the first time. Results showed a significant positive impact of the activities on the environmental awareness goal. Although no significant differences were found in problem-solving performance between experimental groups, other differences and observations allowed us to gain insight and to unfold some preliminary answers and further questions on the use of AI in education through alerting systems.

Keywords: Learning Dashboard; Environmental Awareness; Learning Activities; Problem-solving skills; Alerting system; Educational AI

1 Introduction

1.1 Problem statement

Education is fundamental in the transformation of human societies. As technology evolves rapidly, so do technologies within classrooms and their implementation in all kinds of activities and goals, and the urge to exploit them to address ongoing challenges increases. It is clear that one of the greatest challenges of modern society is the fight against climate change, and education together with technology provides an opportunity to accomplish the substantial transformation needed. In this context, the European TEASPILS project has been established to raise environmental awareness while educating students through experienced-based learning activities using plants with smart IoT planters available in learning spaces[1]. Then, the data collected by the sensors is visualized in a human-centred dashboard[2].

As a consequence of adopting such a learning dashboard for environmental education, the following questions can emerge: Which is the impact on students' cognitive skills of a dashboard of this kind? Does the impact differ in the presence (or absence) of an alerting system? And of an advising intelligent system? What activities can be designed to enhance the development of skills like problem-solving and critical thinking? Some studies have already addressed similar issues, including the cognitive load in multimedia learning environments[3], the impact of augmented reality application on the success and problem-solving skills of students[4], or the orchestration load in a comparison of teacher support through mirroring and guiding tools[5].

The relevance of addressing such questions relies on the fact that learning technologies could help shape the cognitive development of future generations in various directions; devoting effort to gain some insight into them, could be a good starting point and provide some directions for future research on the cognitive impact of learning technologies on students. The results could also contribute to the development of a framework for dashboard technologies based on cognitive design, not only for environmental education but also for other topics relevant to 21st -century education.

In this research project, we aim to conduct a comparison between environmental dashboards tools with no-alerting, alerting, and advising intelligent systems, and to observe their effects on learners' problem-solving skills, through learning activities designed to stimulate specific competencies. The learning activities will aim to promote, on one hand, environmental awareness, plant conservation, and the scientific method, and, on the other hand, some of the

21st-century skills, together with problem-solving. Quantitative and qualitative methods will be used to identify and assess the answers and the solutions proposed to the problems presented by the TEASPILS dashboard. Questionnaires will also be used in a pre-test to collect data to set a baseline and in a post-test to then perform the comparisons of the different dashboard systems by statistical analysis methods.

2 State of the art

2.1 The TEASPILS project

Human life depends on the conservation of nature and environmental health; however, there is no country that is not experiencing the drastic effects of climate change, and the preservation of the natural environment is not only essential but is also becoming a major challenge of our times[6,7]. As with many other relevant areas in our societies, education plays a fundamental role in raising environmental awareness, promoting the importance of plants on young people, and increasing sensitivity towards the natural environment and its effects on our planet and human wellbeing, all of them of high priority[8]. In modern societies, the idea of the natural environment expands beyond the unspoiled, wild ecosystems, and includes as well plants present in urban surroundings co-existing with humans, such as plants placed in working or learning spaces.

In this context, the European research project TEASPILS (Teaching Environmental Awareness with Smart IoT Planters in Learning Spaces)[1] aims to raise environmental awareness while educating students through learning activities based on plants monitored by the sensors in smart IoT planters. The project aligns with the UN's Sustainable Development Goals (SDG) agenda[7] and promotes the goal to build a society aware of its environment, including the effects of plants. From a more pedagogical point of view, a project of this kind enables experience-based environmental awareness learning activities and provides young students with the tools to explore, understand and interpret scientific evidence, developing critical thinking and reasoning skills among others, crucial for a critical and informed society capable of facing current challenges.

Multiple research lines led by different higher education institutions are being unfolded as part of the TEASPILS project, addressing the interdisciplinarity of it. Regarding the IoT technology, a "smart spike" system with sensors to measure various parameters of the environment -at the moment temperature, humidity, illumination, CO_2 concentration and environmental noise- has been developed, together with a data visualization human-centred dashboard[1,2]; this coupled IoT technology should allow teachers and students to interact with the plant and learn more about the factors affecting the plant, as well as the learning environment and its social aspects. The design process of the dashboard considered the data available from the sensors and the desired learning activities to support, following a human-centred methodology based on co-designing workshops with experts and teachers[2]. Moreover, the TEASPILS project involves research on the sociological and emotional effects of indoor nature in classrooms on students, the definition of a digital green competences framework, training for educators, data collection from participating learning classrooms, and the design of innovative learning experiences.

2.1.1 Digital Green Competences

The Digital Green Competences framework comprehends the mission and specific aims of the TEASPILS project mentioned above, related to the environmental awareness through learning activities based on plants monitored by the sensors in smart IoT planters.

In a similar context, the European Commission elaborated the GreenComp framework[45], a sustainability competence framework to promote learning on environmental sustainability. This framework proposes a set of sustainability competences to feed into education programmes, grouped into four interrelated competence areas: ‘embodying sustainability values’, ‘embracing complexity in sustainability’, ‘envisioning sustainable futures’ and ‘acting for sustainability’[45], with the final goal to develop responsibility and caring towards our planet and public health.

The competences in the Digital Green Competences framework[1], then, do not only focus on sustainability and green education, but also relates them to the digital systems available for students to develop them, bridging these two areas and covering the aspects resulting from their intersection in education. The framework comprises a total of 4 general goals, divided into subgoals for the specific competences:

- Goal 1. Foster environmental awareness
- Goal 2. Educate teachers and young people towards ecological learning spaces
- Goal 3. Stimulate knowledge and appreciation of plants
- Goal 4. Explore plant data in classrooms and learning spaces

These goals are then divided into subgoals to further define the competences, and each of them is matched with the specific knowledge and skills (declarative and procedural knowledge) and the specific context, autonomy, and responsibility (conditional knowledge) that apply[1].

Then, the activities with the TEASPILS IoT system -or any other system devoted to plant care, agriculture, monitoring and environmental data, among others- should either be designed considering the framework and its specifications or be able to be mapped to the appropriate competences in a subsequently manner.

2.1.2 The TEASPILS dashboard

The TEASPILS dashboard is the result of a human-centred process involving stakeholders (experts and practitioners) in its co-design through guided hands-on workshops[2]. The current version of it includes interfaces for data visualization over a timeline in the form of line graphs, for comparisons between measures, for single measures data represented graphically in thermometers and its settings for customization depending on the activity, and for adding and consulting observations (text and images) made by the users. Figures A1 to A5 in the Appendix show the dashboard interface described below.

The homepage of the dashboard shows a login form to access each particular plant, using its unique ID and set password. This is aimed to separate plants and access each one individually as a single student, as a group, or as a whole class, instead of having one account per student, providing flexibility for teachers when designing the activities.

Once logged in, the user is redirected to the timeline data visualization interface, with all five current measures (temperature, humidity, soil humidity, CO2, and light) being shown in a line graph. The plot is interactive and configurable; the user can hide or show the data lines for each measure, zoom in and out the plot, display custom selections, and download the plot to their device. Another feature accessible from this interface, is the observations section, where all previous observations can be reviewed and new ones can be added, by including the name of the user or group of users, the text for the observation, and optionally an image. The timeline data visualization interface also offers the possibility to compare measures pairwise, rescaling the axes if needed and allowing a clearer visual comparison and examination.

From the general timeline data visualization, single data points can be accessed, by clicking on them directly from the plot. This leads to another interface where the single measures (temperature, humidity, soil humidity, CO2, and light) for a given timestamp are represented each in a different thermometer, by filling them until the corresponding value. The specific numeric value is also given under the thermometers. This page also allows to add observations -in this case observations related only to the single data points and only accessible from that specific data point, and not shown in the general timeline data visualization- and to configure the lower and upper limits of the measures depending on the optimal values for the plant, in a settings box. Depending on the set limits, the thermometers will display green, if the value is inside the optimal boundaries for that measure, orange if it is just in the limits, or red, if it is outside the given range.

2.2 Learning dashboard research

2.2.1 Review on dashboards

A systematic literature review by Schwendimann et al. in 2017 shows that the field of learning dashboards is still relatively young, and that there is still no consensus on what constitutes a dashboard, as also reflected by the variety of definitions (and synonymous terms) for the concept *learning dashboard*[9]. Some of these definitions include “a container of indicators”[10], “a display which visualises the results of educational data mining in a useful way”[11] or “visualisations of learning traces”[12]. The authors of the review propose instead the following definition: “A learning dashboard is a single display that aggregates different indicators about learner(s), learning process(es) and/or learning context(s) into one or multiple visualisations”.

This diversity is not only present in the formal definition of *learning dashboards*, but also in the learning contexts for which are intended, the characteristics of the dashboards themselves, and the maturity of the proposals[9]. The literature review reveals that, regarding the learning context, four general types of targets users can be identified, being the main one the teachers (targeted by 75% out of the 55 papers reviewed), followed by students, administrators, and researchers, and that for the learning scenarios the most targeted one is formal learning, with little research on dashboards focusing on non-formal or informal learning. Although some trends can be observed -dashboards mainly addressed to teachers in a formal learning scenario-, some other aspects remain less defined by current research, such as the educational level for which the dashboards are designed or the pedagogical approach -for the latter, only a few mention computer-supported collaborative learning, blended or online learning settings. One of the reasons for these undefined aspects of the dashboard may be the lack of or insufficient detail in the description of proposed learning activities for the dashboards.

The purposes and methodologies applied to the current dashboards are also diverse but in line with the focus on teachers and formal learning. Concerning their purpose, they can be directed to self-monitoring, monitoring others or administrative monitoring; regarding the methodology, considers dashboards for traditional face-to-face lectures, for face-to-face group work, and for online or blended learning[9]. By analysing further the developments in learning dashboards in the literature, there can be found many different indicators presented visually in bar charts, line graphs, tables, pie charts and network graphs, including indicators related to the learner, to their actions, to the content to interact with, to the result or outcome of the learners, to the learning context and to social and interaction aspects. Overall, there is a clear tendency towards dashboards for teachers in formal learning that display learning analytics data to monitor learners' progress and behaviour[2,9], and, therefore, a lack of dashboards oriented towards other kinds of activities and purposes, as well as their effects outside these specific settings. Some initial research has addressed the impact of a learning dashboard on students affect[13].

Relevant to this research, there is a lack of dashboards for environmental education. Although the importance of healthy environments has become more notorious in the past years, and both basic and more advanced solutions have emerged, for instance, to provide information about the state of the air in an indoor space[14], most IoT systems are industry-oriented and far from learning purposes. Similarly, existing solutions for plant monitoring present complex visualisations suitable for experts but not for learning contexts. A dashboard for environmental education would require simplification and appropriate representation of the data to adapt to different educational levels, an intuitive and user-friendly interface, and the possibility for students to reflect on their actions within the learning environment[2].

Some other broader limitations found in ongoing research in the field of learning dashboards are the lack of evaluations with larger or different user groups, the ethics and data privacy concerns, and the issues arising from user experience and usability[9].

It is also worth noting that some studies pointed to the integration of systems to automatically analyse information and provide feedback or warnings to educators and learners as a possible path for future work[9]. This highlights the growing interest in bringing AI systems into learning dashboards and, more generally, education.

2.2.2 Teacher dashboards: Mirroring, alerting and advising tools

Orchestration technology aims to support teachers in the task of productively coordinating and managing collaborative classroom activities under multiple constraints in real-time, by adding an extra layer of technology in the learning spaces[15]. Learning analytics dashboards can be an appropriate tool for this purpose; by displaying different indicators about the learners, the learning process and the context, the teacher can understand and interpret the learner-educational platform interaction from the visualizations, and take informed pedagogical actions aligned with the objectives from the learning design[16]. The design of the teacher dashboard also has an impact on the orchestration load -the physical and cognitive effort required from teachers to regulate the learning activity in progress[17]- as shown by Amarasinghe et al. (2021), which compared different types of supporting tools[16].

In learning analytics teacher dashboards, different categories of such supporting tools can be found based on the granularity of the support available and on the function of the orchestration tool. Soller et al. (2005) distinguish between *mirroring tools* and *guiding tools*; mirroring tools visualize the interaction of the learners in the learning system but do not provide interpretation of this information, whereas guiding tools do not only show the relevant learners' interaction information but also provide recommendations for the end-user (the teacher) about the pedagogical actions to take to enhance the learning experience[18]. The results of a comparison between these two categories of supporting tools revealed that mirroring and guiding systems had a different impact on teachers' orchestration actions. The guiding support enabled teachers to perform more orchestration actions, more targeted interactions, and more announcements to the class than the mirroring support, in which teachers focused more on the epistemic aspect[16].

Another proposed categorization of orchestration tools by van Leeuwen and Rummel (2019) considers mirroring, alerting, and advising tools. Here, the concept of guiding tools discussed above is further decomposed into alerting tools, those that alert of critical events occurring during the collaborative learning activity and facilitate this war the interpretation of the information, and advising tools, which additionally recommend specific actions to the teachers[5], bringing artificial intelligence closer to education. The authors encourage further research on the impact of different dashboards' categories in orchestration and cognitive load.

Such findings and classifications suggest that the design of dashboard tools should go beyond technological and pedagogical principles to incorporate human factors as well[16], adopting a more critical point of view on the use and effect of such tools, not only for learning analytics tools for teachers but also for learning dashboards in general. As there is a lack of learning dashboards designed around students rather than teachers -especially of dashboards for environmental education, as discussed above-, there is subsequently a lack of research about the impact of different systems (for example, mirroring, alerting, and advising tools) on students' cognitive development.

2.3 The impact of AI in education

As a natural evolution of the upsurge of artificial intelligence (AI) in almost every aspect of human life and our social interaction, AI has also reached education by producing new teaching and learning solutions that are now undergoing testing in different contexts. The impact of AI technologies on learning and education has opened a discussion weighing the possibilities that they offer but also the disadvantages and risks they entail. Entrepreneurs and policymakers highlight the opportunity for AI to make education more efficient, positively change the learning contexts, and allow large-scale learning analytics[19]. Opposite to this enthusiasm, others claim that AI can easily promote unfounded learning ideas and designs, such as the own experiences and beliefs of engineers and technology companies without clear educational benefits in their objectives[19]. Research around the open debate of the impact of AI on education includes the possible risks of deviating AI in education[20]; the importance of teacher and student relations and how infatuation with technology can have a deep impact in changing the classroom relationships[21]; the challenges and opportunities that present AI in education related to sustainable development (in UN Sustainable Development Goals, corresponding to Goal 4[7]) with a focus on education policymakers and institutions[22]; and the ethics of AI in education and how a framework addressing the ethical arising issues is of vital importance[23], among others.

When looking at previous and current developments in the field since the 1980s, most educational applications of AI have mainly focused on the knowledge-based approach, with the main line of research being intelligent tutoring systems (ITS), an important source of data for learning research. The core strength of data-based AI systems has been the adaptive interfaces to personalize learning experiences, together with the potential to process very complex data streams in real time[19].

AI applications on teaching have been used for diagnostic and assessment tasks, to create student models in real learning contexts, and to identify pedagogically relevant clusters. Other kinds of AI implementations have been devoted to more student-centric systems, such as systems for the early detection of dyslexia, for the diagnosis of autism spectrum disorder and attention deficit hyperactivity disorder (ADHD), for automatic test generation and assessment, for the diagnosis of student's socio-affective aspects in computer-supported learning environments, and for systems that use less granular data to provide course recommendations[19,24].

Apart from the positive and negative impact that AI systems can have in teaching and learning practices in formal learning, we can also consider the impact of AI on cognitive development: how AI influence human cognition and the human brain, as it evolves together with technology. Research on neuroplasticity has revealed that technology -including learning technologies- not only shapes the way we think but also the physical brain itself[25]. Therefore, the question of how learning technologies affect our brains' structure and what are its implications might arise.

Moreover, because there are critical phases during the development of the brain, it is of major interest to research the consequences -if any- of learning technologies in these critical periods[19].

AI technologies can have different purposes associated with different cognitive implications; they can support existing capabilities while emphasizing transversal and domain-independent competencies, they can create new activities involving new cognitive capabilities that otherwise would not be possible, and, lastly, they can reduce or even omit the importance of some human cognitive capabilities[19]. It is on this last cognitive implication where the pedagogical focus should be put to detect the risks of AI on cognitive development.

Taking into consideration all the aspects discussed above, it is clear that there is a need to re-think the role of education in a technological society, and what implications can have educational AI not only at the present but also with a future perspective. Beyond the adoption of such technologies in classrooms, AI will have a great impact on educational systems, along with the emergence of social, economic, and even cognitive challenges to be addressed.

2.3.1 Intelligent Tutoring Systems (ITS)

Intelligent Tutoring Systems (ITS) have been one of the main research lines centred in the intersection of education and artificial intelligence techniques. Intelligent Tutoring Systems (ITS) are described as computer learning environments that help students acquire knowledge and skills by implementing intelligent algorithms that adapt to students at a fine-grained level[26,27], developing more personalized educational systems. Such systems are intended to be used by a single user, as they are designed to focus on an individual's characteristics, needs and preferences to improve student outcomes[28].

A review done by Mousavinasab et al. in 2018, showed that the main educational field in which ITS were implemented was computer science, followed by mathematics and health and medical sciences[29]. This illustrates the trend in developing ITS systems for mathematics and other computationally well-established topics; however, they have been also developed for knowledge domains that have a verbal foundation, such as language or reading comprehension[30].

Although the existing variety of affordances, knowledge domains and learning principles in the field, ITS require components that allow for active students' learning rather than the passive delivery of contents. Then, the common affordances that always occur in ITS could be summarized into interactivity, adaptivity, and feedback, as well as those affordances that can also be present like choice, nonlinear access, linked representations, and open-ended learner input[27].

ITS have been shown to have a positive impact on personalized learning, enhancing the performance of students and the time management[31], as well as on student engagement[32]. However, reviews show that it is not clear that the effectiveness of ITS in several parameters such as task-technology fit, student satisfaction, and student motivation have a direct impact on higher learning performance[28]. Overall, despite the potential benefits of ITS, various authors claim that little research has been done on the impact of such systems on users[28], and that, although they could facilitate reasoning in the learning process, they have been rarely applied in experimental courses including problem-solving and decision-making for research purposes[29]. This suggests a need for further research and contribution to the understanding of the effects of AI on students' learning.

The potential benefits, issues, and aspects being discussed in the literature open the debate around AI in education while tracing a possible path for other intelligent systems related to ITS that share some of the features, like affordances, modules, or AI techniques. Concerning a dashboard for environmental education, questions regarding the integration of an intelligent system to it could be related to those in ITS. For example, what would be the effects of personalized notifications, individually adapted data visualizations, or individual data analysis guides on learning performance or students' motivation, or which AI techniques based on the learner's characteristics would be more appropriate to help deliver personalized notifications on understanding the data to users.

2.4 Inquiry-based learning

Inquiry-based learning is an active learning process that involves students building knowledge from their own discoveries through high-level questioning, experimentation, and observation of the real world[33]. In other words, learners engage in an often-scaffolded experimentation to find real-world connections in the context of problem-solving, requiring active participation. This kind of learning has been suggested not only in the areas of mathematics and sciences, but also in language and literacy development, as it has been shown effective and, moreover, equips learners with the methodology to solve other problems they may encounter during their educational development[34].

Such an active learning process can result suitable for tools and themes -and their subsequent learning activities- as the ones proposed by the TEASPILS project. The TEASPILS dashboard offers a space for exploration of environmental data, and the fact that the data comes from sensors placed in a real plant allows the learners to make those real-life connections between the data -and the problems that it might suggest- and their own observations. Regarding the learning objectives and topics in the scope of the project, the environmental issues can entail many subproblems to be formulated to the learners, to be comprised in an inquiry-based learning context and involving a problem-solving process.

To promote inquiry-based learning, heuristic worked examples have been used in lower secondary school for mathematical tasks[35] and in high school for electrical circuits modelling[36], for instance, both resulting in enhancing performance on inquiry tasks. Other applications include the integration of technology in inquiry-based learning[34], suggesting that the TEASPILS dashboard could be adapted to the framework proposed.

Pedaste, M. et al. (2015) identified through an extensive literature review five general inquiry phases during the inquiry cycle, which are: orientation, conceptualization, investigation, conclusion, and discussion. The orientation phase is based on stimulating curiosity about a specific subject and proposing a problem statement. In the conceptualization phase, learners are implicated in the process of stating theory-based questions and hypotheses. In the investigation phase, the experimentation, data collection, interpretation, and analysis take place, from which to draw conclusions related to the initial questions in the conclusion phase. Finally, the discussion phase is understood as the process of presenting and communicating, often accompanied as well with reflective activities[33]. These five inquiry phases provide an ideal framework in which to frame the activities designed in this research, adopting all the desired requirements; different inquiry phases can be accommodated into different sessions of a whole workshop -giving continuity and a cyclic meaning to it-, while addressing a suitable topic such as the environmental issues related to plants, in which students would develop and use problem-solving skills.

2.5 21st century skills

As our society undergoes fundamental changes in all of its areas with the growth of access to technology and information, the question of how education should be re-designed through education to align with the challenges of the 21st century arise[37]. To answer this question, a set of abilities, skills, and competencies that fit the current needs have been proposed internationally by educational experts, institutions, organizations, and policymakers. The 21st-

century skills comprise a total of 12 skills that can be classified as learning skills -including the skills of critical thinking, creativity, collaboration, and communication-, literacy skills – including skills related to information, media, and technology-, and life skills -including flexibility, leadership, initiative, productivity, and social skills-. Accordingly, this translates into education as innovative learning systems designed around the enhancement and reinforcement of those skills[38,39]. For this purpose, several frameworks have been proposed[40].

The development of learning tools and the design of learning activities should therefore not only take into account the 21st-century skills but also allow to build upon them; the 21st-century skills have become a requirement in learning technologies.

2.5.1 Problem-solving skills

Problem solving is a complex process and, subsequently, its definition, strategies, applications, and assessment have been a subject of research for many decades now[41]. Some authors (Lovett, 2002; Mayer, 1992) define problem solving as the "cognitive processing directed at achieving a goal when no solution method is obvious to the problem solver"[42]; hence, the problem solver needs to represent the problem, analyse and transform the information towards a goal, and follow the built strategy to solve it. According to the definition, four main characteristics of problem solving can be identified: it is *cognitive*, in the sense that it occurs in the solver's cognitive system; it is a *process*, as it involves representing, analysing, and manipulating knowledge in the cognitive system; it is *directed*, as the cognitive processing is guided by the end goal; and it is *personal*, as it can depend on the knowledge and skills that the individual already has developed[42].

Problem solving does not encompass only one specific problem, but instead many problem types can be identified, with different strategies, components, and cognitive skills associated to each one. The main problem types can be grouped as: story problems, decision making problems, troubleshooting problems, strategic performance problems, policy analysis problems, and design problems[41]. Especially relevant to this research are story problems -in which a set of variables embedded within a shallow story context-, decision making problems -which involves the selection of beneficial or satisfying options from a set of options-, and troubleshooting problems -which is based on the search for likely causes of faults through a space of possible causes-. Regarding the cognitive skills, as aforementioned, different kinds of problems require different cognitive skills to solve them, operationalized as cognitive strategies, including problem schemas, analogical comparison, causal relationships, questioning, modelling, arguing, and metacognitive regulation[41]. The assessment of these cognitive skills and strategies is one of the ways to approach problem solving assessment.

The evaluation of problem-solving skills can be done in different ways, ideally combining multiple of them for a deep assessment. We can assess the problem schema or type, through problem classification tasks, for example. Another way is to assess the problem-solving performance of the solver's; this can be done by considering the response or product from the solver, rather than a simple choice from a set of predefined answers, by direct observation of the evaluator on the solver's behaviour, or by assessing the quality of the solution through rubrics, coding schemas or argumentation. Argumentation plays a key role on the assessment of problem-solving, as it is a way for solvers to demonstrate their understanding and their ability to construct arguments in support of their solutions to problems. Argumentation can be collected through multiple-choice questions, open-ended questions coupled to performance rubrics for essays, or directly with verbal protocol analysis. Finally, we could assess the cognitive skills and components required to solve a problem, for instance, assessing causal reasoning by presenting a scenario and letting the solver make an inference based on that scenario[41]. These methods of problem-solving assessment offer a guideline for constructing the problems to then evaluate in this research.

3 Methodology

3.1 Research Questions

The literature review has provided a broad insight into the current state of dashboards for environmental education, as well as a glimpse into their possible opportunities, implications, and research topics to address. Aforementioned, there is a lack of dashboards for environmental education -and hence of designed learning activities using them-, and limited research concerning the impact of dashboards focusing on students rather than teachers. Moreover, the gap between the IoT system to be implemented in real classroom settings and the specific educational opportunities that a technology of this kind supports remains to be filled.

Taking all of this into account, the main objective of this research is to gain insight into the impact of a dashboard for environmental awareness education on students' competencies and the design of learning activities. This general objective identifies two paths for research: the design of learning activities with the Teaspils dashboard, and its impact on the skills and competencies of students, for which different conditions can be tested. Here, the research will focus on the mirroring, alerting and advising systems conditions, as they have already been addressed by previous and extensive research in teachers' orchestration and cognitive load but not in students[5,15,16].

So, more specifically, the study aims to answer the following research questions:

1. What kind of activities can be designed with the Teaspils dashboard?
2. How do the different dashboard systems -mirroring, alerting, and advising- impact the problem-solving capacity of students?

For the second research question, the hypothesis is that: "The implementation of an alerting system to the Teaspils dashboard will improve the performance on problem-solving tasks in primary school students over the implementation of an advising system". This statement focuses on primary school students and assumes a difference between the different implemented systems compared (when compared with a control condition), with concrete expectations:

- In the alerting system condition, we expect that students may improve their performance with respect to the control group in problem-solving tasks when presented with a similar task to the one they have been previously working on with the Teaspils dashboard, as the alerts may help focus on and abstract the key concepts for solving that kind of tasks.

- In the advising system condition, we expect that students may lower their performance with respect to the control group in problem-solving tasks when presented with a similar task to the one they have been previously working on with the Teaspils dashboard, as the advising system may provide too specific and fixed guidance that prevents from abstracting the general concepts for solving that kind of tasks.

These expectations are based on the proven positive aspects of alerting and scaffolding systems, but at the same time on the importance and effectiveness of inquiry-based learning. On the one hand, learning technologies that use similar alerting systems such as ITS have shown to enhance the performance of students[30] and that scaffolding strategies can facilitate elementary students' problem-solving skills for some problems[31]. On the other hand, the advising system condition could limit the space for inquiry-based learning by already providing not only the formulation of questions, problems or scenarios promoted by this form of active learning but also possible answers and fixed guidance.

3.2 Design of activities

The aim of the design process is to propose an entire workshop that consists of several sessions with a central theme, which serves as a common thread throughout the sessions, along with other topics and aspects to be covered, and based on the five phases of inquiry-based learning, as described in Section 2.4. The final design of the activities should contemplate a wide range of activities based on the environmental data shown in the Teaspils dashboard. To achieve this goal, the design process consists of: a review of the contributions from the participants of the dashboard co-designing session; a data collection with learning technologies experts on topics, methodologies and activities ideas; the conceptualization of the main topic for the workshop, other topics to include, and general learning outcomes; the specification of the activities, tools and materials, taking into account both educational levels (primary school and high school); and, after conducting the activities in real-classroom settings, the evaluation of the activities.

3.2.1 Data review and data collection

Some insights on what activities could be designed with the Teaspils technology were already provided by the participants of the dashboard co-designing session. Tables A1, A2 and A3 in the Appendix A.2 collect the participants contributions related to the general categories "content and methodological approach", "requirements", and "learning goals", respectively, coded into subcategories.

Apart from this data collection previous to this research, another data collection on the activities to be designed for the Teaspils project was conducted. This was done with a total of 20 participants: 7 participants from the online Teaspils contributors' course, including teachers, learning technologists and researchers, and 13 participants from a master's course in Learning Technologies. After a brief presentation of the dashboard and research goals, participants were asked to brainstorm, based on their ideas and expectations for an activity using the dashboard, on the following different categories: "Area of knowledge", "Educational level", "Concepts to work on", "Methodologies", "Role of the dashboard", and "Activities ideas". This was done through Padlet[1], an online collaborative tool which allows to post text, images, and other media in a digital board. The data collected has been summarized in Tables from A4 to A9 in the Appendix A.2.

Both sources of contributions were considered in the next stage to decide and define on the specifics of the activities.

3.2.2 Definition of the activities

The general learning outcome of the activities was to understand which are the best conditions for the plant, through the analysis of the environmental data collected by the dashboard. The activities were structured across the different sessions of a workshop with the data analysis process as the main topic, so that the activities fitted the different steps of a data analysis, but also including other topics such as biology, plant care, the scientific method, or emotional aspects of plants.

Moreover, the design of the activities had to take into account various requirements. Considering the experimental design, the activities were designed to allow for the integration of the experimental conditions, either to apply them or to evaluate them. The limitations inherited to the experimental design, such as the schools' availability for conducting the activity and the time and resources for this project, were also considered.

Regarding the skills and competences to work on, the activities were designed focused on inquiry-based learning, some of the 21st-century skills and problem-solving skills. Also, the activities were adapted both for primary school and high school, while maintaining the same

[1] padlet.com

learning goals and outcomes. The activities mainly emphasized group work, to enhance social cooperation and interaction, with some exception of individual and whole-class work.

The tools used for the workshop included individual worksheets, group worksheets such as canvas, wall murals, stationery, and certainly the Teaspils dashboard.

3.2.3 Evaluation of the activities

The participants evaluated the workshop through some questions in a post-test, done in the last session. The questions included the single choice questions and open-ended questions; in the single choice questions, participants had to rate from 1 (totally disagree) to 5 (totally agree) some statements related to the workshop, materials, and dashboard. In the open-ended questions, participants were asked what they had liked the most and what the least from the workshops. Moreover, some of the questions that were present both in the pre-test and the post-test helped evaluate the impact of the workshop activities on the participants' perception of plants, on the Teaspils dashboard, and on environmental awareness. The complete version of the post-test can be found in the Appendix A.4.

Moreover, the activities proposed were mapped against the Digital Green Competences described in Section 2.1.1. Because the framework was being developed at the same time this research was conducted, instead of designing the activities already based on the framework, this had to be done in a post-hoc manner.

3.3 Experimental design

The experimental design proposed is a between-groups design, with three independent groups corresponding to the different dashboard systems: the mirroring system (control condition with no alerts or advice displayed); the alerting system (experimental condition); and the advising system (experimental condition). Hence, the independent variable in this experimental design is the dashboard system (mirroring, alerting, advising) used in a workshop by the students and the dependent variable is the problem-solving skills of students.

The conditions were applied throughout all the sessions of the workshops with primary school students (n = 45) and high school students (n = 18), with the same condition applied to the same group in all sessions. Although the hypothesis focuses on primary school students, a second group of high school students resulted convenient by providing a second real classroom environment and means to explore across age groups.

In order to quantify and compare the differences between groups, qualitative and quantitative data was collected in a pre-test, a post-test, and also during the workshop activities. Quantitative data included answers to numerical exercises and closed-ended questions, whereas for the qualitative data, reasoning answers to open-ended questions were considered.

3.3.1 Dashboard systems: mirroring, alerting and advising

The TEASPILS dashboard was adapted from the original dashboard interface described in Section 2.1.2. to allow the implementation of the alerting and advising systems to its interface.

For the workshops, all the interfaces and features where translated into Catalan; therefore, the languages currently available are English, Spanish, and Catalan. Apart from those adaptations, some visual modifications were made to make the dashboard more appealing to the students. The most significant change in respect to the current versions where the addition of the alerts pop-ups that are described more in detail in the following paragraphs. The pop-ups matched the appearance of the dashboard, showing a light green icon related to the content of the alert and the text of the alert, as in Figure 1. They could be closed by clicking outside the alert box or on the 'Ok' button. The content of such alerts differed according to the experimental condition.

Figure 1. *Example of a pop-up notification from the advising system*

In the mirroring system, no alerts were presented in any section of the dashboard. The dashboard displayed the data visualizations for the environmental measurements and the observations in the observations page with no interpretation or extra information. The students could navigate between the current time measurements, the data visualizations and the observation pages without any limitation, and could access all features (settings for the optimal range of the different measurements for the plant, options for the data visualizations, post new observations, etc.).

In the alerting system, students received alerts in the form of pop-up notifications while navigating through the dashboard interface. The alerts included information about critical events or relevant aspects in regard with the environmental data or the observations introduced, but without any advice, interpretation or guidance towards those events; for instance, "*The temperature has increased by 8% over last week compared to the previous week"*, *"The last observation was introduced 5 days ago"*, or "*Yesterday's highest temperature was at 12:30 p.m.".* The purpose of such alerts is then informative based on the data collected.

In the advising system, students also received alerts in the form of pop-up notifications, but in this case the alerts included not only information about critical events but also suggestions or advice on how to interpret and respond in regard to the events; for instance, and related to the same alerts quoted before, *"The temperature has increased by 8% over last week; check the plant's location"*, "*The last time the plant was watered was 5 days ago; have you watered it enough?*", or *"Today's highest temperature is predicted to be at 12:30 p.m.; make sure the sunlight isn't too direct"*. The purpose of these alerts is to provide information and provide possible interpretations.

For the alerting and advising systems, the alerts were manually programmed to appear for specific plants IDs -depending on the experimental condition- to simulate how a fully developed intelligent system would work, considering that the main focus in the research was not to develop an intelligent system but to study which could be some of its effects in students' competencies. The alerts appeared each time the user changed between pages inside the application, according to the number of times that page had been visited, showing a different alert each time. In case the page had been visited more times than the number of programmed alerts, the alerts would reset and be shown again from the beginning, starting from the first one.

The alerts were written according to the relevant data characteristics of the specific dataset (see the datasets specifics below in Section 3.3.4) and the activities to conduct during the workshop. A total of 57 notifications per condition (alerting and advising) were created: 15 for the first session, 20 for the second session, and 22 for the third one. The alerts in the alerting and advising conditions matched, in the sense that the advising alerts provided a more complete version of the alerting ones, with the information about relevant events (present in the alerting system as well) coupled with the corresponding suggestions or interpretations (only in the advising system). A complete list of the translated alerts in the alerting and advising systems is provided in the Appendix A.9.

3.3.2 Participants

A total of 63 participants took part in this study, consisting of 45 participants from a primary school in Cardedeu and 18 participants from a high school in L'Hospitalet de Llobregat, both from the province of Barcelona, Spain. The legal tutors of the students consented their participation in the workshop designed as part of this research.

For the primary school, participants were students from three classes of 6th grade, with 15 students per class, and an average age of 11.48 (SD = 0.58). Each one of these classes was assigned with one different experimental condition: mirroring, alerting, and advising, respectively. The allocation of each condition was made randomly.

For the high school participants, they were students aged between 16 and 17 enrolled in a biology course of 1st of Batxillerat. Because there was only one class, groups of 3 people were made and each condition was assigned to two different groups, so there were 6 participants per experimental condition. Here the allocation of each condition was also made randomly.

3.3.3 Data collection

In order to analyse if there are any differences between the experimental groups (control, alerting, and advising), data was collected during the workshops' sessions. For the primary school setting, this data collection consisted of data from a pre-test, data from the activities carried out during the workshop, and data from a post-test. Although participants used their laptops during some of the activities, given the educational level and the kind of activities designed, the data was collected from hand-written documents and then transcribed into a digital format. For the high school setting, due to the time limitations, only data from the activities carried out during the second session of the workshop was collected, as the last activity from the workshop and the post-test were highly related. Instead of a pre-test, we assumed the same initial ground given that they were all students from the same class and course.

The instruments used for the data collection were not tested before in a pilot workshop but have been proven to be effective in other workshops conducted in similar settings, such as the *Courage* project[43] -with secondary school students- and *Makers a les aules* project[44]-with primary school students-, both projects being carried out in our research group. Such instruments include the use of wall murals with sticky notes for brainstorming or reflection, rating questions with smiley faces representations for the pre- and post-tests, A3 paper canvas to work in groups, and interactive presentations, among others.

All the data was processed and analysed using Python libraries, with the appropriate statistical methods considering the characteristics of the experimental design and of the data. For qualitative data, the answers to open-ended questions were coded and grouped into subcategories for those analysis that required it.

3.3.3.1 Pre-test

The pre-test questionnaire for primary school students was organised in five different sections. The first one collected personal information: name, age, and gender. The second one was focused on technology and asked the participants which technologies they knew from a list of multiple ones; this section was not intended for comparison with the post-test but to engage students and to learn more about their knowledge to prepare the following workshop sessions. Then, participants were asked about plants and plant care, including how many plants they had at home (numerical answer), indications to take good care of a plant (open question), and harmful factors for plants (open question). Next, they had to complete a table by selecting from 1 (totally disagree) to 5 (totally agree) as agreed with different statements regarding their interests and opinion related to the workshop topics. Finally, in the last section, they had to solve a numerical problem related to temperatures, separated in two subsections; this problem was chosen from official level tests for 6th grade in Catalonia, distributed by the government and openly available online[2], in order to approach a measurement for the problem-solving skills of participants. The complete version of the pre-test can be found in the Appendix A.3.

3.3.3.2 Post-test

The post-test was structured in two main sections: the first one to evaluate the problem-solving skills and knowledge acquired under the experimental conditions, and the second one to evaluate the design and impact of the activities, and to collect the final thoughts from the participants.

In the first section, they are asked two open questions: 1) Why do they think the plant seen in the last activity from the workshop was in an unhealthy state, and 2) How can we take care of plants to avoid them being unhealthy. We expect the reasoning in their answers to be related

[2] http://csda.gencat.cat/web/.content/home/arees-actuacio/avaluacions/avaluacio-sise-primaria/avaluacio_sise_primaria_2014/2012-mates.pdf

to the problem-solving activity done before the post-test, exposing in some way their findings and solutions if any. Also, these two questions can then be compared with the two questions about plant caring and harmful factors for plants in the pre-test. The third and fourth questions were multiple choice questions asking how could know if the plant had been watered and what the indicators of climate change were. Finally, they had to select the certain affirmations about plants related to the contents of the workshop. This first section was key to compare the differences between groups as a result to fulfilling the activities using different dashboard systems (mirroring, alerting, or advising).

In the second section, they had to complete another table by rating from 1 (totally disagree) to 5 (totally agree) as agreed with the statements presented. The statements included questions related to the workshop as well as some of the opinion statements related to the environmental topics also present in the pre-test. Lastly, they were asked in two open questions what did they like the most and the least about the workshop. In this section, some of the questions were intended to evaluate specifically the design, while some others were meant to be compared with the pre-test to observe if the workshop activities could have had an impact on their perception of the environment and appreciation of plants.

3.3.4 Datasets

For the activities in the workshop, two different datasets were generated to simulate the environmental measurements collected for a classroom for one week. Both datasets comprised a total of 8 days with data collected every 40 to 45 minutes and were based on a real dataset generated by a prototype of the Teaspils spike. This real dataset served as a starting point to then generate more days of data, identify the correlations to accentuate them, add the data correspondance of simulated events on the plant to the dataset, and get a general view of the range of values and evolution of measurements during a week, so the dataset for the activities was credible. The two datasets corresponded to a healthy plant and to an unhealthy plant due to the effects of climate change.

Firstly, from the real dataset, the dataset for a healthy plant was generated. This first dataset included light peaks from day versus night-time, accentuated peaks in the soil humidity to simulate watering of the plant, and correlations between light and temperature or humidity and temperature, among others.

Then, a second dataset was generated from the first one; in this case tuning the measurements so that the environmental data would reflect a plant under the effects of climate change; for example, by increasing the amount of CO2 and the temperatures, to simulate greenhouse effect and global warming, or by decreasing the soil humidity, to simulate dryness of the soil. This tuning was programmed in R considering an increasing or decreasing factor as well as a randomizer factor, so the dataset would not look too artificial, and then some final modifications were manually added. Both datasets are available in a link in the Appendix A.5.

3.4 Workshop

3.4.1 General structure

The activities were structured in a workshop around a central topic: how to perform a data analysis to understand what the best conditions for the plant are. This central topic was outlined in three phases, to then structure the sessions of the workshop. The three phases were:

1. Formulate questions and hypotheses, and collect, organize, and display relevant data
2. Understand the data and get some statistics and insight on their meaning
3. Get conclusions and make inferences and predictions

The workshop emphasized on the problem-solving skills to use and develop during each of these phases.

However, the activities were not restricted only to data analysis concepts but also included other learning goals inherit to the nature of the project, exploring its possibilities in a classroom; for example, some activities were related to biology and natural sciences (plant care, plants' physiology, the scientific method or scientific journaling), to technology (sensors, IoT systems), to maths and statistics (interpreting graphs, computation of statistics), and even to anthropogenic action (climate change, importance of plants) and to emotional aspects of plants.

The same learning goal -how to perform a data analysis to understand what the best conditions for the plant are- was translated to the two educational levels, primary school and high school, adapting the materials and activities but sharing the same data and conclusions.

The workshop consisted of 3 sessions of 1.5/2 hours of duration for the primary school setting, and of 2 sessions of 1 hour each for the high school setting, considering the time limitations of the teachers. In the cases where the sessions needed to be longer, the extra time was distributed across the corresponding presentation of the session through extra slides with miscellaneous content, but not to the activities where the experimental conditions were applied, to try to control all the variables. Regarding the primary school sessions, they were scheduled one or two weeks apart from each other, whereas for the high school students, they were scheduled on the same week separated by two days, corresponding to two consecutives lectures of the biology course.

3.4.2 Primary school workshop

The activities in the workshop were structured so that each session would have a content or theory part -mainly in the form of interactive presentations-, at least one activity using the dashboard, and other hands-on activities still related to the topic but using other materials, such as paper worksheets or stationery material. For the majority of the activities, students worked in the same small groups of 4-5 people through all the sessions of the workshop, unless stated that it was an individual or plenary activity.

Regarding the presentations, their purpose was to present the topics of the session (plants, the Teaspils IoT system, climate change, etc.) using interactive elements like clickable elements, pop-ups, videos, and animations, to encourage the students to contribute with their ideas while relating concepts that they had already learned in previous sessions or as in part of the academic curriculum. All presentations and materials are available in the Appendix A.6. and A.7.

For the workshop, each class were given an indoor plant, an *Asplenium Nidus*, to relate the concepts and events found in the data to a real plant, and to enhance the motivation to learn more about plant care.

3.4.2.1 Session 1

The first session is centred on the first step of the proposed data analysis outline -formulating questions and hypothesis, and collecting relevant data-, as well as on introducing and relating various notions of plants, technology, and their intersection with the Teaspils system.

Firstly, students are asked to complete the pre-test individually for the experimental design. Once they have completed the pre-test, the session starts with a presentation about basic concepts of plants, other projects in which technology is useful for the benefit of plants, the Teaspils IoT system, and, finally, they are introduced to the concept and steps of a data analysis related to their problem: finding the optimal environmental conditions for their plant.

After the presentation, students are given some time to freely explore the plant, the 3D prototypes of the spike (small-scale prototypes without sensors), and the dashboard. In this first contact with the Teaspils dashboard, they are not given any indication or explanation on the features or on the data displayed in it.

In the last part of the session, students are asked to fill with their ideas the "hypothesis mural", a brainstorming activity, corresponding to the first step for their data analysis. This is done in three blocks of 10 minutes, each corresponding to the questions *What environmental data do we want to collect?*, *What can we observe from the plant?*, and *Hypothesis (combinations)*. The hypothesis are formulated as combinations of ideas from the first and second blocks, which would correspond to the independent and dependent variable in a hypothesis. Students are asked one question at a time, they discuss it in small groups, and they stick their ideas in post-it's at a wallpaper mural. The session finishes with a brief recap reading aloud some of the hypothesis formulated and recalling the next step for their data analysis.

Table 1 shows the timings and tasks mentioned in this section, also relating them with the experimental design conditions.

Table 1. *Structure of session 1 in the primary school workshop*

Time	Task	Description	Experimental design
5'	1	Presentation	Same for all conditions
15'	2	Pre-test	Collect pre-test data
15'	3	Presentations on plants, spike, and dashboard	Same for all conditions
20'	4	Exploration of the spike prototype and the dashboard	Application of experimental conditions
30'	5	Brainstorming mural: Hypothesis mural	Collect activity data
5'	6	Session recap	

3.4.2.2 Session 2

The second session of the workshop focuses on the second step of the data analysis: understanding the data and getting some statistics and insight on their meaning. In this session, students work more on the basic concepts and processes of a data analysis, introducing the mathematics and statistics behind them.

As in the previous one, the second session starts with a short presentation about the data analysis process and a recap of the hypothesis formulated in the mural from the first session. Afterwards, students solve a worksheet in groups to discover which is the plant that they were given, by completing some exercises focused on the observable aspects of the plant and on some biological facts. They can search for extra information and the exact name on the Internet.

This initial hands-on activity provides them with some intuition of what conditions could the plant need. The translated version of the worksheet can be found in the Appendix A.7.2.

The next activity is the main focus of the second session, consisting of completing a canvas with data analysis exercises in groups. The eight activities in this canvas guide the students to understand the data and are intended to be completed in order, as follows:

1. Interpret the line plots
2. Understand the relationship between the line plot and single point measurements
3. Find relevant statistics, in this case maximums and minimums
4. Classify environmental conditions as good or bad for the plant
5. Assign health states to the plant based on the environmental data collected for a week
6. Find relevant measurements to understand events of the plant, in this case watering of the plant
7. Identify correlations between measurements
8. Accept or reject the initial hypothesis

Each group completes the activities within a 60 minute frame, using the dashboard and the data for one week -including temperature, CO_2, humidity, soil humidity, and light- displayed in it. The canvas worksheet can be found in the Appendix A.7.3.

The session concludes by sharing with the whole class their findings and answers to the accepting or rejecting hypothesis activity, to set a common ground for the next session. Table 2 shows the timings and tasks mentioned in this section, together with the experimental conditions, as while using the dashboard alerts and advice appear to the experimental groups.

Table 2. *Structure of session 2 in the primary school workshop*

Time	Task	Description	Experimental design
10’	1	Presentation: Data analysis	Same for all conditions
30’	2	Discover which plant it is	Same for all conditions
15’	3	Tutorial	Application of experimental conditions
60’	4	Canvas	Application of experimental conditions + collect activity data
5’	5	Session recap	

3.4.2.3 Session 3

The third and last session of the workshops aims to translate the insights gained in the previous session into the real-world present context, emphasizing on the climate emergency. For this purpose, the initial presentation focuses on climate change and its effects on plants. The slides cover the importance of plants (recalling from the first session) and the definition, causes and effects of climate change, putting emphasis on plants.

After the presentation, the next activity is a whole class “true or false” game in which students vote whether they think the presented statements about plants (plant care, biological facts, or historical and social curiosities) are certain or not. The goal of including this activity is two-sided; on the one hand, it is an appropriate ludic activity for the students, in which they can both check and acquire knowledge on the topic, while sharing discussions with the whole class. On the other hand, it serves for the experimental design as a break from the climate change topic to then conduct more powerful post-tests, as the problem that is being tested is related to climate change.

The next activity aims to put into practice all the concepts worked on in the workshop -plant care and environmental conditions, data analysis processes, and climate change- into one single problem. Out of the two different weekly datasets (healthy plant vs unhealthy plant due to climate change) described in Section 3.3.4, the activity consists of finding which dataset corresponds to the healthy plant and which one to the unhealthy one. Students have to reason why based on the data (e.g. finding key indicators) and state why the plant could be unhealthy and how to help it. Students solve the problem in groups by connecting to the two different plants in the dashboard and completing a worksheet. Once they finish, they complete the post-test individually, which also relates some of the questions to this activity.

Finally, to conclude the session and the workshop, students work on the emotional aspects of the humans-plants relationship with a hands-on activity. The activity consists of asking the students to cut three different shapes of leaves and to write in them the answer to *What would you ask to a plant?*, *How would you feel if you were a plant?*, and *An advice to help plants and the environment*, matching one specific question to one specific leaf shape. Then, they stick the leaves to a big wall mural with the silhouette of a tree. Table 3 summarizes the structure of this session.

Table 3. *Structure of session 3 in the primary school workshop*

Time	Task	Description	Experimental design
25’	1	Presentation: Climate change & effects on plants	Same for all conditions
15’	2	Facts about plants: True or false game	Same for all conditions
25’	3	Activity: differences in data between healthy vs unhealthy plants	Application of experimental conditions
15’	4	Post-test	Collect post-test data
30’	5	Mural: Reflection on the importance of plants	Same for all conditions
10’	6	Session & workshop recap + diplomas	

3.4.3 High school workshop

In the high school setting, the workshop was adapted to fit with the biology course curriculum for 1st of Batxillerat. The workshop was designed taking into account that students were already working on plants through experimental designs related to the contents of the biology course. The workshop was structured around the lesson related to climate change and anthropogenic actions, also proposing an experimental design for students to prepare and related to the workshop.

In this case, opposite to the primary school workshop, students only used the dashboard in the second session. The first session was devoted to present the topics of how to perform a scientific data analysis and of the greenhouse effect, and to prepare an experimental set up related to the first step of the data analysis outline proposed: formulation of hypothesis and data collection. In the second session, students then analysed the data from the dashboard and draw some conclusions, corresponding to the second and third phases of the data analysis outline. For all the activities, students worked in small groups of 3 people.

3.4.3.1 Session 1

The first session starts with a short presentation on the Teaspils IoT system and on how to integrate a data analysis with an experimental design following the scientific method, thus in a *scientific data analysis*. In this presentation, students are introduced to the steps of a scientific data analysis and how the dashboard can be useful along these steps.

Afterwards, a group of students is in charge for another short presentation on the topics of climate change and the greenhouse effects. Given that the students themselves prepare the presentation, this presentation covers the topics in a general way without focusing on the effects on plants and neither on how to relate it to a data analysis. After this presentation, all groups of students formulate hypothesis and prepare an experimental design to prove and show the effects of the greenhouse phenomena, detailing the independent and dependent variables, replicas, etc. The proposals are then shared with the whole class and students decide on one design to go ahead with.

The final part of the session is dedicated on preparing the hands-on experiment with plants and other materials needed to simulate the greenhouse effect, such as plastics and a structure for a self-made small greenhouse in which to place the plants under the greenhouse effect (experimental condition). Table 4 shows the structure of the session.

Table 4. *Structure of session 1 in the high school workshop*

Time	Task	Description	Experimental design
15’	1	Presentation: Teaspils IoT system & scientific data analysis	Same for all conditions
15’	2	Students’ presentation: Climate change & the greenhouse effect	Same for all conditions
15’	3	Other students propose an experimental designed using plants related to the topic	Same for all conditions
15’	4	Preparation of the experiment proposed by the initial group	Same for all conditions

3.4.3.2 Session 2

The session starts by resuming the experimental set up from the first session, by checking the experimental results so far, and making a recap of the scientific data analysis process. Between the two sessions, students are supposed to have made observations, to relate them with the results from the data analysis.

Following the outline of the data analysis proposed for the workshops, students move to the next activity based on exploring, visualising, and extracting the key information from the dashboard data. This activity is a direct adaptation of the data analysis canvas explained in Section 0, but for the two datasets, the dataset for a healthy plant under “normal” conditions and the dataset for an unhealthy plant under the effects of climate change. They have to complete exercises related to: interpretation of the graph; finding maximums, minimums, and means; reasoning which days the plant had been watered; finding correlations between measurements of the environmental data; and relating the observations they have been making to the data. Based on this data analysis and exploration, students then have to decide in groups which dataset corresponds to the healthy plant and which one to the unhealthy plant, reasoning why. This is the same activity as in the primary school session.

The session concludes with a final short presentation about the effects of climate change on plants, to cover the aspects not mentioned in the previous presentation made by the students, and to stimulate the reflection and impact of their results. To conclude, they are proposed to reflect upon the next steps of their research and share it with the rest of the class.

An extra individual activity is proposed in case there is time left, or to do it after the workshop. The activity consists of completing the "Wheel of effects" with climate change reflections; students complete a circle divided concentrically in equal parts by writing a cause in the centre followed by its consequences (the "effects"), as in *The temperature rises* → *The icebergs melt* → *The sea level rises* → *etc.* or, more related to plants, as in *The temperature rises* → *The soil dries* → *The plant cannot absorb water and minerals* → *The leaves dry and difficult respiration* → *etc.*, until completing the whole wheel. This can be done with good environmental conditions versus bad environmental conditions for the plants. The template for the wheel can be found in the Appendix A.8.

Time allocation, tasks and the experimental conditions are detailed in Table 5.

Table 5. *Structure of session 2 in the high school workshop*

Time	Task	Description	Experimental design
10'	1	Presentation: Data analysis summary + Checking the experiment results so far	Same for all conditions
25'	2	Data analysis activity	Application of experimental conditions
15'	3	Activity: differences in data between healthy vs unhealthy plants	Application of experimental conditions
10'	4	Recap presentation: climate change, data analysis, results, and conclusions	Same for all conditions

4 Results

4.1 Design of activities

4.1.1 Final designs of the activities

As a result of this research, a total of 10 activities (6 for primary school and 4 for high school) have been designed and validated in real-classroom settings, in the context of a workshop. Moreover, these activities have been accompanied by 3 presentations in the primary school setting and 3 different ones in the high school setting distributed across the sessions, presenting content related to the activities. Figures 2 and 3 illustrate the methodologies employed in such activities regarding the use of the dashboard and the social form, respectively. Although some activities did not directly use the dashboard, they were related to it by the previous activities using the dashboard or the learnings from the data, for example.

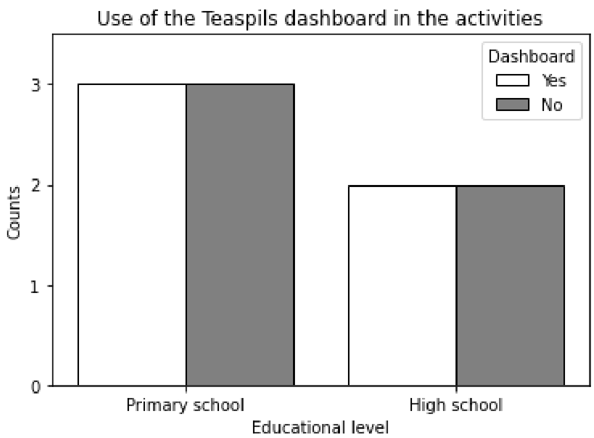


Figure 2. Use of the Teaspils dashboard in the learning activities. *For both educational levels, half of the activities used the dashboard. However, all the activities were related to it through the content to work on.*

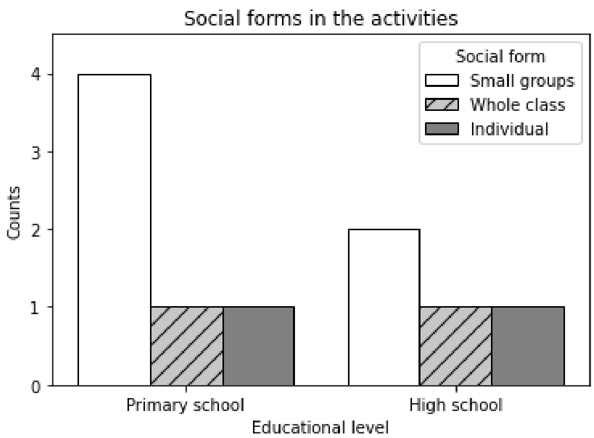


Figure 3. Social forms in the learning activities. *For most of the activities, students worked in small groups of 3-4 students. There was also a plenary activity and an individual activity in each workshop.*

Regarding the Digital Green Competences framework, all the competences were matched by at least one activity from the primary school workshop and by one activity from the high school workshop, as shown in Table 6. Some activities were mapped to more than one goal depending on their learning outcomes.

Table 6. *Learning activities mapped to the Digital Green Competences goals*

	Primary school activities	**High school activities**
Goal 1. Foster environmental awareness	Plant identification activity Reflection mural	Wheel of effects
Goal 2. Educate teachers and young people towards ecological learning spaces	Reflection mural True or false game activity	Experimental set-up
Goal 3. Stimulate knowledge and appreciation of plants	Healthy vs unhealthy plant activity Reflection mural True or false game activity	Healthy vs unhealthy plant activity
Goal 4. Explore plant data in classrooms and learning spaces	Hypothesis mural Data analysis canvas activity Healthy vs unhealthy plant activity	Data analysis activity Healthy vs unhealthy plant activity Experimental set-up

All the translated activities worksheets and materials can be found in Appendix A.7. and A.8.

4.1.2 Evaluation of the activities

In the primary school workshop, participants rated from 1 (worst) to 5 (best) different aspects of the workshop in the post-test. The average punctuation for the overall workshop was of 4.65 out of 5 (SD = 0.62). Regarding the materials they had been using, they rated how much they had enjoyed them with an average of 4.26 (SD = 0.88) and their difficulty with an average of 3.92 (SD = 0.84). Finally, they evaluated how much they had liked using the dashboard in the workshop with a 4.5 of average (SD = 0.85). These results are illustrated in Figure 4.

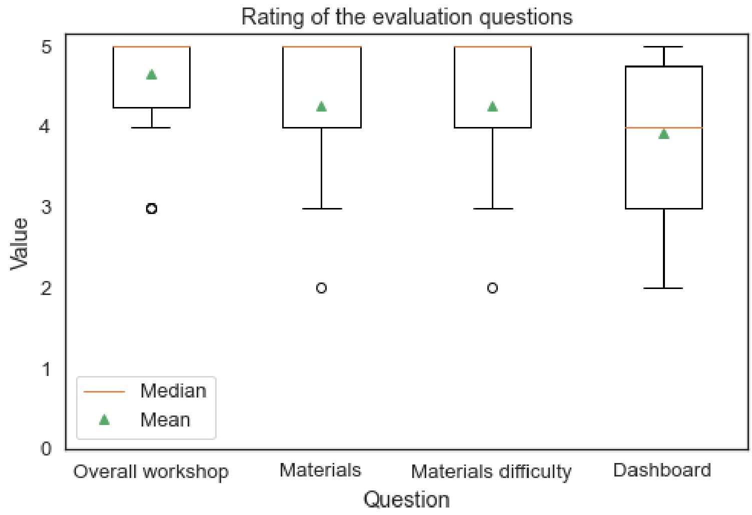


Figure 4. Ratings (1 to 5) of students in evaluation questions. *Questions were, in order: "Did you like the workshop?", "Did you enjoy using the materials you had to complete?", "Did you find the materials you had to complete easy?", "Did you like the Teaspils dashboard application you used in the workshops?".*

In the open-ended questions, most of the participants (14 counts) answered that what they had liked the most from the workshop was the "dashboard application", followed by "everything" (8 counts). Other participants answered the "True or false game", "gaining knowledge", or "working in groups", among others. Regarding what they had liked the least, the majority of participants (22 counts) answered "nothing", followed by 4 counts on "completing worksheets". Other answers included "the duration of the workshop being too short" or the "canvas worksheet". Figures 5 and 6 show the complete coded answers with their frequency.

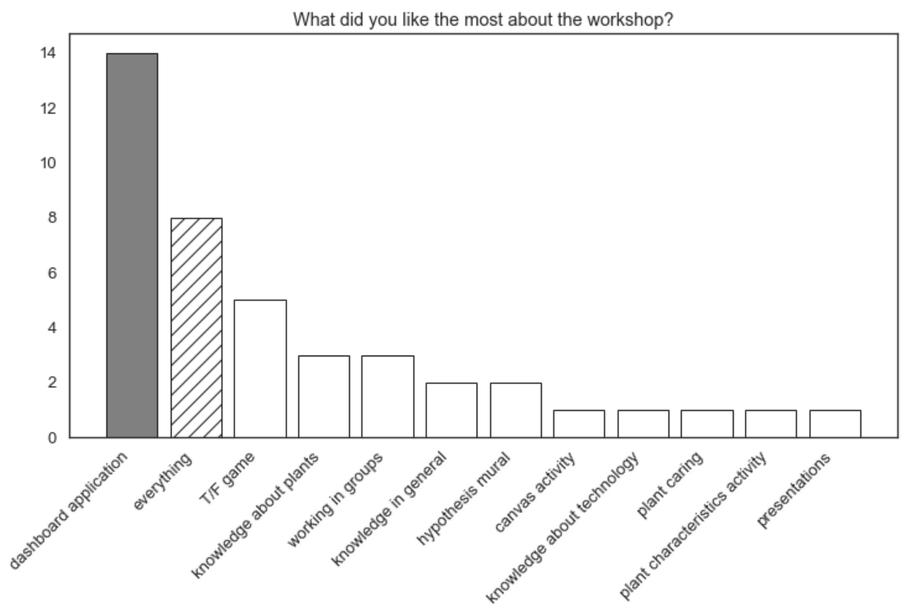


Figure 5. *Categories of what students liked the most about the workshop*

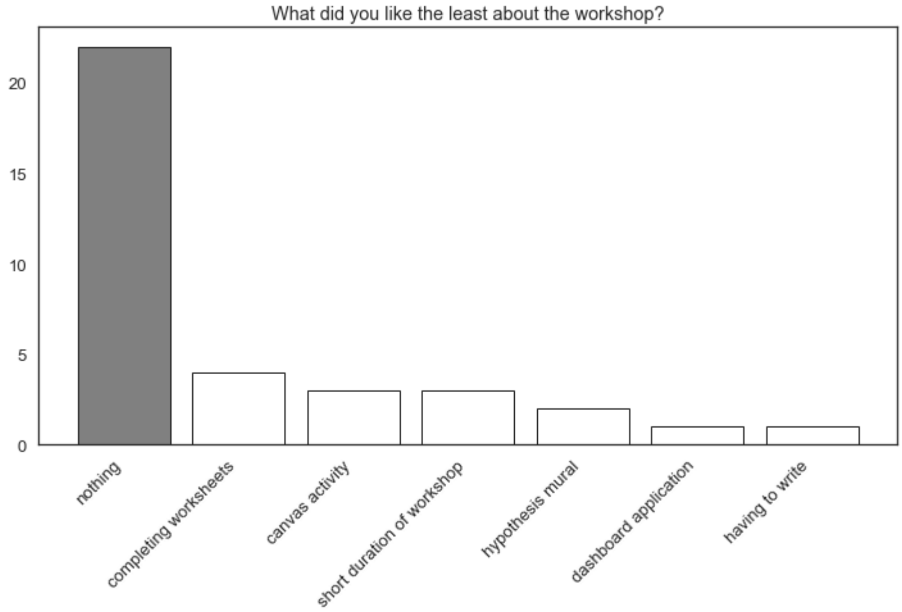


Figure 6. *Categories of what students liked the least about the workshop*

4.1.3 Impact of the activities

The comparison of the pre-test against the post-test revealed some significant differences in some questions that were used to approach the measurement of the impact of the activities regarding the goal of the project to promote environmental awareness.

Both the pre-test and the post-test included two open-ended questions formulated differently but asking for the same content: the beneficial factors and the harmful factors for a plant. In order to compare them, we performed a content analysis by counting the frequency of the most relevant words to the questions among all the participants and grouping them into the following categories: light, water, soil, humidity, air, location, quantity, CO_2, temperature, and climate change. The frequencies accross the tests were compared by means of a Chi-square test of independence of variables in a contingency table, based on Pearson's chi-squared statistic, as the frequencies were considered for the whole group of participants and not individually. We considered the word categories as the samples and their frequencies as the values, and only included those word categories with at least 5 counts in one of the groups to adjust to the requirements of the test.

Significant differences were found both for the beneficial factors (p-value = 1.676392e-09) and the harmful factors (p-value = 0.000291) when comparing the answers in the pre- and post-tests. Figure 7 reveals how although *light* and *water* categories are the most recurrent environmental factors in both tests, other factors appear in the post-test, such as temperature, CO2, and climate change related. Figure 8 shows how none of the answers in the pre-test considered the temperature or CO2 as harmful factors whereas they were counted multiple times in the post-test. Also, the difference in the *quantity* category shows that these factors were accompanied by some quantitative adjustment (e.g. high temperature, low humidity, etc.).

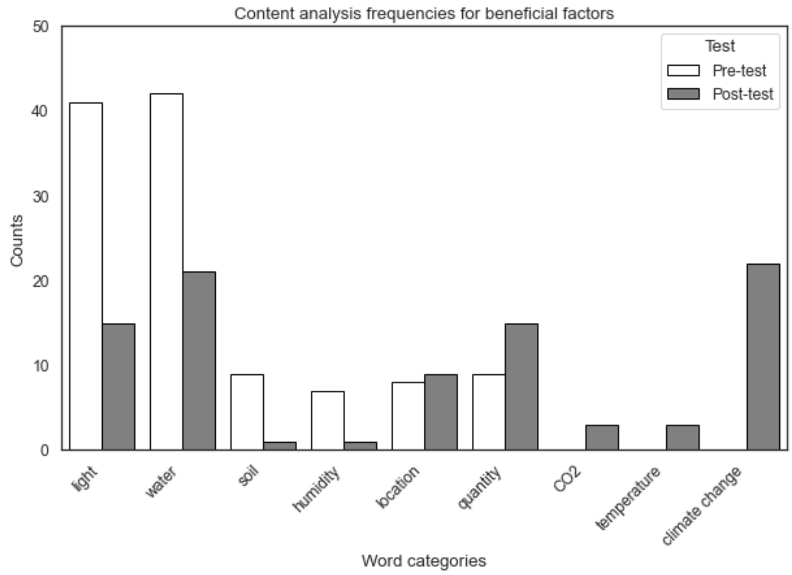


Figure 7. *Frequencies of the words categories related to the beneficial factors for plants in the pre-test and post-test*

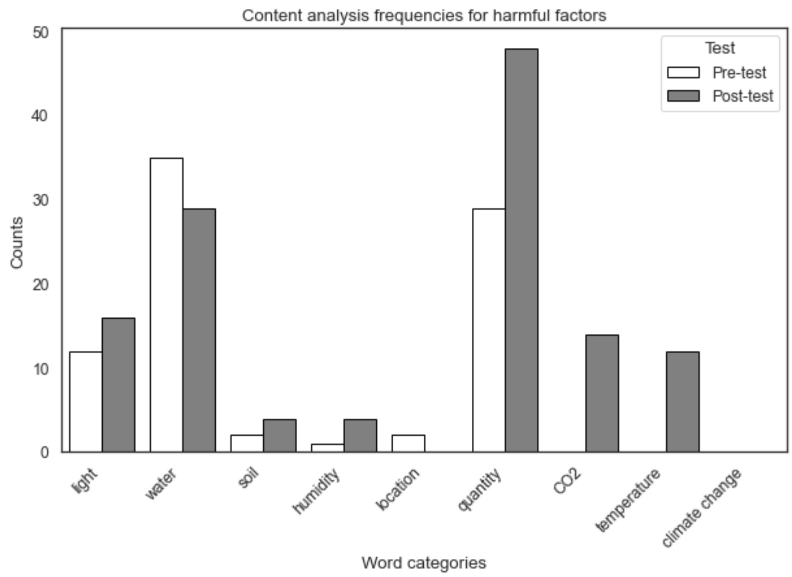


Figure 8. *Frequencies of the words categories related to the harmful factors for plants in the pre-test and post-test*

The comparison through paired t-tests between the ratings of statements from the pre-test and from the post-test also showed significant differences. The pre-statement “I like plants” was matched with the post-statement “I would like to have plants”, and hinted some insight into the attitude towards plants, as the mean increased from 4.09 (SD = 0.92) to 4.61 (SD = 0.71) with a significant p-value of 0.0002. For the statement “I know how to take care of a plant”, the mean increased from 3.74 (SD = 1.08) to 4.16 (SD = 0.84) with a significant p-value of 0.0438. The statement “I believe plants are important” also showed significant differences between the tests, with a pre-test mean of 4.70 (SD = 0.59) and a post-test mean of 4.95 (SD = 0.22) and a p-value of 0.0014. Finally, the matched statements “I have sometime asked for or searched for information about climate change” and “I am interested in climate change and its effect on plants, I will look for more information” also hinted some impact on this aspect, as the pre-test mean was 3.34 (SD = 1.35) and the post-test mean was 3.97 (SD = 1.04), and the t-test revealed a significant p-value of 0.0057. There were no significant differences in the statement “I am good at browsing the web”. There were no differences between the three groups of students for any of the statements. Figure 9 illustrates all these findings mentioned above.

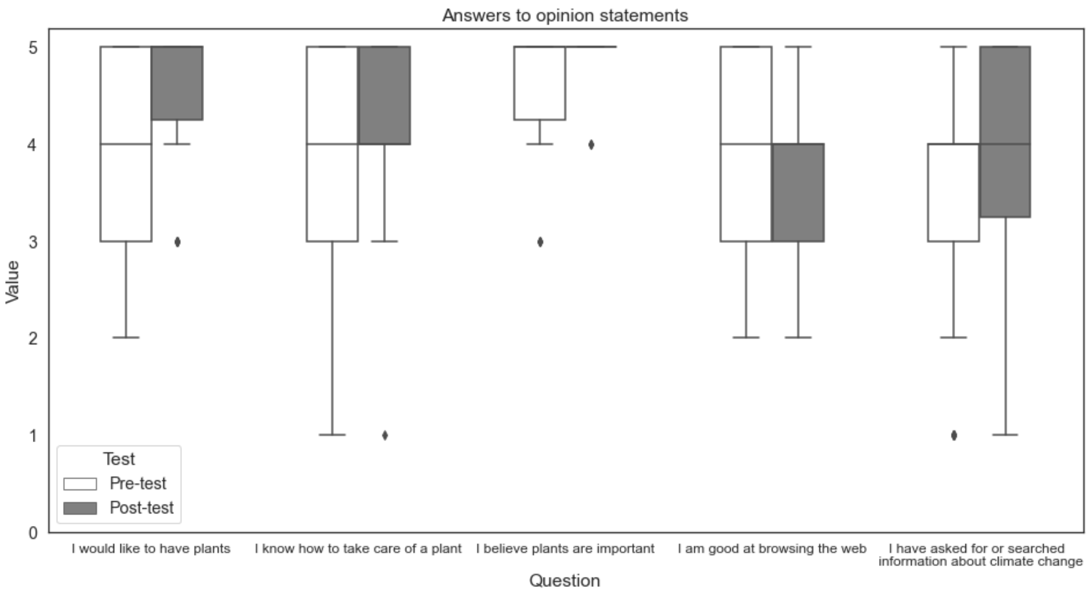


***Figure 9**. Comparison of answers to opinion questions (ratings from 1 to 5)*

4.2 Dashboard systems

This study found no significant association between the dashboard system and the problem-solving performance by means of direct evaluation. However, it found some significant differences in other activities of the workshop and in related queries in the post-test.

The initial pre-test confirmed that there were no differences between the three experimental groups, as expected given the fact that all participants were students from the same primary school and grade. All sections of the pre-test were tested, including problem-solving performance. The data collected during the activities and the post-test was analysed as described in the following sections to see if there were any significant differences.

4.2.1 Activities data

4.2.1.1 Session 1

From the first workshop session, significant differences were found among groups for the hypothesis activity. In the activity, as described in Section 3.4.2.1, participants worked in small groups -resulting in 4 groups per experimental condition- to generate hypothesis with the option to consult the dashboard. For each of the small groups, all the hypothesis collected were revised and only those that were considered valid were taken into account in the analysis. A Kruskal-Wallis test revealed significant differences in the counts of unique hypothesis amongst experimental groups with a p-value of 0.044611 and almost significant differences (p-value < 0.1) in the counts of unique relationships of variables, that is unique pairs of independent and dependent variables, with the p-value = 0.080326. Mann–Whitney U tests indicated that the significant differences were between the control and alert group (p-value = 0.039609) and between the control and advice group (p-value = 0.057547), but that there were no differences between the two groups receiving notifications (alerting and advising groups). These results are illustrated in Figures 10 and 11. Although there were significant differences in the final hypothesis and relationships of variables, no significant differences were found in the individual variables annotated in the first phases of the activity.

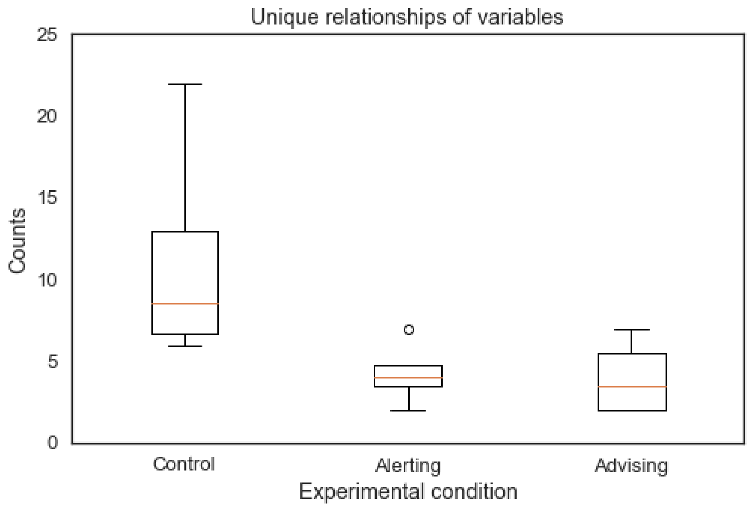


Figure 10. Results from the hypothesis activity (unique relationships of variables). *Each boxplot includes the total counts of unique relationships of independent and dependent variables from the small groups in each experimental condition. Almost significant differences were found between groups (p-value=0.080326).*

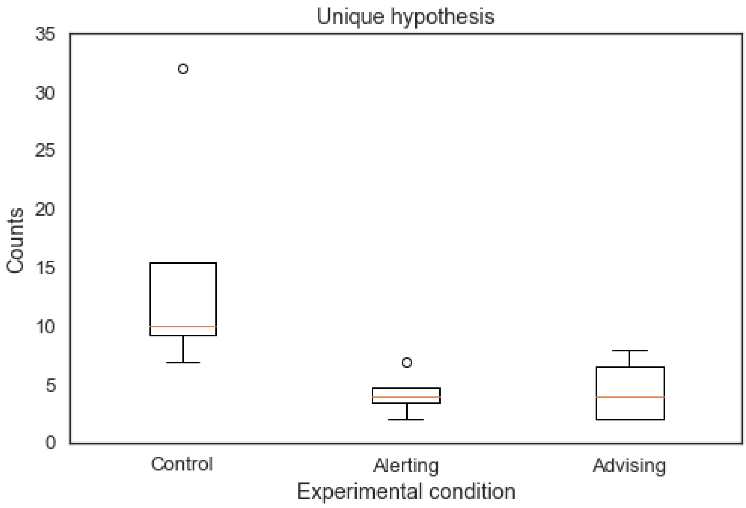


Figure 11. Results from the hypothesis activity (unique hypothesis). *Each boxplot includes the total counts of unique hypothesis from the small groups in each experimental condition. Significant differences were found between groups (p-value=0.044611).*

4.2.1.2 Session 2

In the second session, participants had to complete a canvas with 8 different activities related to a data analysis in small groups (Section 0). There were 4 small groups per condition, which completed and delivered one canvas each. Statistical tests revealed significant differences in two of these activities, although some answers to other activities also provided some insights.

In activity 1, no significant differences were found among the experimental groups; however, one workgroup from the alerting condition and one group from the advising condition answered “35 minutes” to the question “how much time has elapsed between two data points”, as written in one of the notifications, although the actual time between 2 data points was not 35 minutes but between 40-45 minutes. The rest of the groups in all the conditions answered “1 day”, referring to the ticks in the x axis. Activities 2 and 3 were devoted to doing calculations of some statistics, and no significant differences in the correctness of the answers were found. Activity 4 asked again for beneficial and harmful factors, and although there were no differences, we could make some observations; the answers resembled those in the pre-test, focusing mostly on the light, watering, and soil factors, with only two groups from all mentioning CO2 and two groups mentioning temperature, from which one even specified ranges of the appropriate temperature degrees.

Significant differences were found in the judgment of the plant’s health state during the week based on the data, in Activity 5. Participants were asked to assign one of the three health states -*good*, *regular*, or *bad*- to the plant, twice for each day (morning and afternoon) during a week. A Chi-square test for a contingency table showed significant differences in the frequencies of the assigned health states between experimental conditions, with a p-value of 0.014239. Further Chi-square tests revealed differences between control and alerting groups (p-value = 0.056878) and between advising and alerting groups (p-value = 0.057839). We could observe that none of the groups in the control or alerting conditions assigned the *bad* health state, whereas all groups in the alerting condition did assign it at least once. Separated Kruskal tests for the different health states reaffirmed the differences between conditions, with a significant p-values for the *bad* health state of 0.027324. Figure 12 represents the counts for each health state according to the condition.

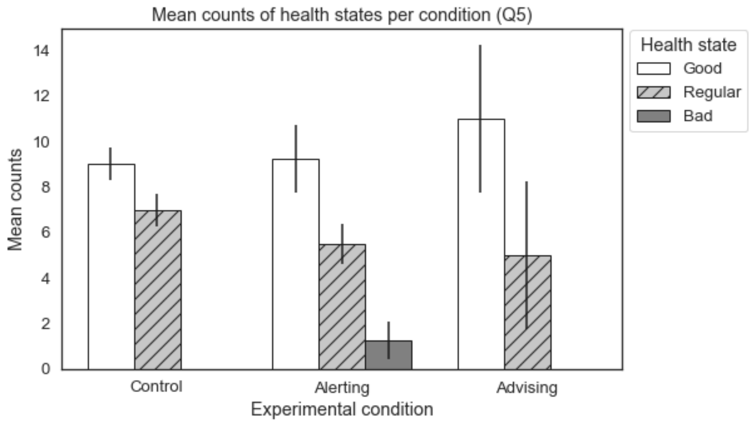


Figure 12. Results from Activity 5 in the canvas. *Mean counts of health states assigned to the plant per condition. The error bars show the standard deviation of the mean.*

In Activity 6, students were asked to indicate which days of the week the plant had been watered; for each day, then, the answer could be correct or incorrect. Mann–Whitney U tests revealed significant differences between control and advising groups with a p-value of 0.044690. Figure 13 illustrates the differences in accuracy between experimental condition.

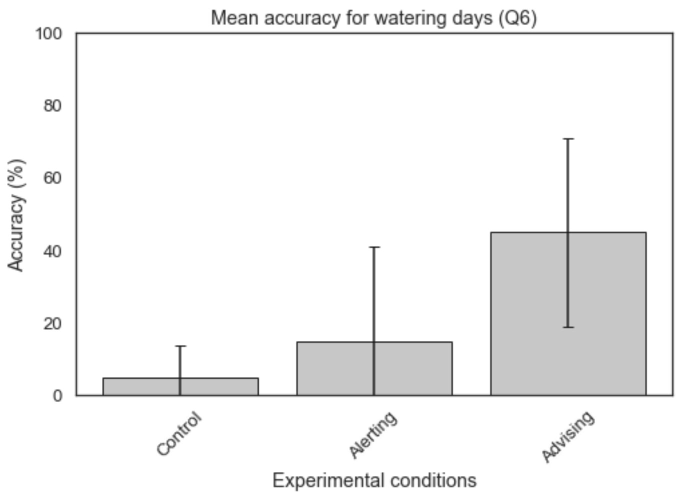


Figure 13. Results from Activity 6 in the canvas. *Mean accuracy of correct watering days identified per condition. The error bars show the standard deviation of the mean.*

There were no significant differences in Activity 7 and 8, which focused on finding correlations between the environmental measurements and on indicating which hypothesis could be accepted, respectively.

4.2.1.3 Session 3

In the last session, students completed a problem-solving activity in which they had to apply the previously learned concepts to identify the healthy and the unhealthy plants from their datasets (Section 3.4.2.3). In this activity, students also worked in small groups (4 groups per condition).

In the problem of identifying the plants through their datasets, all the groups in the alerting and advising conditions resolved it successfully, whereas one of the groups in the control condition did not solve the problem correctly, although having correctly calculated all the data statistics they were asked for.

As part of the problem, they were also asked to reason on how they had identified the plants. A Chi-square test revealed significant differences between experimental conditions for the reasonings, coded into four categories, with the p-value = 0.039517. The four coded categories were: CO2/Temperature; intuition (balanced dataset, extreme values, etc. but without specification); colour coding in the individual measurements' thermometers; and notifications.

As the dataset for the unhealthy plant was partly generated by increasing the temperature and the CO2, according to the content on global warming they had been seeing, it was expected that some groups could mention this increase as the reason. Only one group from the alerting condition explicitly referred to both the increase in CO2 and temperature as the reason; another group from the alerting condition referred to the increase in temperature, and a last one in the control condition referred to the increase in CO2. No group in the advising condition mention explicitly either temperature or CO2; instead, one of the groups in this condition said they identified the unhealthy plant through the "bad notifications". We could observe during the activity that one of the groups wrote down all the notifications in order to help them decide.

Other reasonings included: that one of the datasets had "worse factors" than the other, but without specification on which were the worse factors; that one dataset was more "unbalanced" or "extreme" than the other, or with "better " or "worse" conditions; or that there were more thermometers indicating "green" or "red" measurements in one of the datasets, although this was more arbitrary as the settings for the adequate ranges of measurements had been set by the same students in the previous session.

Although the majority of the reasonings did not specify the increase on temperature and CO2 as the main cause for identification, the before mentioned reasonings suggest some intuition to it. There was not any random assignment of the plants to the datasets in any of the groups; in fact, even the group from the control condition who misidentified the plants mentioned that the temperature and the CO2 were very high.

Figure 14 illustrates a summary of all the reasonings from the groups who correctly solved the problem. There were two reasonings per correct solution, one corresponding to each plant.

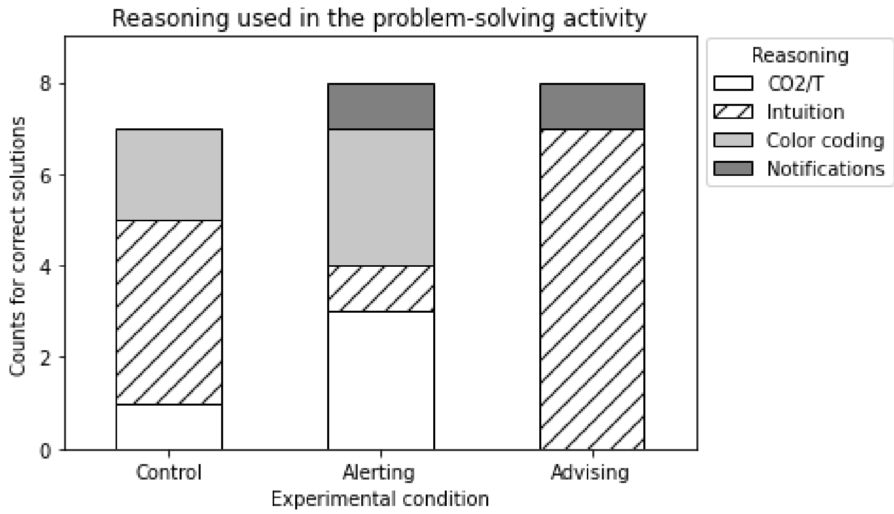


Figure 14. Results from the problem-solving activity. *The bars show the counts of correct answers together with the reasoning strategy used, coded into four categories.*

4.2.1.4 High school workshop

For the high school workshop, we analysed the data collected in the second session in a qualitative and observational manner, since the sample size and the duration of the workshop were too small for a more complete analysis for this age group. The students worked in small groups of three people, resulting two groups per experimental condition.

When asked for the time between two data points, we could observe that similarly to the primary school responses, almost all groups indicated that it was “1 day”. Only two groups had different answers, which were “35 minutes” as in the notifications for a group in the advising condition and “50 minutes”, manually calculated by a group from the alerting condition.

All groups correctly identified the days in which the plant had been watered and indicated that they checked it with the soil humidity measurement, and one group also included that they had also consulted “the observations from the dashboard”.

For the rest of questions related to the computation of statistics and the data analysis, including the identification of correlations between measurements, no relevant differences or observations were found.

Finally, four of the groups identified correctly the two plants based on their datasets, and there were two groups that misidentified them. From these two groups, one corresponded to the control condition and the other to the advising condition; whereas the group from the control condition did not justify their decision, the group from the advising condition reasoned that the healthy plant was that with "higher CO2", opposite as what it was expected for a correct answer. Regarding the groups who identified them appropriately, their justifications were all based on the differences in CO2 and in temperature. One of the groups from the control condition also mentioned the soil humidity factor, and wrote that "under the greenhouse effect, the environment would retain more temperature, more CO2 and less soil humidity". Other groups related it directly to their experimental design and mentioned that "when we add the independent variable, in this case the greenhouse we constructed, the levels of CO2 and temperature increase".

4.2.2 Post-test data

The first two questions in the post-test for primary school students were related to the last activity of the workshop, that is identifying the healthy and the unhealthy plants from their dataset, so we could also collect individual answers to the problem formulated. Students were first asked to reason why they thought the unhealthy plant was in that state based on what they had been working on in the activity, and, secondly, to propose a solution to avoid plants being in a bad health state. The analysis found no significant differences in the answers between the experimental groups, neither by considering the correctness of the reasonings individually nor by a content analysis considering the frequency of the most relevant words, both tested through a Chi square test.

Almost significant differences ($p\text{-value} < 0.1$) were found when asking directly in a multiple-choice question which were the main indicators of climate change, with a p-value of 0.068408 on a Chi square test. The control and alerting groups presented no differences when testing the corresponding 2x2 contingency table, with both groups having a higher proportion of correct answers. However, significant differences were found with a p-value of 0.051097 when comparing the alerting with the advising groups, considering that the advising group was the only condition with a higher proportion of incorrect answers. Figure 15 illustrates these results.

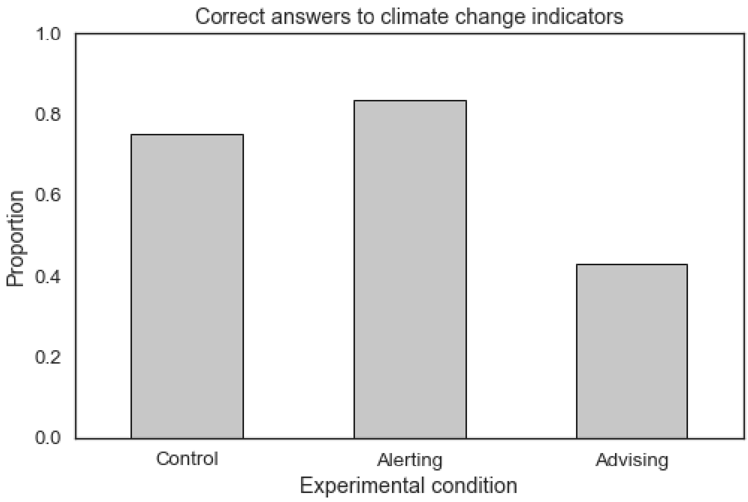


Figure 15. Results from the post-test related to the climate change indicators. *The alerting group had the highest proportion of correct answers, followed by the control group.*

In the other multiple-choice question, students were asked for the environmental measure with which they could know if the plant had been watered, directly related to one of the canvas questions they had completed in the second session. Again, almost significant results were found with a Chi-square test with p-value = 0.084526, and with the alerting group also showing the best performance. In this case, the control group showed the worst performance, with a noticeable higher proportion of incorrect responses, as shown in Figure 16.

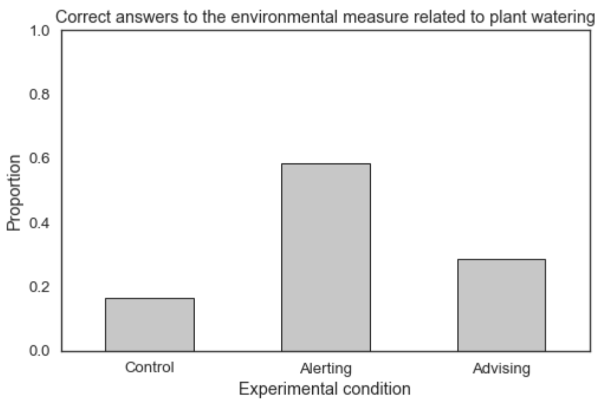


Figure 16. Results from the post-test related to the watering days indicator. *The alerting group had the highest proportion of correct answers, followed by the advising group.*

No significant differences were found for the last multiple-choice question in which students had to choose the correct statements about plants.

5 Discussion

5.1 Research Question 1

Regarding the question "*What kind of activities can be designed with the Teaspils dashboard?"*, the results show that both activities using the dashboard directly and indirectly (relating concepts, extending findings, reflection on data, etc.), for individual, in groups, or plenary social forms, can be designed and carried out in real classrooms for different educational levels, with a significant impact demonstrated for students of 6^{th} grade in primary schools. Moreover, the results suggest that further activities for other educational levels and around other related topics could also be designed based on the Teaspils system.

After a workshop of 6 activities and 3 presentations, students changed positively their opinion on environmental issues, considering plants more important than before and increasing their interest on the topics, as supported by our significant results. Furthermore, the comparison of the answers regarding plant care in the pre-test and post-test revealed how students went from the smaller to the bigger picture, adopting a more environmental-aware view on the topic. This is an encouraging finding that, once again, highlights the importance of education and the power it has in building our society; this also leads us to consider what would be the impact on climate change of an educational curriculum where environmental awareness played a more relevant role and the topics covered in the proposed workshop were further explored.

The design of the activities was not only successful in delivering the contents and creating an impact on students, but participants also claimed to have enjoyed the workshop in the post-test, some even suggesting a longer duration of it. This also supports the idea of including more activities of this kind -about environmental issues, using technological systems, relating data events to real phenomena, with hands-on activities- to the educational curriculum. However, although all of these components together have worked positively, it would be interesting to break them down to see which ones can really have a greater impact or can be applied to more educational areas.

The main limitation to these results could be the novelty factor; while students showed an increased interest and motivation, this could be due to the fact of having a different educator rather than their usual teacher, changing their regular schedule, or using the Teaspils technology for the first time. Also, the tutors, the class configuration -in this case in small classes with few students-, and the general policy and values of the school could play a role in obtaining these results; more workshops in different classroom settings and other schools should be conducted to be able to generalize them.

The main contribution of these results is directly related to the Teaspils project, as the Teaspils dashboard -and the IoT system as a concept- has been brought to real classrooms for the first time, with activities designed specifically for it. Moreover, the design of the activities supports the validity of the Digital Green Competences framework described in Section 2.1.1, and the development of the 21st century skills. Finally, the workshop relates directly to the inquiry-based learning approach, as students had to make discoveries on their own and link the concepts with real facts. With the different activities as the scaffolding, students followed the 5 phases proposed for IBL[34]: in the orientation phase, students were presented with the real plant and the Teaspils IoT system; the conceptualization phase was materialized in the hypothesis mural activity; the investigation phase corresponded to the data analysis canvas with the dashboard; for the conclusion phase, students solved the final problem-solving activity, from which students had to draw conclusions related to the initial questions; finally, the discussion phase was done through the reflective activity.

5.2 Research Question 2

Regarding the question *"How do the different dashboard systems -mirroring, alerting, and advising- impact the problem-solving capacity of students?"*, no significant differences between groups were found in problem-solving. However, significant differences were found in activities related to it. Moreover, some insight into the problem addressed is provided by almost significant results and direct observations.

The results of the activity of formulating hypotheses indicated that the control group had generated a significantly higher amount of unique and valid hypothesis than the other two groups receiving the notifications. A possible explanation could be that having already some written ideas for relationships between variables in the alerts and advice limited or directed the brainstorming flow of the students. This result was not expected, as it was the first contact with the dashboard, and it brings to surface other questions such as whereas the alerting systems can impact not only the problem-solving skills but also the creative thinking of students.

Other significant results were found in the canvas activity. Students in the alerting condition assigned more *bad* health states to the plant during the week than the other two groups, which in fact only assigned *good* and *regular* health states. These results were not due to only one group assigning a lot of “bad” states, as all groups assigned at least one *bad* health state. This could imply that the notifications may alter the perception about certain data events. Although both alerting and advising groups received notifications, this was only observable in the alerting group; perhaps students in the alerting condition did not have enough information to assess whether the events presented where positive or negative, while students in the advising group had more information to consider the events to not be bad enough.

Also in the canvas activity, significant differences were found when interpreting data to find which days the plant had been watered; the advising group showed the best performance whereas the control group showed the worst. In this case, opposite to the previous results in the hypothesis generation, notifications appeared to be beneficial by helping students to interpret the data and complete the specific exercise. These results are directly related to the ones found in the post-test. However, there, when slightly changing the question and asking it after some time, the results changed: the alerting condition showed a moderately better performance than the advising one, with the control one still showing the worst. One explanation could be that specific notifications helped to solve a specific problem, but were not broad enough to extrapolate the solution or to apply the underlying content in another question after some time, even if the knowledge required to answer it was the same. For the control group, the poor performance could be explained by the fact that they did not receive any of the hints and the answer might have been not obvious enough considering their previous knowledge. Naturally, these results lead to other questions, such as which is the effect of the alerting and advising notifications over time, or which would be the adequate balance of information in them to be effective in learning.

In the activity of identifying the healthy and unhealthy plants from their datasets, we can observe how most of the groups, both from the primary and high school workshops, correctly solved the problem, with significant differences in the coded reasonings between the conditions for the primary school setting. Only groups from the control and alerting conditions reasoned their answers with the increase in CO_2 and temperature, with the higher proportion of these answers being in the alerting condition. Although further research with a larger sample size would be needed to claim so, it seems that the alerting system was the best to guide the problem-solving and reasoning towards the desired response by providing a balanced amount of information, aligned with the initial expectations of this research.

When comparing age groups, we see differences in the reasoning and interpretation of data. The high school groups that correctly solved the activity (4 of the 6 in total) all justified the response with the high measurements of CO_2 and temperature, and even one group mentioned the low soil humidity; one of the groups that misidentified the plants even relied on these measurements. Instead, for primary school students some approached it and showed some intuition (e.g., "more extreme" measurements) and some reasoned it with CO_2 and temperature, but there were also those who exclusively relied on the notifications; the latter occurred in the advising condition, where no group mentioned explicitly either the increase in temperature or CO2 as possible factors. Although it is a very simple comparison with a small sample size, it could be worthwhile to delve into the effect across age groups, as it seems that younger ones could be more susceptible to notifications.

Also in the post-test, almost significant results were found when asking for the indicators of climate change. These results, although not directly related to the problem-solving skills, were the ones that approximated the most the expectations for our hypothesis. The best performance was found in the alerting group, followed by the control group, and, lastly, the advising group. A possible explanation could be that the alerts would help to approach the bigger picture of climate change on plants, required to solve the problem, without focusing too much on specific events of the data. Instead, the latter could have happened to the advising group; the advising system could have difficulted or prevented to reach this bigger picture by being too specific. However, one limitation to this explanation could be the presence of a presentation on climate change at the beginning of the session, although distractor activities were included in between and although it being the same for all groups.

Although there were no significant differences in the problem-solving skills, the observations and other results from the activities contributed to gaining insight into the problem addressed. The alerting and advising systems showed both positive and negative aspects. Apart from the differences observed in creative thinking and the perception of the plant, observations revealed that some students were not critical with the notifications and relied on the information provided. Specially during the last session activity, in which some groups justified their problem-solving decisions exclusively based on the alerts. On the other side, the alerting and advising systems could help focus on the relevant aspects, as it happened with the watering days exercise. From these results and observations, it is not clear what kind of notifications - alerting or advising, if any- would be better to implement in a tool of this kind. However, it seems that the alerting system could be a safer option for now than the alerting system when balancing all the data and observations collected in this research, together with the performance in the activities and post-test. Nevertheless, urther research is needed before implementing an alerting system to the Teaspils dashboard.

These results present some limitations and challenges as well. The main limitation of this study is the small sample size, which becomes even smaller when working in small groups of 3-4 students, resulting in 4 groups per experimental condition. In order to avoid this, the activities could have all been done individually; however, we tried to balance the trade-off between working in groups to explore the activities designed for the Teaspils technologies and the data collection for testing the dashboard systems. Moreover, the study should be repeated with more participants to be able to generalize the results; expanding the research with more schools and different ages could also be an opportunity to find more reliable results.

The high school workshop also presented many limitations in terms of time, sample size, and data collection; the time restrictions limited the activities, and many of the participants did not have time to carefully complete them. This directly impacted on the data analysis, which did not allow for in-depth results and comparisons.

Another limitation could have been how the problem to solve was formulated, as the formulation of the problem itself could have impacted how the students answered. An initial pilot study could have helped refine the formulation of the questions so that the answers were as accurate as possible with respect to the problem investigated. Other limitations to the results are the influences that could have had the different tutors and previous methodologies for each class, different schedules for the sessions of the workshop, and different physical class organizations. This last point could have also had an influence on the pre- and post-tests; although they were done individually, two of the classes were arranged so that students sat in pairs, whereas in the other one they sat in groups.

Regarding the notifications, because of how they were programmed, not all the notifications might have been displayed, especially in the first session in which students interacted little with the dashboard compared to the other sessions.

Finally, some of the limitations are not new to the educational field; the classes comprised a great diversity of students, including diversity in learning abilities, cultural backgrounds, language domain, technology expertise, and motivation, among others, with the challenges it implies.

6 Conclusions

The work in this research has addressed the implementation of a dashboard for environmental awareness education from different points of view, by designing and conducting learning activities based on it and by implementing and analysing the impact of different dashboard systems -no alerts, alerting, and advising- on the problem-solving skills of students, focusing mostly on primary school students but including some inquiry into high school students.

Our results have allowed to unfold some initial answers and further questions in response to the research questions, by proving the effectiveness of the activities on the environmental awareness goal and by providing some differences, insights, and observations on the effects of different alerting systems, although the hypothesis could not be accepted.

The main contribution to the Teaspils project is that the dashboard technology has been tested for the first time in real classrooms, with activities designed specifically for this and in line with the Digital Green Competences framework. The Teaspils IoT system has been shown to allow for a great variety of activities, from which some can be adapted to other educational levels while keeping the same learning outcomes. After the workshop, primary school students were able to grasp a bigger picture on the importance of plants, fulfilling to the objective to promote environmental awareness.

On the other hand, and more generally, this research has contributed to investigating the effects of a dashboard focused on the students and not on the teachers, as it has been done more extensively in the field and collected here in the state of the art. Finally, although we had to reject the hypothesis relating the alerting systems to the problem-solving skills, this project has approached in some way the use and impact of artificial intelligence in learning technologies through alerting and advising systems, but, more importantly, it has outlined other research questions that might arise, and provided a starting point for further research to answer them.

Our project leaves space for further and more in-depth research related to the implementation of a dashboard for environmental awareness education. Future steps include the evaluation of the design of the activities with experts, the evaluation of the learning outcomes with the teachers who participated in the workshop, conducting the workshop with more schools and more educational levels, testing the workshop with their usual teachers to suppress the novelty factor, the design of new activities, re-defining and improving the current experimental design, and, finally, the formulation of new research questions on the field of AI in education, since the impact of notifications of this kind on student learning remains unclear.

7 List of figures

8 References

1. Tabuenca, B., Greller, W., Hernández Leo, D., Gilarranz Casado, C., García Alcántara, V., & Tovar Caro, E. (2021). Talking to plants: an IoT system supporting human-plant interactions and learning.
2. Hernández-Leo, D., Ferrer, J., Vujovic, M., Tabuenca, B., Greller, W., Carrió, M. & Moyano, E. (2022). Activities using smart IoT planters in learning spaces: designing a human-centred dashboard. Manuscript submitted for publication.
3. Mutlu-Bayraktar, D., Cosgun, V. & Altan, T. Cognitive load in Multimedia Learning Environments: A systematic review. *Computers & Education* **141,** 103618 (2019).
4. Karagozlu, D. Determination of the impact of augmented reality application on the success and problem-solving skills of students. *Quality & Quantity* **52,** 2393–2402 (2017).
5. van Leeuwen, A. & Rummel, N. Orchestration tools to support the teacher during student collaboration: A review. Unterrichtswissenschaft 47, 143–158 (2019).
6. Soergel, B., Kriegler, E., Weindl, I., Rauner, S., Dirnaichner, A., Ruhe, C., ... & Popp, A. (2021). A sustainable development pathway for climate action within the UN 2030 Agenda. Nature Climate Change, 11(8), 656-664.
7. Osborn, D., Cutter, A., & Ullah, F. (2015). Universal sustainable development goals. Understanding the Transformational Challenge for Developed Countries.
8. Thor, D. & Karlsudd, P. Teaching and fostering an active environmental awareness design, validation and planning for action-oriented environmental education. *Sustainability* **12,** 3209 (2020).
9. Schwendimann, B. A. *et al.* Perceiving learning at a glance: A systematic literature review of Learning Dashboard Research. *IEEE Transactions on Learning Technologies* **10,** 30–41 (2017).
10. Ji, M., Michel, C., Lavoué, É. & George, S. DDART, a dynamic dashboard for collection, analysis and visualization of activity and reporting traces. *Open Learning and Teaching in Educational Communities* 440–445 (2014). doi:10.1007/978-3-319-11200-8_39
11. Yoo, Y., Lee, H., Jo, I.-H. & Park, Y. Educational dashboards for smart learning: Review of case studies. *Emerging Issues in Smart Learning* 145–155 (2014). doi:10.1007/978-3-662-44188-6_21

12. Steiner, C. M., Kickmeier-Rust, M. D., & Albert, D. (2014). Learning analytics and educational data mining: An overview of recent techniques. *Learning analytics for and in serious games*, *6*, 61-75.
13. Muldner, K. *et al.* Exploring the impact of a learning dashboard on student affect. *Lecture Notes in Computer Science* 307–317 (2015). doi:10.1007/978-3-319-19773-9_31
14. Esquiagola, J., Manini, M., Aikawa, A., Yoshioka, L. & Zuffo, M. Monitoring Indoor air quality by using IOT Technology. *2018 IEEE XXV International Conference on Electronics, Electrical Engineering and Computing (INTERCON)* (2018). doi:10.1109/intercon.2018.8526380
15. Prieto, L. P., Sharma, K., Kidzinski, Ł, & Dillenbourg, P. (2018). Orchestration load indicators and patterns: In-the-wild studies using mobile eye-tracking. *IEEE Transactions on Learning Technologies*, *11*(2), 216–229. https://doi.org/10.1109/TLT.2017.2690687
16. Amarasinghe, I., Hernández-Leo, D. & Ulrich Hoppe, H. Deconstructing orchestration load: Comparing teacher support through mirroring and guiding. *International Journal of Computer-Supported Collaborative Learning* **16,** 307–338 (2021).
17. Sweller, J. Cognitive load theory and educational technology. *Educational Technology Research and Development* **68,** 1–16 (2019).
18. Soller, A., Martínez, A., Jermann, P., & Muehlenbrock, M. (2005). From mirroring to guiding: A review of state of the art technology for supporting collaborative learning. *International Journal of Artificial Intelligence in Education*, *15*(4), 261–290.
19. The Impact of Artificial Intelligence on Learning, Teaching, and Education (JRC Science for Policy Report)
20. Zanetti, M., Iseppi, G. & Cassese, F. P. A "psychopathic" artificial intelligence: The possible risks of a deviating AI in Education. *Research on Education and Media* **11,** 93–99 (2019).
21. Guilherme, A. Ai and education: The importance of teacher and student relations. *AI & SOCIETY* **34,** 47–54 (2017).
22. Pedro, F., Subosa, M., Rivas, A., & Valverde, P. (2019). Artificial intelligence in education: Challenges and opportunities for sustainable development.
23. Holmes, W. *et al.* Ethics of AI in education: Towards a community-wide framework. *International Journal of Artificial Intelligence in Education* (2021). doi:10.1007/s40593-021-00239-1

24. Drigas, A. S., & Ioannidou, R. E. (2012). Artificial intelligence in special education: A decade review. *International Journal of Engineering Education*, *28*(6), 1366.
25. Sagi, Y., Tavor, I., Hofstetter, S., Tzur-Moryosef, S., Blumenfeld-Katzir, T., & Assaf, Y. (2012). Learning in the fast lane: new insights into neuroplasticity. *Neuron*, *73*(6), 1195-1203.
26. Sottilare, R., Graesser, A., Hu, X., & Goodwin, G. (Eds.). (2017). *Design Recommendations for Intelligent Tutoring System-Volume 5: Assessment Methods* (Vol. 5). US Army Research Laboratory.
27. Graesser, A. C., Hu, X., & Sottilare, R. (2018). Intelligent tutoring systems. In *International handbook of the learning sciences* (pp. 246-255). Routledge.
28. Yuce, A., Abubakar, A. M., & Ilkan, M. (2019). Intelligent tutoring systems and learning performance: Applying task-technology fit and IS success model. *Online Information Review*.
29. Mousavinasab, E., Zarifsanaiey, N., R. Niakan Kalhori, S., Rakhshan, M., Keikha, L., & Ghazi Saeedi, M. (2021). Intelligent tutoring systems: a systematic review of characteristics, applications, and evaluation methods. *Interactive Learning Environments*, *29*(1), 142-163.
30. Xu, Z., Wijekumar, K., Ramirez, G., Hu, X., & Irey, R. (2019). The effectiveness of intelligent tutoring systems on K-12 students' reading comprehension: A meta-analysis. *British Journal of Educational Technology*, *50*(6), 3119-3137.
31. Akyuz, Y. (2020). Effects of intelligent tutoring systems (ITS) on personalized learning (PL). *Creative Education*, *11*(6), 953-978.
32. Kim, B., Suh, H., Heo, J., & Choi, Y. (2020). AI-driven interface design for intelligent tutoring system improves student engagement. *arXiv preprint arXiv:2009.08976*.
33. Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. Educational research review, 14, 47-61.
34. Wang, F., Kinzie, M. B., McGuire, P., & Pan, E. (2010). Applying technology to inquiry-based learning in early childhood education. Early Childhood Education Journal, 37(5), 381-389
35. Hänze, M., & Leiss, D. (2022). Using heuristic worked examples to promote solving of reality-based tasks in mathematics in lower secondary school. Instructional Science, 1-21.

36. Mulder, Y. G., Lazonder, A. W., & de Jong, T. (2014). Using heuristic worked examples to promote inquiry-based learning. Learning and instruction, 29, 56-64.
37. Peña-López, I. (2015). Schooling Redesigned. Towards Innovative Learning Systems.
38. Funke, J., Fischer, A. & Holt, D. V. Competencies for complexity: Problem solving in the twenty-first century. *Educational Assessment in an Information Age* 41–53 (2017). doi:10.1007/978-3-319-65368-6_3
39. Khoiriyah, A. J. & Husamah, H. Problem-based learning: Creative thinking skills, problem-solving skills, and learning outcome of seventh grade students. *Jurnal Pendidikan Biologi Indonesia* **4,** (2018).
40. Voogt, J., & Roblin, N. P. (2010). 21st century skills. *Discussienota. Zoetermeer: The Netherlands: Kennisnet*, *23*(03), 2000.
41. Jonassen, D. H. (2010). *Learning to solve problems: A handbook for designing problem-solving learning environments*. Routledge.
42. Lawson, M. J. (2003). Problem solving. *International handbook of educational research in the Asia-Pacific region*, 511-524.
43. Puvia, E., Monteleone, V., Fulantelli, G. & Taibi, D. (2020). Facing the Appeal of Social Networks: Methodologies and Tools to Support Students towards a Critical Use of the Web. *Proceedings of the 12th International Conference on Computer Supported Education.* Published. https://doi.org/10.5220/0009571105670573
44. Martínez Moreno, J., Santos, P., & Hernandez-Leo, D. (2021, October). Maker Education in Primary Education: Changes in Students' Maker-Mindset and Gender Differences. In *Ninth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'21)* (pp. 120-125).
45. Bianchi, G., Pisiotis, U. and Cabrera Giraldez, M., GreenComp The European sustainability competence framework, Punie, Y. and Bacigalupo, M. editor(s), EUR 30955 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-46485-3, doi:10.2760/13286, JRC128040.

Appendix

9 Appendix

A.1 TEASPILS dashboard

The following figures show the interface of the version of the TEASPILS dashboard used in the workshops.

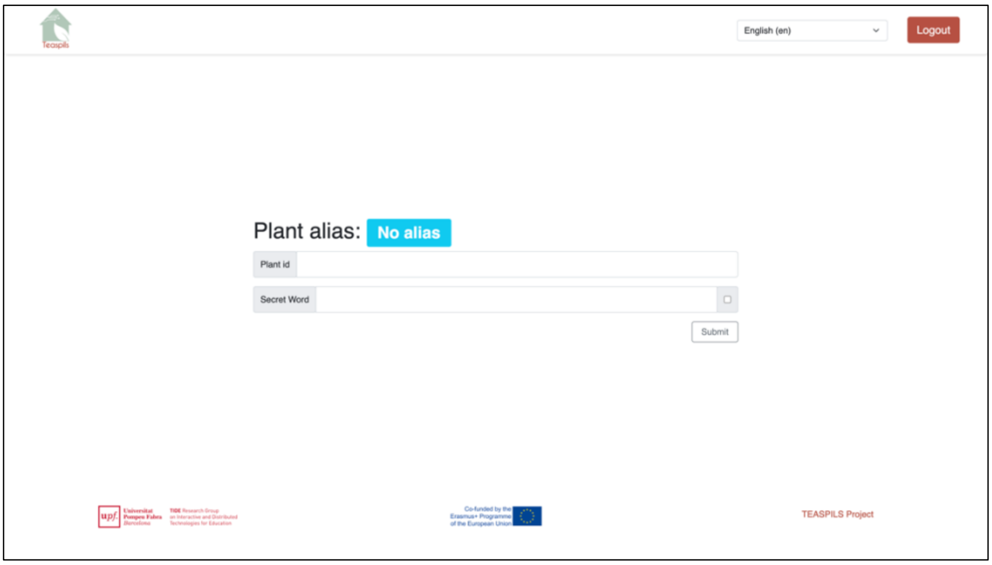


Figure A1. *Home page with login*

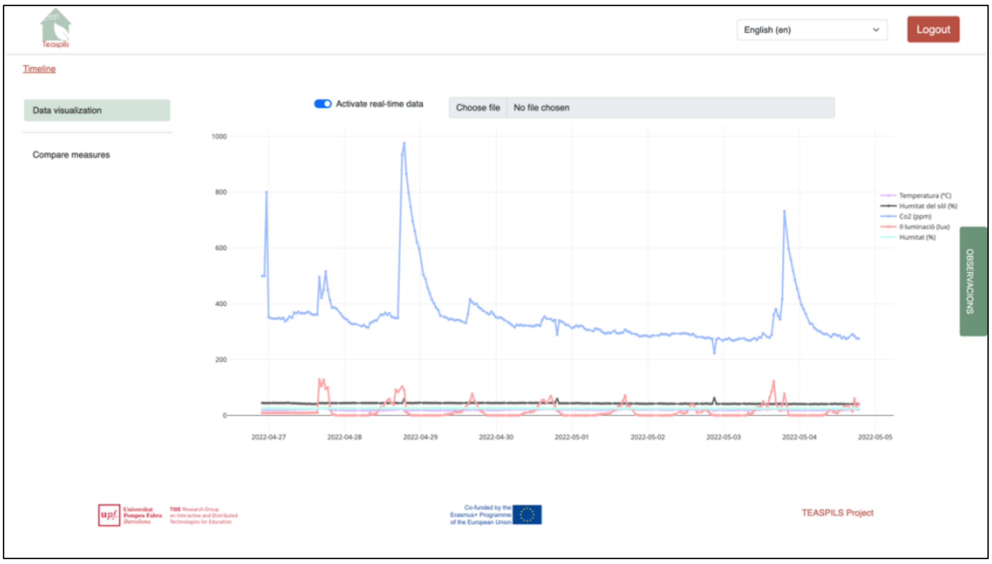


Figure A2. *Timeline data visualisation page*

Figure A3. *Observations tab*

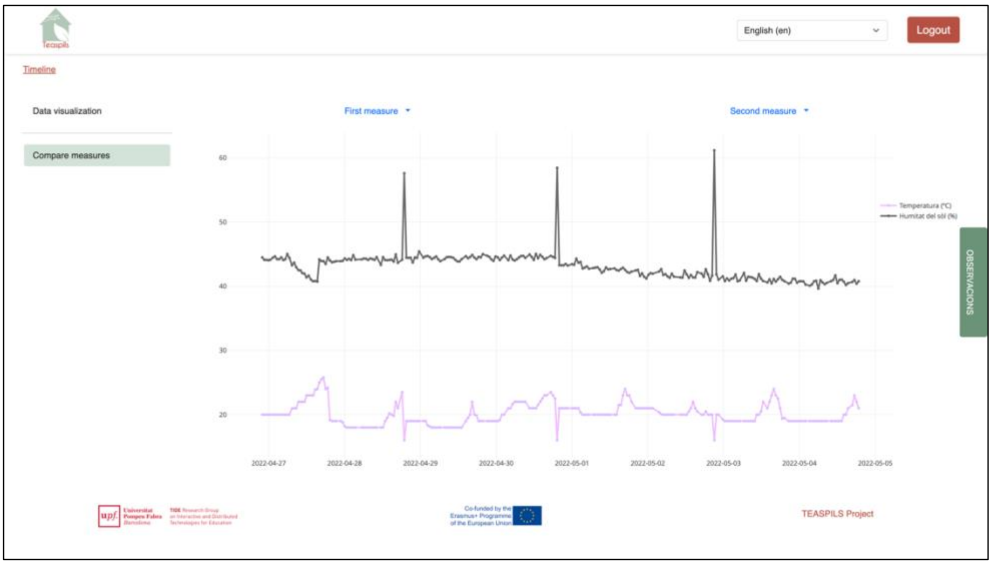


Figure A4. *Pairwise comparisons page*

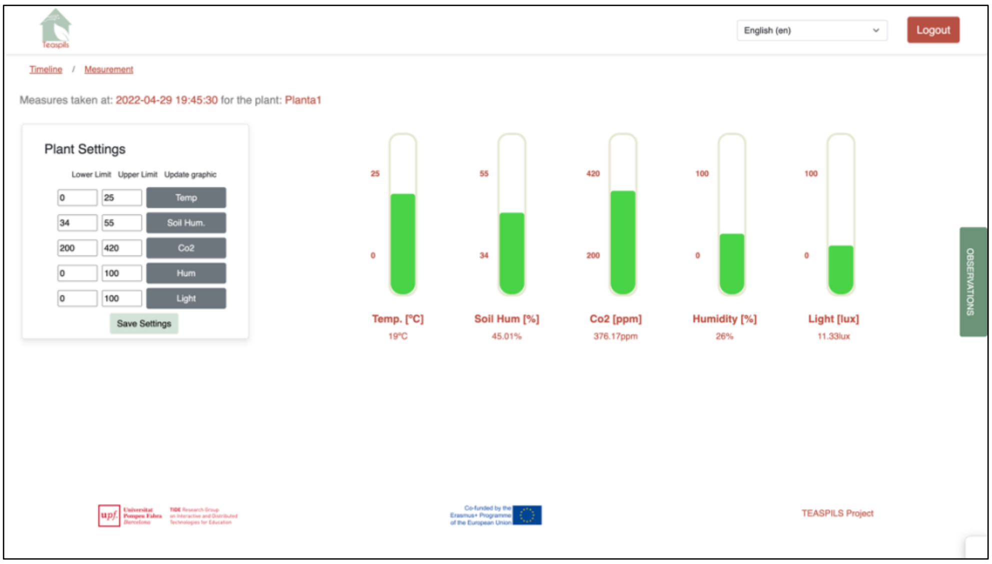


Figure A5. *Thermometers page with single point measurements*

A.2 Data collected for the design of activities

Regarding the learning activities to design with the Teaspils dashboard.

A.2.1 Data from the co-designing session

Subcategories of Content and methodological approach	Counts
Multidisciplinary	2
Beyond classrooms	5
Multi-class cooperation	1
Social cooperation and interaction	Almost all, 3 explicit

Table A1. *Content and methodological approach*

Subcategories of Requirements	Counts
Periodical / Recurrent measurement	3
More than one plant	3
More than one specie	2
More than one location	2

Table A2. *Requirements for the activity*

Subcategories of Learning goals	Counts
Students' self-awareness and critical thinking	5
Correlation of the project and its data to some real phenomena	5
Checking the Plant Well-Being	Almost all
Environmental evaluation	3
Influence of external factors towards the plant	7

Table A3. *Learning goals*

A.2.2 Data collected through Padlet with educators and learning technologists

Subcategories of Area of knowledge	Counts
Mathematics	1
Green architecture	1
Agricultural engineering	1
Ecology	1

Table A4. *Area of knowledge*

Subcategories of Educational level	Counts
Pre-school	1
Primary school	2
Secondary school	2
High school	3
University	2
Graduate school	1
Formative cycles	

Table A5. *Educational level*

Subcategories of Concepts to work on	Counts
Effects of fertiliser	3
Photosynthesis	1
Scientific method / experimental design	2
Water analysis	3
Delayed feedback of plants	1
Seasonality	1
Crop rotation	1
Plant perception / plant communication	2
Optimal conditions for plants	1
Plant diary / Scientific journaling	1
Life cycle	1
Plant care	1

Table A6. *Concepts to work on with the activity*

Subcategories of Methodologies	Counts
Small groups	3
Role groups	1
Groups for scheduled maintenance	2
Individual work	1
Hybrid work	1

Table A7. *Methodologies*

Subcategories of Role of the dashboard	Counts
Alert system	2
Data collection	2
Data visualisation	2

Table A8. *Role of the dashboard*

Subcategories of Activities ideas	Counts
Emotional aspects humans-plants	1
General approach to plants	1
Comparison of plants with different environmental conditions	2
Growing a plant / plant care	3
Identify the best conditions for the plant	2
Growing multiple plants together	1

Table A9. Activities ideas

A.3 Pre-test

Nom i cognoms: ____

Teaspils: Plantes i tecnologia

En aquesta enquesta hauràs de respondre a unes preguntes. Tingues en compte que:

- Has de respondre les preguntes de manera ordenada
- Has de donar respostes sinceres, no hi ha respostes correctes o incorrectes
- No direm les teves respostes a ningú!

1. Parla'ns de tu!

1.1. Quina edat tens? _______ anys

1.2. Ets…

- Noi
- Noia

2. Sobre tecnologia i aplicacions

2.1. Coneixes algun d'aquests conceptes i/o aplicacions tecnològiques? Pots triar més d'una opció.

- ❑ Sensors (per ex. els sensors Arduino)
- ❑ IoT (Internet de les coses)
- ❑ Ciència de les dades (Data science)
- ❑ Intel·ligència Artificial (AI)
- ❑ Mètode científic
- ❑ No en conec cap

3. Sobre les plantes

3.1. Tens alguna planta a casa? Quantes? _______ plantes

3.2. Què s'ha de tenir en compte a l'hora de **cuidar d'una planta**? Escriu aquí les indicacions que seguiries per cuidar d'una planta:

____

____

____

- ❑ No en conec cap

3.3 Quins són els **factors perjudicials** per les plantes? Escriu aquí aquelles coses que evitaries per no fer malbé una planta:

____

____

____

- ❑ No en conec cap

4. Què en penses?

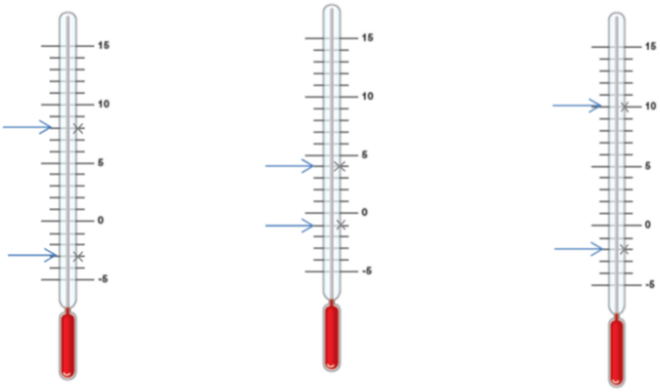
4.1. Fes una creu dintre del quadrat que correspongui segons el que tu **creguis**. No poseu la creu entre la línia de dos quadrats.

	Horrible 	No gaire bé 	Bé 	Molt bé 	Genial 
M'agrada la tecnologia					
Vull aprendre sobre tecnologia					
M'agraden les plantes					
Crec que sé cuidar bé d'una planta					
Crec que les plantes són importants					
Vull aprendre sobre plantes					
Se'm dóna bé navegar per una web					
Alguna vegada he demanat o he cercat informació sobre el canvi climàtic					

5. Per acabar...

5.1. Al mes de gener, vam registrar les temperatures en dos moments del dia, a les 6 del matí i a les 3 de la tarda. Quin termòmetre marca les dues temperatures?

a) Temperatura a les 3 de la tarda: +8ºC
b) Temperatura a les 6 del matí: -3ºC



❑ Termòmetre A ❑ Termòmetre B ❑ Termòmetre C

5.2. Quants graus ha augmentat la temperatura entre les 6 del matí i les 3 de la tarda?

❑ 5ºC ❑ 8ºC ❑ 11ºC

Moltes gràcies!!

A.4 Post-test

Nom i cognoms: ____

Teaspils: Plantes i tecnologia

En aquesta enquesta hauràs de respondre a unes preguntes. Tingues en compte que:

- Has de respondre les preguntes de manera ordenada
- Has de donar respostes sinceres, no hi ha respostes correctes o incorrectes
- No direm les teves respostes a ningú!

I. Sobre el que hem après al taller

1.1. Què creus que li ha passat a la planta que hem vist abans que estava en un mal estat de salut? Per què pot emmalaltir o empitjorar l'estat d'una planta? Escriu el que tu creguis:

____

____

____

1.2. Com podem ajudar a les plantes en el nostre dia a dia i evitar que estiguin en mal estat? Escriu el que tu creguis:

____

____

____

1.3. Amb quina mesura podem observar si s'ha regat la planta? Tria **una** opció.

- ❑ Temperatura
- ❑ Humitat
- ❑ Humitat del sòl
- ❑ Il·luminació
- ❑ CO2
- ❑ Soroll
- ❑ No en conec cap

1.4. Quins són els **dos** principals indicadors del canvi climàtic? Tria **2** opcions.

- ❑ Temperatura
- ❑ Humitat
- ❑ Humitat del sòl
- ❑ Il·luminació
- ❑ CO2
- ❑ Soroll
- ❑ No en conec cap

1.5. Quines de les següents afirmacions són certes? Pots triar més d'una opció

- ❑ Tenir a l'aula una planta pot tenir beneficis.
- ❑ Totes les plantes necessiten les mateixes condicions per créixer.
- ❑ Podem saber l'estat d'una planta a partir de les seves dades recollides.
- ❑ L'augment de temperatura i de CO2 que està succeint al planeta és beneficiós per les plantes, ja que necessiten molts rajos de sol i molt CO2 per créixer.
- ❑ El canvi climàtic afecta a les plantes.

2. Després del taller... què en penses?

2.1. Fes una creu dintre del quadrat que correspongui segons el que tu **creguis**. No poseu la creu entre la línia de dos quadrats.

	Horrible	No gaire bé	Bé	Molt bé	Genial
T'han agradat els tallers de "Teaspils: Plantes i Tecnologia"?					
T'ha agradat fer servir els materials que heu hagut de completar?					
T'ha semblat fàcil els materials que heu hagut de completar?					
T'ha agradat l'aplicació que heu fet servir en els tallers?					
Vull tenir plantes a casa					
Crec que sé cuidar bé d'una planta					
Crec que les plantes són importants					
Se'm dóna bé navegar per l'aplicació de Teaspils					
M'interessa el canvi climàtic i el seu efecte en les plantes, i buscaré més informació					

1.1. Què és el que **més** t'ha agradat dels tallers?

____

____

____

1.2. Què és el que **menys** t'ha agradat dels tallers?

____

____

____

Moltes gràcies!!

A.5 Datasets

Links to the datasets:

- Dataset of the healthy plant
- Dataset of the unhealthy plant (under the effects of climate change)

A.6 Workshop presentations

Links to the presentations used in workshops.

A.6.1 Primary school workshop:

The presentations for the different classrooms -corresponding to the different experimental conditions- are the same; only the duration for longer sessions (with extra slides of miscellaneous content to the experimental design) and the login credentials for the Teaspils dashboard were different.

Session 1:

- 6èA (control)
- 6èB (alerting)
- 6èC (advising)

Session 2:

- 6èA (control)
- 6èB (alerting)
- 6èC (advising)

Session 3:

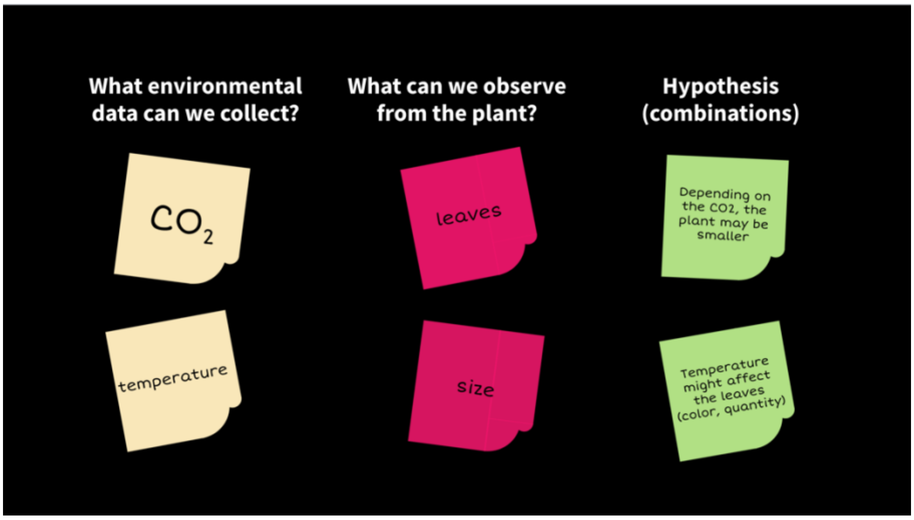
- 6èA (control)
- 6èB (alerting)
- 6èC (advising)

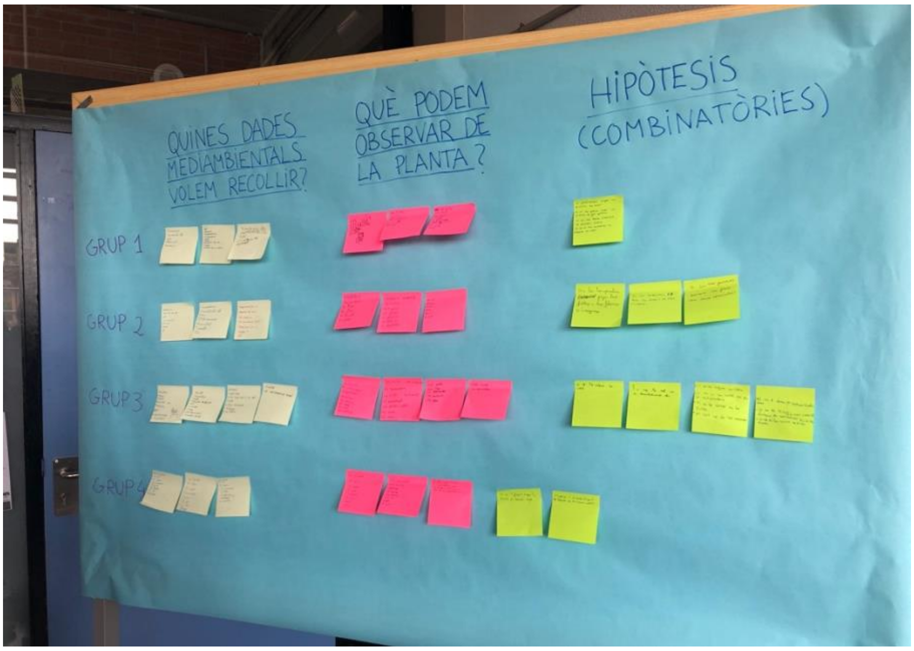
A.6.2 High school workshop:

- Session 1
- Session 2

A.7 Learning activities: Primary school workshop

A.7.1 Hypothesis mural





A.7.2 Worksheet: Discover which plant it is

Group: ____

Teaspils: Our plant

In this activity we will try to discover the species of our plant, based on observations made by us and its characteristics. You can use the internet to find out.

1. Let's observe the plant

Make a cross inside the square that corresponds to the characteristics that we can observe from our plant:

Observation	YES	NO	Not observable
Presence of flowers			
Presence of leaves			
Visible roots			
Visible stem			
Presence of spikes			
Edible			
Presence of insects			

2. Describing the plants

Which of the following adjectives do you think describes best our plant? Circle one for each feature.

- Colour: pale green / light green / dark green
- Leaf texture: smooth / slightly wavy / wrinkled
- Leaves shape: round / elongated
- Plant size: small / medium / large
- Smell: no smell / loose smell / strong smell

3. Getting to know our plant

Below you will find a few clues on some of the most relevant features:

- It has no fruits or seeds, and it is reproduced by spores
- Originally from Australia, Eastern Tropical Africa, and Tropical Asia
- Grows in warm and humid areas, with partial or total shadow
- In its natural habitat, it can be found in places where the shadow predominates, so it can be turned into a good interior plant
- Regarding its state of conservation, it is not in danger of extinction
- Its common name has some relation to birds, due to his appearance

Do you know which plant is it?

Common name: ____

Scientific name: ____

A.7.3 Data analysis canvas

3 Find the following values in the data of the week:

Temperature
- Maximum:
- Minimum:

Soil humidity
- Maximum:
- Minimum:

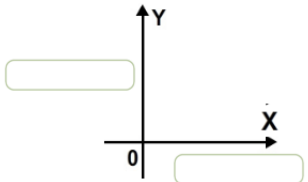
CO_2
- Maximum:
- Minimum:

Light
- Maximum:
- Minimum:

Humidity
- Maximum:
- Minimum:

1 Complete the following information to interpret the graph:

- What do each of the axes on the graph represent? Write it in the boxes:



- Between two points on the graph, how long has it been approximately? ____________

5 What was the condition of the plant during the week according to the measurements? Was it good (green), regular (yellow) or bad (red)? Complete the table:

	Wednesday 27	Thursday 28	Friday 29	Saturday 30	Sunday 1	Monday 2	Tuesday 3	Wednesday 4
Morning								
Afternoon								

4 What conditions contribute to the good condition of the plant? And to its bad condition? Make a list:

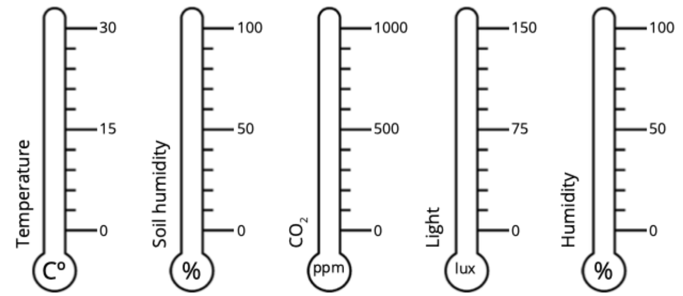
6 What days of the week was the plant watered? With what environmental measure could we know ir? Circle the days:

Wednesday 27	**Sunday 1**
Thursday 28	**Monday 2**
Friday 29	**Tuesday 3**
Saturday 30	**Wednesday 4**

8 Finally... which hypotheses can we affirm that they are certain?

- ☐ The temperature changes according to the location of the plant.
- ☐ The soil humidity increases when the plant is watered.
- ☐ The humidity around the plant increases when we water it.
- ☐ If the temperature is very high, the plant will surely die.
- ☐ The plant lives well with less than 50% humidity.
- ☐ If the leaves are long, the plant dies.
- ☐ If the temperature is above 20°, the color of the plant is brown.
- ☐ If the CO2 reaches 800ppm, the plant dies.
- ☐ The plant needs sunlight to survive.
- ☐ During the day, the lighting can exceed 50 lux.

2 What are the values of the last measures of the week? Paint it on thermometers.



7 Comparing the graphs, which measurements are correlated?

A.7.4 Identification of a healthy plant and an unhealthy plant under the effects of climate change from their datasets

UNHEALTHY PLANT ☺

Plant ID:

Secret word:

Data of the week:

Temperature	CO_2	Light
Max:	Max:	Max:
Min:	Min:	Min:

How did you know it was the healthy plant?

UNHEALTHY PLANT ☹

Plant ID:

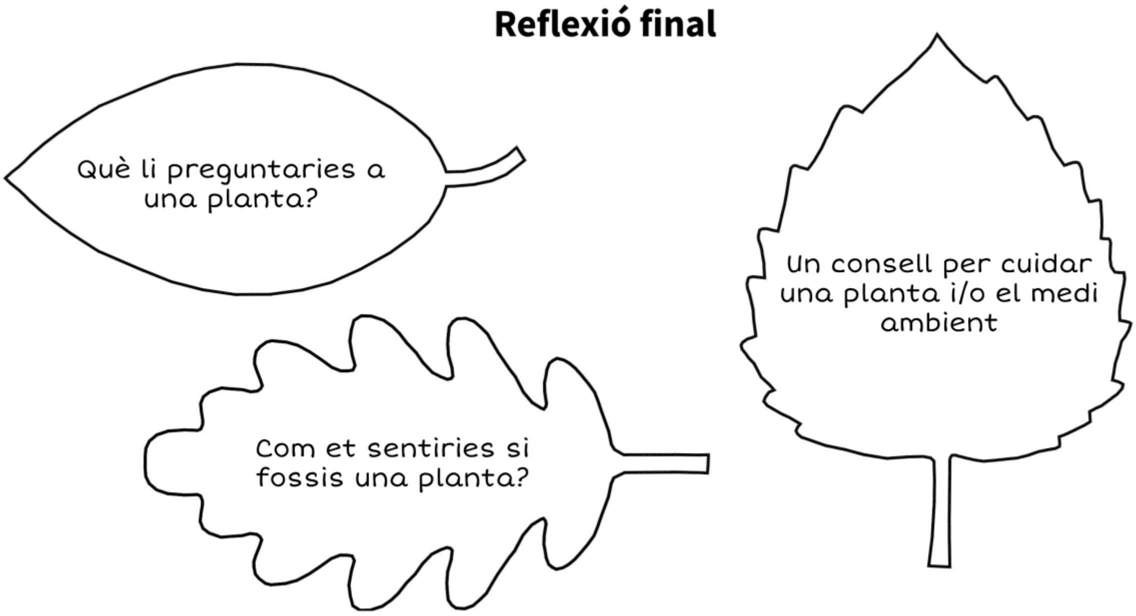
Secret word:

Data of the week:

Temperature	CO_2	Light
Max:	Max:	Max:
Min:	Min:	Min:

How did you know it was the unhealthy plant?

A.7.5 Activity: Reflection on the importance of plants



A.8 Learning activities: High school workshop

A.8.1 Experimental design and set-up (Session 1)

Materials:

- A clear acrylic or plastic box
- Two groups of plants that fit inside the box
- Two thermometers

Procedure[3]:

In this experiment, we are going to reproduce the conditions that generate global warming on Earth, simulating the effects of the Sun on living beings.

As a requirement for the experiment to go well, it must be carried out on a sunny day and around noon so that there is a lot of solar radiation. The first thing we have to do is build a transparent box that simulates the greenhouse effect. It can be made from clear plastic.

Once we have all the materials prepared, we will place a group of plants and a thermometer inside the box, and we will leave the other group of plants and the other thermometer outside. It is important that the part of the thermometer that records the temperature doesn't get direct sunlight, and they can measure the ambient temperature.

After about 15 minutes, you will see how the temperature inside the box will be much higher than the outside and the condition of the plants will also be different.

[3] Procedure adapted from Portal Andaluz de Cambio Climático

A.8.2 Worksheet (Session 2)

Noms del grup: ____

TEASPILS: Plantes i tecnologia

Anàlisi de dades a partir d'un experiment

1. Feu una primera exploració de les dades i completeu la següent informació:

Dades mediambientals recollides pels sensors:

____

____

Se t'acudeixen altres dades que podria ser interessant recollir?

____

____

Temps total del gràfic: ____

Temps entre dos punts del gràfic (aprox.): ____________________________

2. Anoteu els següents valors a partir de les dades:

PLANTA 1

Temperatura:
- Màxim:
- Mínim:

CO2:
- Màxim:
- Mínim:

Humitat:
- Màxim:
- Mínim:

Humitat del sòl:
- Màxim:
- Mínim:

Il·luminació:
- Màxim:
- Mínim:

PLANTA 2

Temperatura:
- Màxim:
- Mínim:

CO2:
- Màxim:
- Mínim:

Humitat:
- Màxim:
- Mínim:

Humitat del sòl:
- Màxim:
- Mínim:

Il·luminació:
- Màxim:
- Mínim:

3. Segons la hipòtesi plantejada a l'experiment, calculeu la mitjana (aproximada, no cal que utilitzeu tots els valors) d'aquelles mesures més rellevants:

4. Quins dies de la setmana s'han regat les plantes? Amb quina(s) mesura(s) ho podem saber?

- ❏ Divendres 29
- ❏ Dissabte 30
- ❏ Diumenge 1
- ❏ Dilluns 2
- ❏ Dimarts 3
- ❏ Dimecres 4
- ❏ No s'ha regat cap dia

Ho podem saber amb: ____

5. Al comparar visualment els gràfics, quines mesures semblen estar correlacionades?

6. Observacions en les plantes durant l'experiment:

CONCLUSIÓ DE L'EXPLORACIÓ

Plantes del grup control:

ID: **Contrassenya:**

Com heu identificat que es tractava del grup control?

____

____

____

____

Plantes del grup d'intervenció (hivernacle):

ID: **Contrassenya:**

Com heu identificat que es tractava del grup d'intervenció?

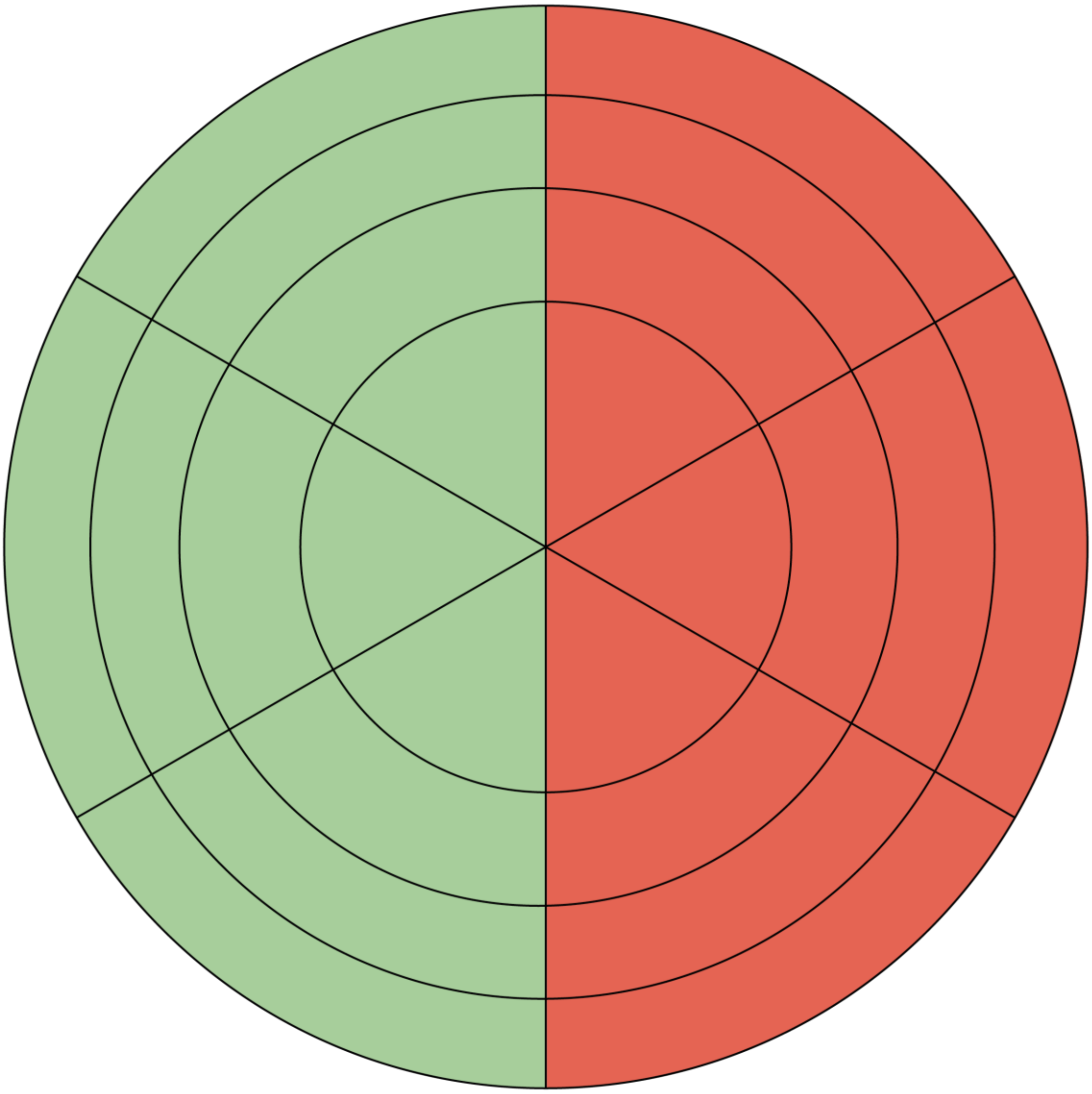
____

____

____

____

A.8.3 Extra activity: Wheel of effects



A.9 List of alerts and advice notifications

The translated version of the alerts and advice notifications displayed in the different sessions of the workshop are listed below. Each one was displayed in a pop-up accompanied by a related icon from Font Awesome[4] to support the content also graphically.

A.9.1 Session 1

Alerts

Alerts shown in the timeline visualization:

- Temperature has increased by an 8% compared to last week.
- The last observation was introduced 5 days ago.
- The highest temperature of yesterday was at 12.30h.
- There have been 3 peaks in soil humidity these days.
- The maximum measurement for CO2 has been 800 ppm.
- There have been 3 decreases in CO2.
- The maximum measurement for illumination has been 10 lux.
- There are 2 decreases in the measurements that match when comparing the temperature and illumination.
- The minimum measurement for humidity has been 22.72%.
- There are 3 peaks in soil humidity that match 3 decreases in the humidity.

Alerts shown in the single measurement visualization:

- You can adjust the upper and lower bounds for your plant in the settings.
- The CO2 measurement is in red.
- Measurements for a specific day and time are being shown.
- Most measurements are in green.
- Add observations for this specific moment by clicking on the "Observations" tab.

Advice

Advice shown in the timeline visualization:

- Temperature has increased by an 8% compared to last week; if you have changed the location of the plant, the temperature may have changed.
- The last observation was introduced 5 days ago; remember to water enough the plant for good growth.

[4] fontawesome.com

- The highest temperature of yesterday was at 12.30 h; if the temperature is too high, the plant can die.
- There have been 3 peaks in soil humidity these days; did you water the plant then?
- The maximum measurement for CO_2 has been 800 ppm. There was probably cross ventilation by opening doors and windows.
- There have been 3 decreases in CO_2; did you open only the windows?
- The maximum measurement for illumination has been 10 lux; make sure the sunlight is not too direct, as it can damage the leaves.
- There are 2 decreases in the measurements that match when comparing the temperature and illumination; this may occur at night time.
- The minimum measurement for humidity has been 22.72%; make sure the plant is in a place with the right humidity so that the leaves are kept moisturised.
- There are 3 peaks in soil humidity that match 3 decreases in the humidity; when you water the plant, soil humidity may increase.

Advice shown in the single measurement visualization:

- You can adjust the upper and lower bounds for your plant in the settings; search for information to find out what are the appropriate measurements for your plant.
- The CO_2 measurement is in red; make sure that the boundaries are well configured and, if they are fine, that there are no sudden changes in the environment.
- Measurements for a specific day and time are being shown; check if there is any observation that indicates if you have water the plant, ventilated the class, if the plant has flourished, etc. to better understand the measures.
- Most measurements are in green; check first that the boundaries are well configured and, if they are fine, try to keep these environmental conditions.
- Add observations for this specific moment by clicking on the "Observations" tab; observations can help you keep track of when you have watered the plant and if it has affected any of the measures, for example.

A.9.2 Session 2

Alerts

Alerts shown in the timeline visualization:

- The temperature has risen by 8% over the last week.
- Data was collected every 35 minutes.

- The maximum temperature was 25.8ºC.
- The maximum temperature was at 17:20h.
- The minimum temperatures have been during night time and at three different times of different afternoons.
- There have been 3 peaks in soil humidity during the last week.
- There has been 1 decrease in soil humidity during the last week.
- The maximum measurement for CO_2 has been 975 ppm.
- The minimum measurement for CO_2 has been 222 ppm.
- There have been 2 small decreases in CO_2.
- The plant has been thirsty once this week.
- Every day there has been 1 peak in the lighting between 16:30h and 18:00h in the afternoon.
- There have been 3 peaks in soil humidity that coincide with 3 decreases in environmental humidity.
- The maximum lighting was 127 lux.
- The maximum humidity was 26%.

Alerts shown in the single measurement visualization:

- Thermometers show the values for each measure collected.
- The maximum and minimum values of each thermometer may be different.
- Measurements for a specific day and time are being shown.
- The measure for CO_2 is in red.
- Most measures are in green.

Advice

Advice shown in the timeline visualization:

- The temperature has risen by 8% over the last week; if you have changed the location of the plant, the temperature may have changed.
- Data was collected every 35 minutes; check the exact time that has elapsed by comparing the timestamps of two consecutive points on the graph.
- The maximum temperature was 25.8ºC; the right range for your plant is between 15ºC and 25ºC.
- The maximum temperature was at 17:20h; see if it coincides with the hours when the sun hits the plant the most. Make sure the plant has the right temperature and lighting.

- The minimum temperatures have been during night time and at three different times of different afternoons; the temperature does not usually drop as much during the afternoons, check if it is related to any other measure that may have caused these drops in temperature, such as irrigation water (soil humidity).
- There have been 3 peaks in soil humidity during the last week; is it when you watered the plant? Soil humidity increases with water. Look at the hours to find out what the days are.
- There has been 1 decrease in soil humidity during the last week; this means that the soil is drier. Did you forget to water the plant? It looks like the plant has gone thirsty and this is contributing to poor condition.
- The maximum measurement for CO2 has been 975 ppm; although plants need CO2 for photosynthesis, excess CO2 can also be harmful.
- The minimum measurement for CO2 has been 222 ppm; was there enough ventilation in the classroom? The plant needs ventilation and fresh air.
- There have been 2 small decreases in CO2; check if they match 2 peaks in soil humidity.
- The plant has been thirsty once this week; if the soil humidity has dropped significantly, it is because there has not been enough water and the soil has dried up.
- Every day there has been 1 peak in the lighting between 16:30h and 18:00h in the afternoon; check if they match the peaks in temperature.
- There have been 3 peaks in soil humidity that coincide with 3 decreases in environmental humidity; when we water the plant, the soil humidity increases with water, and the humidity in the air around the plant decreases.
- The maximum lighting was 127 lux; make sure the sunlight is not too direct so it damages the leaves.
- The maximum humidity was 26%; remember your plant requires a lot of humidity.

Advice shown in the single measurement visualization:

- The thermometers show the values for each measurement collected, and correspond to the points on the graph.
- The maximum and minimum values of each thermometer may be different; each measure has its interval and its units, look at it and take this into account when comparing visually.

- The measurements are shown for a specific day and time; check if there are any observations that indicate if you have watered the plant, ventilated the class, if the plant has flowered, etc. to better understand the measures.
- The measurement for CO_2 is in red, remember that the plant is not necessarily in danger; you can adjust the upper and lower limits for your plant to the settings.
- Most measurements are in green. This does not indicate that the condition of the plant is good; first check that the boundaries are well set and, if they are already well, continue to take good care of your plant.

A.9.3 Session 3

Alerts

Alerts shown for the healthy plant:

- Temperatures have increased by 1% compared to the average measurements.
- The temperature is within adequate levels.
- The maximum temperature was 25.8ºC.
- CO_2 levels have decreased by 2% compared to the average measurements.
- CO_2 levels are within the adequate levels.
- The maximum CO_2 level has been 731ppm.
- Soil humidity shows two peaks during the week.
- Soil humidity can help us know which days the plant has been watered.
- Soil humidity is within adequate levels.
- Temperature and CO_2 seem to be correlated.
- There has been a small peak in CO_2 levels.

Alerts shown for the unhealthy plant:

- The temperature has increased by 10% compared to the average measurements.
- The temperature is above the adequate levels.
- The maximum temperature was 27.2ºC.
- CO_2 levels have increased by 20% compared to the average measurements.
- CO_2 levels are above adequate levels.
- The maximum CO_2 level was 880ppm.
- Soil humidity show two peaks during the week.
- Soil humidity can help us know which days the plant has been watered.
- Soil humidity is below adequate levels.

- Temperature and CO_2 seem to be correlated.
- There has been a noticeable peak in CO_2.

Advice

Advice shown for the healthy plant:

- Temperatures have increased by 1% compared to the average measurements; if you have changed the location of the plant, the temperature may have changed.
- The temperature is within adequate levels; maintain a good irrigation, good lighting, and a good location for the plant.
- The maximum temperature was 25.8ºC; control the temperature with the location, lighting, etc. to prevent the plant from being in poor condition.
- CO_2 levels have decreased by 2% compared to the average measurements; you do not need to change plant's location or ventilate the space, it is normal that there are small variations in the measurements.
- CO_2 levels are within the adequate levels; keep maintaining adequate ventilation and adequate floor location.
- The maximum CO_2 level has been 731ppm; remember to ventilate the space to renew the air and reduce CO_2 levels.
- Soil humidity shows two peaks during the week; do they correspond to when you watered the plant? Soil humidity increases with water.
- Soil humidity can help us know which days the plant has been watered; remember to water the plant enough for good growth.
- Soil humidity is within adequate levels; maintain this frequency of watering, you do not need to water the plant more.
- Temperature and CO_2 seem to be correlated; check if the temperature rises when CO_2 levels rise.
- There has been a small peak in CO_2 levels; maximum CO_2 levels collected are not harmful, but remember to ventilate the space or move the plant to a suitable place to prevent them from increasing.

Advice shown for the unhealthy plant:

- The temperature has increased by 10% compared to the average measurements; if you have changed the location of the plant, the temperature may have changed.
- The temperature is above the adequate levels; try to move the plant to another location.

- The maximum temperature was 27.2ºC; if the temperature is too high, the plant may die.
- CO_2 levels have increased by 20% compared to the average measurements; try to open doors and windows to ventilate the space.
- CO_2 levels are above adequate levels; remember to ventilate the space to renew the air and reduce CO_2 levels.
- The maximum CO_2 level was 880ppm; there has probably been cross ventilation opening doors and windows.
- Soil humidity show two peaks during the week; do they correspond to when you watered the plant? Soil humidity increases with water.
- Soil humidity can help us know which days the plant has been watered; remember to water the plant enough for good growth.
- Soil humidity is below adequate levels; this means that the soil is too dry and the plant needs to be watered. Remember to avoid high temperatures and water the plant regularly.
- Temperature and CO_2 seem to be correlated; check if the temperature rises when CO_2 levels rise.
- There has been a noticeable peak in CO_2; be aware that too much CO_2 can be harmful to the plant.