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An educational IoT lab kit and tools for energy awareness in European schools

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ABSTRACT

The use of maker community tools and IoT technologies inside classrooms is spreading to an ever-increasing number of education and science fields. GAIA is a European research project focused on achieving behavior change for sustainability and energy awareness in schools. In this work, we report on how a large IoT deployment in a number of educational buildings and real-world data from this infrastructure, are utilized to support a "maker" lab kit activity inside the classroom. We also provide some insights to the integration of these activities in the school curriculum, along with a discussion on feedback produced through a series of workshop activities in a number of schools in Greece. Moreover, we discuss the application of the lab kit framework towards implementing an interactive installation. We also report on how the lab kit is paired with a serious game and an augmented reality app for smartphones and tablets, supporting the in-class activities. Our initial evaluation results show a very positive first reaction by the school community.

1. Introduction

Raising awareness among young people and changing their habits concerning energy usage is considered key in achieving a sustainable energy behavior. Education ministries manage thousands of buildings, while educational institutions revolve around students, educators, and policy makers, all of which are essential in implementing energy-awareness policies. Furthermore, the European Union (EU) considers environmental education one of the most prominent instruments to influence human behavior towards sustainability [1], while educational buildings constitute 17% of the EU non-residential building stock (in m^2) [2]. On top of these, evidence shows that a focus on energy use in schools results in multiple benefits, along with educational excellence and a healthy learning environment [3].

Moreover, a key objective of energy efficiency initiatives in schools is making students aware that energy consumption is influenced by the sum of individual behaviors and that simple behavior changes and interventions can have a tangible impact towards energy savings. To this end, Internet of Things (IoT) technologies can support such initiatives with immediate feedback regarding the impact of our actions and automating the implementation of energy-savings policies, while maintaining comfort levels. The availability of actual measurements of environmental parameters, such as energy consumption, indoor and outdoor luminosity, temperature, noise, and so on, can aid the conception and realization of a number of diverse education-related applications and scenarios. Additionally, teachers could use collected data and analytics during class to explain basic phenomena related to the parameters monitored, or they could organize projects where students monitor such parameters during class hours or at home.

Green Awareness In Action (GAIA [4]), a Horizon2020 EC-funded project, is developing an IoT platform that combines sensing, web-based tools and gamification elements, in order to address the educational community. Its aim is to increase awareness about energy consumption and sustainability, based on real-world sensor data produced by the school buildings where students and teachers live and work, while also lead towards behavior change in terms of energy efficiency. In this context, we believe an approach based on open-source, replicable and widely available technology, providing a "foundation" that lets educators to adapt to the needs of each class, opens up many possibilities. We base this strategy on the assumption that, by using this hands-on approach, it will allow for a more personalized and engaging experience for the students, making science classes more engaging, interactive and productive.

In this context, we discuss here an educational lab kit that has been developed over open-source technologies and utilizes

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the IoT infrastructure of GAIA as an input generator, i.e., its use is based on real-world data. The approach followed means it aims to be replicable for any schools that wish to combine science/technology classes with a twist on energy efficiency and sustainability. We discuss our design, as well as its integration with a gamification component and how it could lead to other directions, such as building an interactive installation. This discussion is complemented with a set of positive end-user evaluation results, along with a brief presentation of an augmented reality companion mobile app, which will be used to enhance the overall end-user experience.

In terms of questions that could help focus the discussion regarding our work, the first one is whether the use of real-time IoT data from the end-users' environment, i.e., the school buildings where students and teachers spend a large part of their time, can act towards motivating them to participate in energy-saving activities. GAIA's approach is based on such data in order to act on a personal level and change behavior inside buildings, instead of focusing solely, e.g., on replacing inefficient electrical appliances. A second question is whether the implementation approach taken by the GAIA project in terms of decisions like using open-source IoT software and hardware, along with educational activities, works in practice inside European classrooms. Moreover, one central question is whether hands-on educational activities like the ones described in this work can be successfully integrated into the curriculum of schools in Europe. Furthermore, we wanted to investigate the potential effect of such activities on student's learning performance.

Regarding the structure of this work, we proceed to discuss recent related work in the next section, followed by a quick introduction to GAIA and its overall philosophy. The educational lab kit of GAIA is presented in more detail in Section 4, followed by a discussion on GAIA Challenge, the gamification component of the project. The design of an interactive installation and of an augmented reality component are presented in brief in Section 6, discussing how they tie together with the overall kit approach as extensions to its overall scope. We also present results from a series of workshops with school students and educators in Greece, along with a discussion on our findings. We then conclude in Section 8, discussing our future work as well.

2. Related work

Overall, there is a lot of activity taking place with respect to inclusion of makerspace elements in school curricula, aided by the availability of IoT hardware as well. [5] summarizes recent activity within the Maker Movement approach, presenting relevant recent findings and open issues in related research. [6] discusses a study stemming from a large-scale national testbed in Sweden in schools related to the maker movement, along with the inclusion of maker elements into the school curriculum of Sweden. [7,8] report on the results of the use of digital fabrication technologies and design activities among students aged 11–15 years in Danish schools, among of which are improved understanding of digital fabrication technologies, along with improved learning outcomes and motivation. The reported dependency of the outcomes on the specific school environment also agrees with our own observations.

Moreover, [9] presented the application in schools of a plug-and-play toolkit using hardware similar to the one used in our work, together with some suggestions for successful implementation of activities in high schools. [10] discusses the implementation of makerspace activities as a dedicated subject in the curriculum of schools in Sweden, in which mixed results have been found. Our approach shares many similarities with such studies, while at the same time choosing to focus on a specific area in terms of envisioned goals (e.g., energy savings) and allowing some flexibility in terms of how these goals are achieved and through what part of a school's curriculum.

Furthermore, there is a large number of research projects and activities that focus specifically on the energy efficiency domain. BuildUp [11] is a European portal presenting in a systematic manner many related approaches. In addition, ZEMedS [12] and School of the Future [13] are examples of projects that involve the educational community and energy efficiency, but which also relate to building retrofitting with new materials, etc. Our work sees energy awareness through the prism of behavioral change towards more sustainable practices in school buildings.

There are also a number of past projects, like SEACS [14], that produced material related to sustainability and STEM, or on-going ones like UMI-Sci-Ed [15], that tie educational content to the Internet of Things. However, very few attempts are made to tie together real-world IoT data with a curriculum aiming for long-term behavioral change, like in the case of GAIA. We plan to incorporate our work in the form of open content in platforms like UMI-Sci-Ed in the near future, or through established portals/communities, like the one provided by Scientix [16]. Moreover, a number of recent projects like Charged [17], Entropy [18], GreenSoul [19], Tribe [20], target diverse end-user communities and do not focus on the educational community. Although to a certain extent their target users belong to schools or universities, the apps, serious games and content they have developed does not aim to provide an educational tool tied to a school's curriculum.

With respect to the use of augmented reality (AR) in education, [21] reviews recent and current trends in the integration of AR inside classrooms in a STEM-specific context, while [22] is another similar attempt to review the current situation with respect to AR. Moreover, [23] reviews recent trends in a more general context (i.e., not STEM-specific), noting that there are reported benefits to using AR in classrooms but there are also downsides, together with technical complexities and usability issues in currently available platforms. All of these works seem to agree that augmented reality has its place in education, due to findings such as improved academic performance and greater student engagement.

Our work, overall combines elements from works that preceded it with a strong focus on using real-world data from the actual buildings in which the end-users are living and working daily, along with an open-source approach. Instead of building upon closed-source software or hardware, our approach aims to be replicable, using elements that have worked so far. In any case, since each school and building have many special characteristics apart from common traits, it is important to give by design a degree of freedom in implementing such activities.

This work provides a continuation of previous work that first presented the GAIA lab kit [24]. We provide here a more detailed discussion of some of our design decisions and philosophy, in order to showcase better the rationale behind the lab kit. We also provide a concrete example of how the lab kit can be used as a starting point and allow schools to create things like the interactive installation showcased in one of the biggest educational events in Greece, that are closer to their own realities and reflect better the strengths and interests of their students. Moreover, we provide additional evaluation data concerning the reception of the GAIA activities by teachers and students; in addition, we discuss findings during in-class activities and comments provided by educators involved in these activities. Furthermore, we discuss the addition of an augmented reality application to the software lineup of GAIA, that aims to provide additional possibilities to the lab kit and further increase students' engagement. Finally, we discuss at length a number of conclusions related to the goals that we had when starting work on the lab kit.

3. The GAIA project

GAIA utilizes a number of IoT installations in school buildings in Greece, Italy and Sweden. In order to change the behavior of students and teachers in terms of energy consumption and achieve sustainable results, GAIA utilizes a loop-based approach focused around three pillars: *raise awareness*, *support action*, and *foster engagement*. Each installation consists of a multitude of IoT nodes, which communicate with a cloud infrastructure via a gateway device. Such nodes comprise multiple sensing endpoints, while the gateway nodes coordinate communication and enable interaction with cloud-based services [25].

The overall design pattern for the installation of IoT infrastructure in the school buildings participating in the project is as follows: (a) nodes installed to monitor the power consumption of the building as a whole, or specific floors/sectors, (b) classroom nodes monitoring parameters such as temperature, humidity, motion and noise levels, and (c) gateway nodes bridging IoT nodes that use IEEE 802.15.4 with the Internet. The IoT gateways communicate directly with GAIA cloud services.

The hardware design of the IoT nodes utilized in GAIA follows an open-source approach [26], using hardware components widely available, paired with some custom designs, for example custom printed circuit boards for interconnecting sensors to microcontrollers, etc. Almost all available infrastructure is based on Arduino-compatible or Raspberry Pi components (see Fig. 1). GAIA releases the specifications for this infrastructure and related results as open-source, in all cases wherever possible. For this purpose, a series of related material is available at the project's GitHub repository.[1]

Based on this IoT infrastructure, we monitor energy consumption and environmental parameters inside school buildings that participate in the project. Such data are used as input to the educational aspects of the project. The idea is to provide students and educators with a more "personalized" approach: GAIA's educational material and applications use the actual setting inside the school buildings to make interaction with data more engaging, fun and useful. Activities around the use of energy could be part of science classes explaining natural phenomena, or used as a means to engage students in various educational contexts (e.g., teach programming, statistics or other informatics skills). Additionally, another option could be to investigate related financial aspects, e.g., calculate pros/cons of additions/changes to existing building infrastructure in order to achieve energy savings.

Additionally, since the hardware used is open-source and components are commercially available, schools and students have the option to purchase the components and assemble the IoT nodes themselves. In fact, one of the schools participating in the project has already done exactly this: a technical high school/college in Sweden purchased the required hardware, and its students assembled and installed the devices in their building, under the supervision of the school staff.

4. The GAIA educational lab kit

In short, the kit aims to teach students using a "hands-on" approach, in which they get to use IoT components and electronics. Based on guides provided by the project, they examine data from their school building and go through the peculiarities of consuming energy, how the building behaves in the various classrooms in terms of environmental parameters, and more. The kit includes already assembled devices and commercial IoT sensors and actuators to allow students complete classes and lab tutorials regarding energy and sustainability, as well as provides guidelines for implementing crowdsensing quests (also related to the gamification component of GAIA). It also serves as an additional means of interacting with the project and further increasing the end-user engagement, along with the other tools of GAIA, such as the gamification platform and the BMA (Building Manager Application).

In the majority of the available educational lab kit activities (see Figs. 2–4), the focus is on mapping what is actually happening inside the school building in real time. This is achieved on a first level by using a floorplan of their school as a surface to place electronic components and devices, essentially assembling a small-scale interactive installation. In addition, students conduct simple "missions" inside the different parts of their buildings, indoors and outdoors, detecting and pinpointing specific energy-efficiency-related rooms or devices.

The Lab Kit includes IoT devices, commercial or GAIA-designed, together with other hardware components that can be used to assemble custom electrical circuits, which can enable familiarization with electronics, using common components, such as LEDs, resistors, switches, etc. Monitoring of real-world parameters, in a way similar to the fixed IoT infrastructure installed inside GAIA school buildings, but in a more "personalized" and direct manner. Interaction with GAIA software services, in similar ways to the ones used by the infrastructure, also providing a clearer picture of how the overall GAIA system works.

We have avoided the use of things such as extensive wiring between the different components, or complicated interconnections by using conductive ink. Instead, students "draw" the interconnections required between the various electronic components. In this manner, we avoid the extensive use of cables and breadboards, simplifying the overall activity and saving time. We also utilize Raspberry GrovePi "hats" that have standardized connectors for input/output interfaces, i.e., students and teachers do not have to worry about how to connect the components, since all interconnections are carefully labeled to prevent confusion. We use electronic components that on the one edge connect to these "hats" and on the other carry magnets, in order to enable easy placement on top of a metal surface. The use of magnets prevents the components from slipping and moving around during the lab kit activity. We also utilize printed school building floorplans, which illustrate both the parts of the building and the placement of electronic components for the lab activity. The floorplans are placed on top of a metal surface so that magnets are kept firmly connected during the lab activity.

Regarding the actual bill of materials for the Lab Kit, we utilize the following components:

- Raspberry Pi model 3B or 3B+, as the device handling the main computing and networking duties for the lab activities.
- Conductive ink markers, for sketching out wire paths onto paper. At this point, we are using the Circuitscribe markers.
- Electronic components, such as LCD screens, resistors, switches, potentiometers, etc. At this point, we are using Circuitscribe components, mainly due to their magnetic clip attachments, ease of use and overall safety.
- GrovePi sensors with standardized interfaces for connecting to the Raspberry Pi, an open-source family of sensors available from various distributors, which use standardized interfaces and are suitable for educational activities due to their design.
- Custom electronic boards, which ease interfacing with GAIA and visualization of real-time data used during the lab activities. One of such boards is the LED ring board used to visualize the 3-phase energy consumption in the building (Fig. 7).

[1] GAIA GitHub repository: https://github.com/GAIA-project.

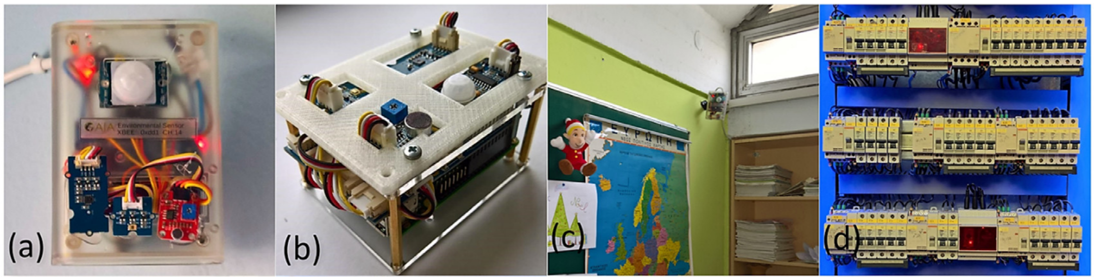

Fig. 1. Sample photos of the device lineup inside GAIA's schools: (a) an Arduino-based IoT node for classrooms, (b) a Raspberry Pi-based node for classrooms, (c) an IoT node inside a classroom, (d) power meters installed on electricity distribution panels.

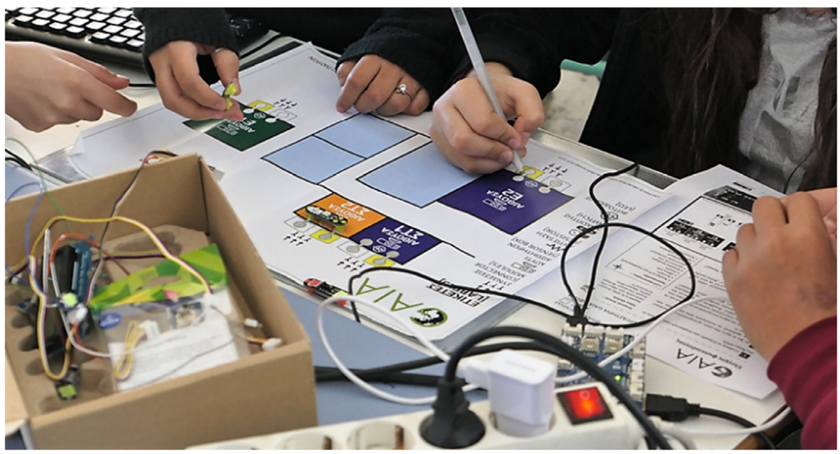

Fig. 2. Example of an in-class activity with the Lab Kit. Primary school students use conductive ink to draw circuits on top of a printed floor map of their school.

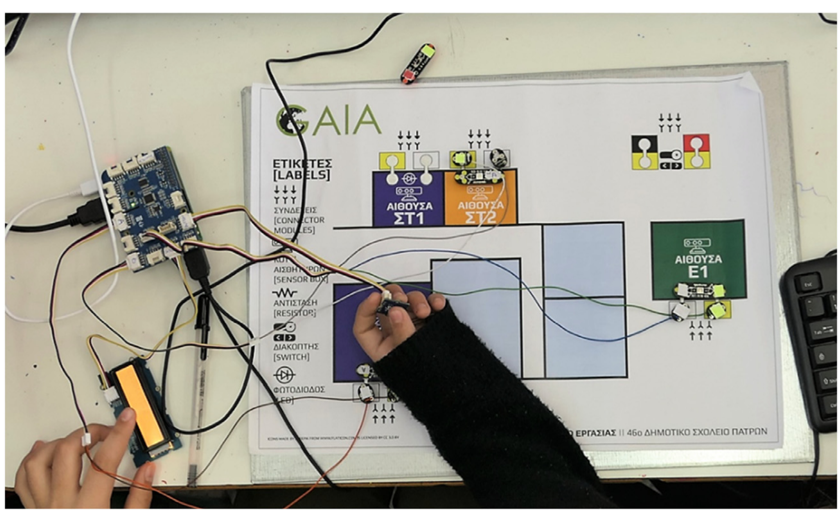

Fig. 3. Example of an in-class activity with the Lab Kit. A student uses the kit to visualize temperature readings in different classrooms of her school building (purple, orange and green rooms) . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

We plan to enhance the available options and use additional components and technologies in the coming months, to provide more options for interfacing as well as cover cases where schools may already have similar equipment and would like to utilize it.

Regarding the software part of the Lab Kit, the Raspberry Pi devices use the Raspbian Linux distribution, while the activities are based on a number of Python scripts provided by the consortium. The activities use the default options for Python provided by Raspbian. We use the standardized Web interfaces of GAIA for communicating with the system for real-time data, thus no additional changes are required to the vanilla Raspbian distribution for Raspberry Pi.

4.1. Organization of the lab kit activities

Regarding the overall organization of the activities and the provided material, the consortium has prepared a series of lab activities, covering aspects of energy consumption and efficiency inside school buildings. The thematic list covered is the following: (a) Energy consumption in our school, (b) Lighting inside school buildings, (c) Heating inside school buildings, (d) Temperature,

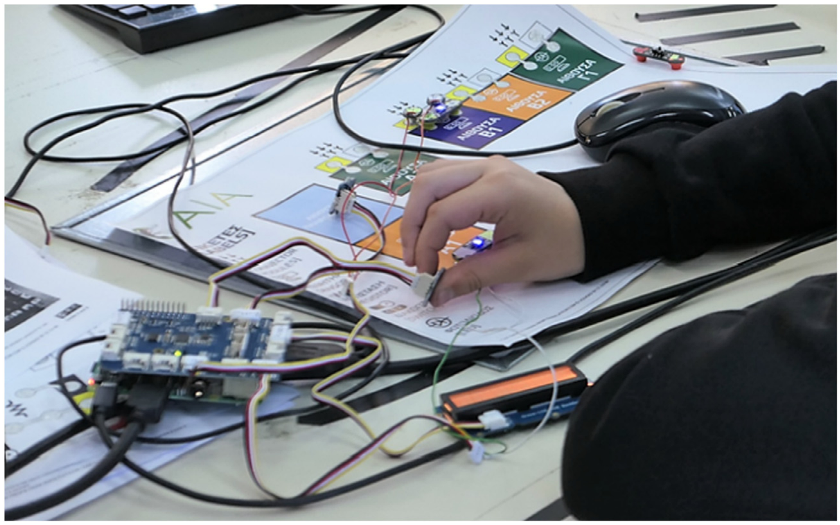

Fig. 4. Example of an in-class activity with the Lab kit. A student uses a button to visualize different modes of readings inside his school on LEDs and an LCD screen.

Humidity and Thermal Comfort, (e) Devices and Energy efficiency, and (f) Energy Inspectors — The energy footprint of our building. An additional activity can be implemented in case schools would like to implement an interactive installation in the form of a class project by students, in order to depict some kind of energy efficiency metric in its own school building.

Regarding the provided material, there are available guides for each activity. In the description of each activity, we include the title of the subject, the necessary cognitive background for the teams (theoretical and practical) and a short description of the tasks to be completed (goal). One set of material concerns the educators, identifying the educational target for each activity, the methods used, as well as a schedule for the proposed lab activity. Another set of material addresses the students' part, giving specific instructions on how to perform the envisioned activities, explaining how to interconnect sensors and electronic components, and how to execute the Python scripts provided by the project. Difficulty levels are also indicated in the material, with more complex challenges such as coding questions and exercises are available for e.g., high school, or more advanced students).

4.2. Summary of a sample lab kit activity

We present here briefly the activity "Temperature, Humidity and Thermal Comfort", in order to give an idea about the lab kit activities. Students are given a short introduction to the aims of the activity, as well as instructions on how to draw circuits for the lab using conductive ink, on top of a printed floorplan of their school. They are then instructed to assemble a small electronic circuit using 2-color LED lights, buttons and an LCD screen, and place the components over a predefined set of classrooms in the floor map. After assembling the circuit, students power up the Raspberry Pi's, and start looking into the Python code. They execute a series of available Python scripts that connect to GAIA's cloud infrastructure to fetch real-time data. They then go through a series of activities, where they see the temperature and humidity inside their classrooms, which are visualized on the LED lights of the circuit (e.g., red for temperatures above 25 degrees) and the LCD screen.

They use hardware switches and buttons to navigate between different visualization modes. A set of activities on the instructions provides the background to assess thermal comfort levels, to note down differences between classrooms, and try to reason the origin of such differences due to room orientation, construction, etc. They also provide examples of how to customize the Python code to provide additional functionality and visualization modes.

5. The GAIA challenge

GAIA Challenge is an online serious game, which raises the students' and teachers' energy awareness within their own facility, accessible through a web browser. The challenge utilizes gamification mechanics to motivate participants to engage in energy saving topics by collaboratively working on online "quests" and participating in real-life activities. Moreover, students experience their impact on the facilities' energy consumption over the course of the challenge, while also competing and comparing against other classes and schools in other countries.

Real-time data from sensors in the buildings are used as part of the challenge, in order to visualize the real life impact of the participants' behavior and build collaborative (within a facility) and competitive (between facilities) gamification elements. Teachers are invited to Class Activities to work together with their students on hands-on observation and optimization tasks in classrooms. The online challenge offers the following core features:

Quest Map: The Quest Map is the main view for the end-users. It is an interactive visual representation of multiple entities of the online challenge. It symbolizes the user's journey from the start (top) to the finish line (bottom) of the challenge. Along the way, there are also Quest Sequences and Class Activities, with multiple quests for the user to play. These quests are grouped into five subject areas related to energy consumption reduction. In this map, a number of nodes are included for each subject area, where students have to answer various questions related to these specific energy consumption categories. There are also bonus areas with additional quests available for classes.

Class Activities: Class Activities are crossovers of learning in class, engaging in the online challenge and on-site engagement in the facility, requiring a teacher and on-site engagement. A Class Activity is divided into three parts: (a) learning the theory, (b) consolidating the knowledge and (c) applying it. Teachers can decide on the topic, the actual activities and the physical space of these Class Activities.

Community Dashboard: users can compare the performance and score between classes and schools. The user can select a class from the list and inspect its achievements, its user ranking and a list of recent snapshots by the class' students is shown.

Regarding the integration with the Lab Kit, the lab kit activities have been linked with GAIA Challenge, in the form of additional quests unlocked for the schools that are planning or are participating in such activities (see Figs. 5 and 6). Essentially, these quests are a visual "tutorials" for students to prepare for the lab or understand better aspects such as e.g., the wiring between specific electronic components. Educators can choose to "unlock" these Lab Kit-specific quests before or after the first Lab Kit activity, in order to familiarize students with the Lab, or repeat some of the activities to get a better understanding of the tools used.

We also provide sample additional activities to the educators, suggesting ways to integrate the rest of the GAIA toolkit with the lab activities, e.g., in the period between two successive lab activities. Students can use the Building Manager Application to monitor environmental parameters that they checked during a lab activity. They can then discuss their findings with their teachers when they have their next lab activity at school.

6. Extending the lab kit

In this section, we present two possibilities for using the Lab Kit as a foundation to provide additional educational aspect to the lab activities. The first one discusses using it for building an interactive installation as a project, while the second one presents an augmented reality app used as a companion to the activities.

6.1. An interactive installation example

We present here an example of an interactive installation built on the same components used in the Lab Kit, in order to highlight the possibilities made available to the schools with the kit. Such installations could be assigned to groups of students e.g., as semester projects, since they require several hours to complete, along with getting more creative with the design of the installation. In this specific case, the design and implementation was performed solely by the authors of this work. However, since apart from cardboard it uses only components already included in the kit, it is feasible for a student group to assemble an identical one. The installation was exhibited at the Athens Science Festival,[2] a 6-day exhibition taking place at the center of Athens, Greece. It is attended mainly by members of the educational community, hosting a number of school and academic groups exhibiting their work.

The idea was to enable the comparison of environmental conditions and power consumption in real-time between a number of school buildings in Athens and other cities in Greece. All data were retrieved in real time from GAIA's cloud services. More specifically, the installation consisted of two parts, as can be seen in Fig. 7. The left part was meant to display the conditions and power consumption inside a specific school building in Athens. A printed floor map of one of the school's floor was placed on top of a steel frame, inside a cardboard frame. On top of the cardboard frame, parts from the lab kit were used to provide the framework for retrieving and visualizing the sensor readings from inside the building. The right part represented a "generic" school building, containing similar components to the one on the left, but with the added option of being able to rotate between 5 different schools. By clicking a button, visitors could change the origin of the readings currently visualized.

The students of a high school in Athens that had already participated in lab kit activities in their school took the role of the "hosts" of the GAIA stand, presenting what the project is about and what does this installation do. Students were already familiar with the technologies used through the activities and had only 1 h of preparing before the exhibition opened to the public. The students ran shifts to make the presentation for its duration (4 h) (see Figs. 8 and 9).

6.2. The supporting augmented reality app

As mentioned in the related work section, there is already a body of work that suggests that augmented reality (AR) can produce a positive effect in students' learning performance and overall engagement. At the same time we have noticed, mostly through our own observations during lab kit activities and informal conversations with educators, that in-class activities could benefit from having additional end-user interfaces as a means to simplify access to IoT sensor data. In some cases, when educators or students wish to see such data e.g., over a long time period, they have to log in to GAIA's web portal and then find and select the respective section to monitor, i.e., a process that requires a number of additional steps. Such issues prompted us to start thinking about adding new end-user interfaces.

Having these in mind, we started integrating AR capabilities to the workflow of the lab activities. The result is a tablet/ smartphone app for iOS devices, that could be used alongside the main lab kit experience, and which currently is in a prototype form. The overall aim was for these AR extensions to act as a companion to the core lab activities; by adding AR visual elements, we aim to clarify some parts of the activities' workflow. Moreover, since the lab kit activities are implemented over hardware that allows only limited visualization opportunities, the AR tool provides additional options. Such graphs present information in much better granularity than the ones presented with the lab kit components, and also allow for "live" visualization as a backstop solution in case there are issues with the actual "circuits" assembled by the students.

We can also utilize AR to simplify the completion of the lab activities, since, the activities are aimed at students of various age ranges and educational backgrounds. We can assume that in a number of cases such characteristics will contribute to a longer than expected time of completion, that, as a result, could end up in a subpar educational experience. In this case, AR can provide the functionality to have a visual guide for the parts of the circuit, e.g., display squares around the points which we want to connect using conductive ink during the lab activities. In Fig. 10, we can see this kind of functionality displayed. There are (a) blue squares over parts of the floormap that need to be inked and connected with cables, (b) text legends giving guidelines for how to complete this "step" of the lab exercise, (c) arrows that move between steps of the exercise, and (d) a graph visualizing sensor readings updated dynamically.

7. End-user evaluation and discussion

In this section, we report on some preliminary results we have from the use of the lab kit in schools in Greece the past months. Since the lab kit is in many aspects still an ongoing work, we report our experiences from its initial application inside the curriculum of a number of schools. It is important to note that several of the schools participating in the project have educational staff that utilizes, or is comfortable with the use of e.g., Arduino-based activities. However, not all educators or students have experience with such technologies. Moreover, in some cases there are educators participating in the project, which do not have a technological background. Thus, it is important to stress that the discussion here applies to a diverse set of end-users.

For a preliminary evaluation of the lab kit inside classrooms, we conducted two workshops with two groups of Greek students

[2] http://www.athens-science-festival.gr/.

Fig. 5. Screenshots for the Lab Kit mission included in the GAIA Challenge.

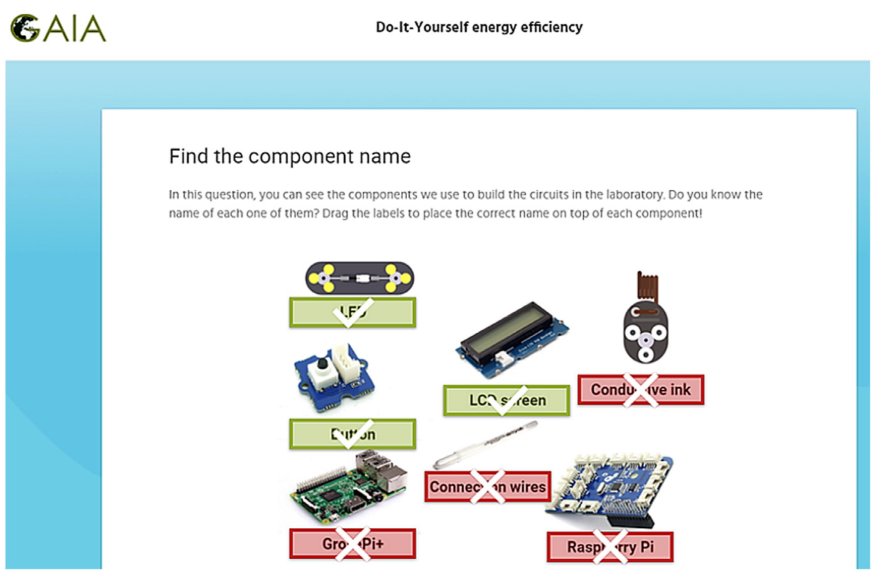

Fig. 6. Example of activity within GAIA Challenge, asking students to identify the names of the components used with the Lab Kit, in order to prepare for the activity before class time.

aged 11-15 years old (primary and secondary school students), including 48 and 58 students in each workshop.

The questions asked were the following:

- Did you have prior experience with electronic circuits before the lab (Y/N)?
- Did you face serious difficulty completing the activities during the lab (Y/N)?
- Do you think such an activity will help you learn something about your school building and energy consumption (grade 1–5)?
- If possible, would you consider repeating similar activities at your home (grade 1–5)?
- Did you enjoy the lab activity overall (grade 1–5)?

With respect to the answers given by the students, there was a very positive response overall. In the first lab, 71% answered that they liked the activity "very much" (5/5), 23% gave out 4/5, and the rest 3/5. In this case, 58% had some sort of previous contact with electronics, while 87.5% stated that they did not face difficulties during the lab. 98% said that they thought such an activity could help them to learn something about energy in buildings, while 94% said that they would consider doing such an activity at home, if possible. In the second lab, there was some change in terms of positive response, with 58% rating it 5/5, 26% 4/5, and 12 3/5, possibly also reflecting the change of topic for the lab. An 80% stated that they did not face difficulties during the lab, while 96% thought that they learned useful about their building.

Another group consisting of seven primary and secondary school teachers in Greece participated in a daily workshop displaying some sample lab kit activities. After completing the workshop, an evaluation questionnaire was given to them. The questions asked in this group were:

- Did you find the activity and instructions clear (Y/N)?
- Do you believe you could conduct the activities at your school without help from GAIA (Y/N)?
- Did you face difficulties in the activities (Y/N)?

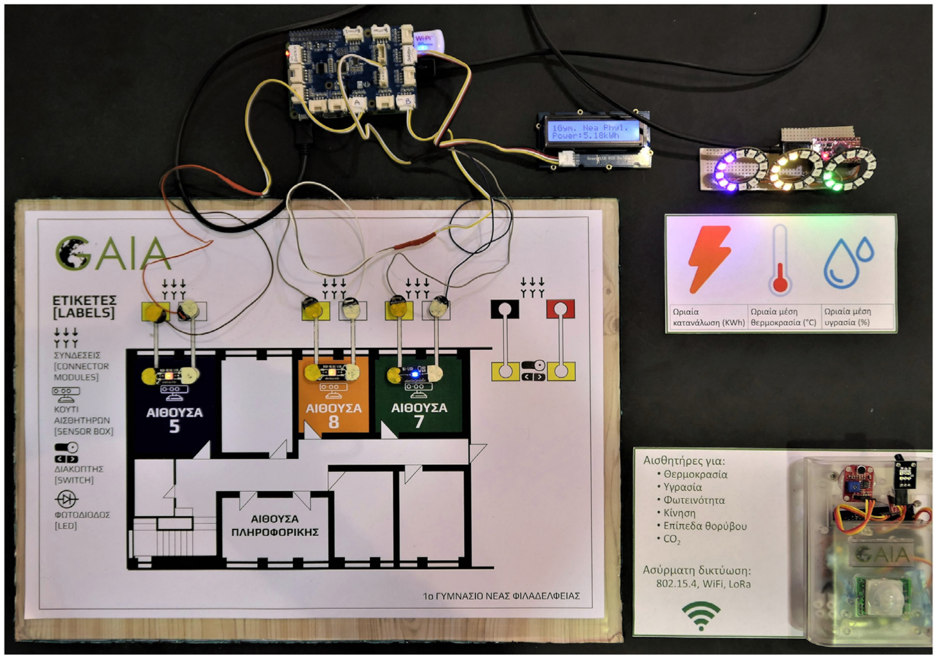

Fig. 7. The installation showcased at the Athens Science Festival. On top of a cardboard surface we place all the components of the lab kit. A steel plate sits underneath the printed paper floormap of the school, providing a means to attach cable "clips" with magnetic properties. A Raspberry Pi provides computational and networking capabilities. Visitors used a button to browse through the various data available.

Fig. 8. Instance from the public display of the GAIA interactive installation, showcased by high school students during the Athens Science Festival 2018.

- Do you believe that students will gain/learn something out of this activity (Y/N)?

Regarding their answers, five teachers answered that they found the activity and instructions "quite clear", 1 "absolutely clear" and 1 "clear enough". Regarding difficulties faced, only one teacher commented that enough time should be given to complete the activities, depending on the conditions in each school. All teachers answered that they thought that students "could learn something by engaging in such activities".

In addition to the evaluation discussed above, we wanted to investigate overall learning performance outcomes regarding students as well. Given that both teachers and students found the lab activities engaging and useful, the question here is whether these activities contributed to some change in the performance of the students during class in general. With regard to this question, we produced questionnaires and had interviews with 5 teachers from 5 different schools, whose classes participated in the lab activities, over a period of 4 months belonging to the abovementioned student group.

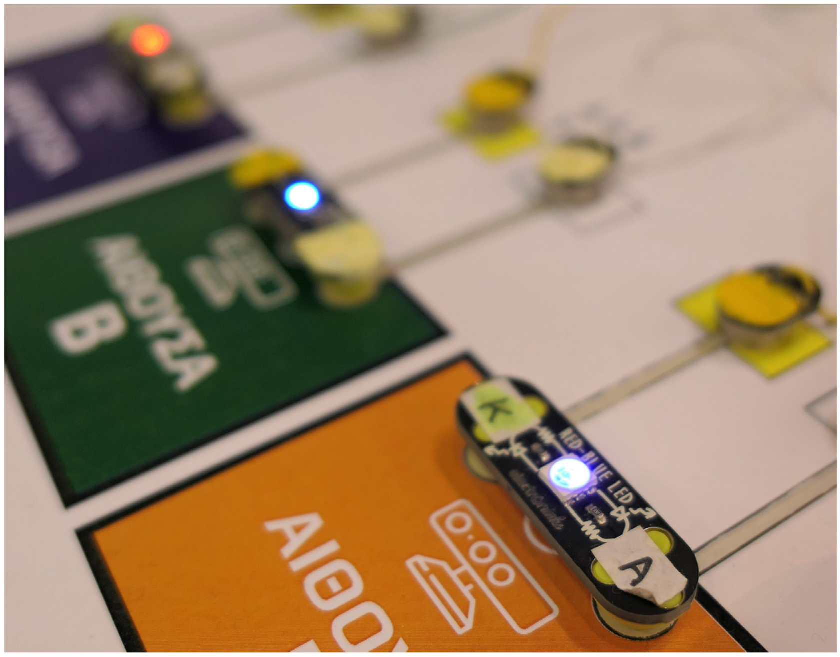

Fig. 9. Close-up of the installation, showing the placement of LED components on top of a paper floormap.

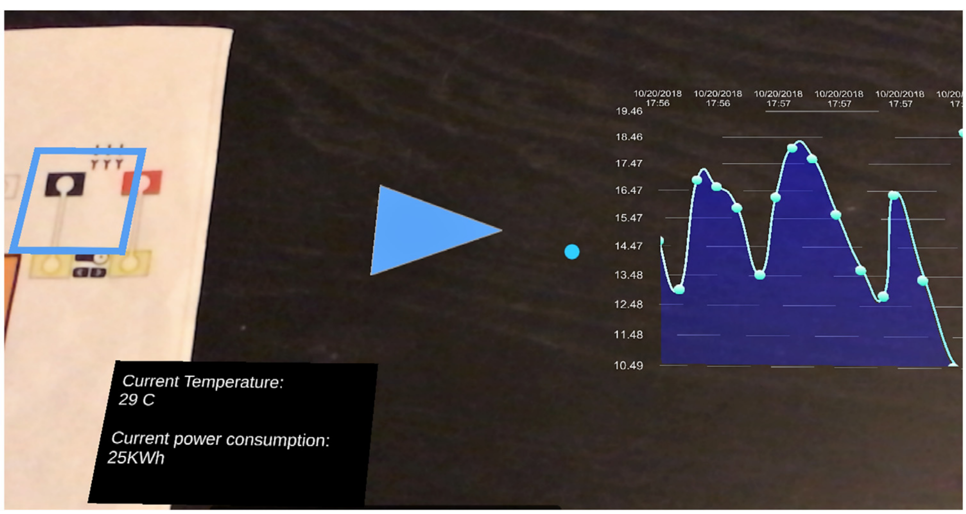

Fig. 10. Aspects of the AR app acting as a companion to the lab kit activities.

The most substantial question asked was "have you noticed any substantial change with respect to students' performance after GAIA activities began?", to which 1 teacher noticed a "mild change" (4), while the 4 others answered with "very significant change" (5), in a scale from 1 to 5. In order to make their answers more specific, we included a free text field for them to fill in. In their free text answers, the teachers who noticed a very significant change noted "positive changes in daily class activity and greater interest towards programming" and that "students who previously were indifferent, now have significant participation during lab activities". In another interesting remark, one teacher noted that "low-performing students had a chance to exhibit their capabilities and receive positive comments from the rest of their class", i.e., this type of students found the activities engaging and easy enough to complete, in comparison with other in-class activities. This kind of detailed remarks help us to identify the strengths and weaknesses of our approach.

In terms of a more broad educational setting and contribution to the community, our work can be seen as a verification of the fact that educational activities using IoT hardware and software and that are flexible enough to be combined with the curriculum of each school can produce good results. Moreover, in practice we have seen from our early steps in designing the lab kit that educators can often be indifferent towards educational activities that do not take into account their background, or require them to spend considerable amounts of time to adapt the content to their school's schedule. Having this in mind, we produced content that could be tied together with various classes, is accompanied by educational material and gamification aspects, and also has some tangible goals that can be achieved by students in their own environment, i.e., energy savings. Our initial results verify that this combined approach was received positively by both educators and students.

An interesting observation regarding schools in Greece was that there exist large differences in the kind of experience in maker activities, equipment and educators' backgrounds between schools. Thus, the way that the lab kit is interpreted/received in each school is different. However, even in schools without a "maker" mentality, educators and students welcomed such interventions. In fact, one of the remarks made by the educators was that students that did not exhibit much interest in science classes, during lab kit activities were probably encouraged to participate more actively by the fact that they were able to complete the activities. We have also noticed in some cases that these students were eager to share this achievement with the rest of their class.

From our experience, the most important issue in this case is to communicate that such activities present an opportunity for educators and schools to integrate new aspects in existing curricula. Another finding that we observed during the lab kit activities was that girls, especially in primary and junior high schools, tended to be more focused than boys in the same class during the kit activities, resulting in them completing the assignments easier and in less time. However, we did not plan to monitor aspects such as this, so this finding is based purely on our own empirical observations during the activities conducted.

In the context of the research questions included in the introduction, we have to stress that GAIA takes a holistic approach; it tries to offer a set of tools and class material that can function as part of the curriculum, and not as an additional activity that exists outside of the realities in today's schools. The educational lab kit, which is presented in this work, aims on the one hand to engage students and teachers to participate in GAIA, and on the other hand, to be a part of an existing class curriculum, e.g., the existing physics or informatics class in the schools participating in the project. One example to further clarify this aspect is that in a number of GAIA schools there were already several activities taking place using maker/do-it-yourself platforms like Arduino, e.g., as part of the informatics class. The lab kit is meant to offer a structured approach to teachers conducting such activities and help them to make their class activities richer and more diverse, while also helping students to understand certain aspects of school buildings' energy behavior.

Regarding the question whether GAIA's approach can motivate students towards energy-saving activities, the answer is "yes". In practice, we have seen that the lab kit activities are an efficient engagement mechanism, since the activities span across multiple weeks and gradually introduce students to certain energy-related concepts. Through this procedure and through the GAIA Challenge, we saw good engagement results from both teachers and students. However, we also noticed in some cases a tendency of the educators to perceive these activities as the main part of the energy-saving actions. In other words, it should be made clear to educators that the lab activities are complemented by school-driven actions.

With respect to the second question about whether the open-source approach followed works in practice, the answer is a resounding "yes". The educational community in Europe has embraced the use of open-source platforms like Arduino and they are comfortable with what we use in GAIA's activities. In some cases, schools purchased directly the equipment for the activities themselves, and were able to kickstart the activities with little help from the GAIA team.

Finally, with respect to the third question, the answer is again a "yes", but the degree of successful integration into a school's curriculum depends on the educator's familiarity with the related technologies and the school's overall approach to updating its daily schedule. Although the activities were well-received and educators thought in general that the instructions and lesson plans provided were clear enough to carry them out, scarcity of additional lecture hours and familiarity with existing lesson plans meant that in some cases certain schools decided to dedicate significantly less hours to GAIA-related activities than others.

In terms of other shortcomings to our work, we tried to minimize the time and interaction required by students and educators participating in the activities, in order to fill out the questionnaires handed out to them. Therefore, the respective set of questions was rather small, in order to balance out the time spent on the activities and filling out e.g., informed consent documents. Another shortcoming was that a number of educators involved did not have a maker or even a technological background overall. However, this was also seen as a challenge for us, i.e., to test our implementation and verify whether it can be successfully applied within such constraints, and to what extent.

8. Conclusions

We presented here an educational lab kit that uses real-time data from school buildings, in order to enable a more personalized approach to educational activities for energy awareness and sustainability. This is included as part of the educational approach of GAIA, an EU-funded research project that uses real-world data from school buildings to provide a more hands-on and personalized experience aspect in class activities. We discussed in detail its design philosophy and structure of educational activities, along with a presentation of how it is combined with a serious game. Moreover, we presented an example of an interactive installation implemented over the same hardware and software, that was used as a demonstrator in a public science expo.

Regarding end-user evaluation, the lab kit has been used in the context of the GAIA project in a number of schools in Greece, with some very encouraging results in terms of end-user acceptance from both students and educators, as well as its suitability for use in schools in a broad range of students' age (from primary to high school). Lastly, we briefly presented a prototype for an augmented reality app meant to serve as a companion to the lab activities.

We believe that activities such as the lab kit have potential as tools for teaching sustainability concepts and science topics, as made clear by the very positive reaction from both the educators and the students to the approach described in this work. As we are progressing in the coming months with our implementation of the lab activities within classrooms, we will also be looking into more substantial results with respect to behavioral change and energy efficiency, in combination with the main body of educational activities in the project.

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Conflict of interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.ijcci.2019.03.003.

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