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MONITORING ABIOTIC FACTORS USING SENSORS AND ARDUINO PLATFORM: A SCIENCE CLASSROOM PROJECT

MONITORIZAÇÃO DE FATORES ABIÓTICOS COM SENSORES E A PLATAFORMA ARDUINO: UM PROJETO DE SALA DE AULA DE CIÊNCIAS

SUPERVISIÓN DE FACTORES ABIÓTICOS CON SENSORES Y PLATAFORMA ARDUINO: UN PROYECTO DE AULA DE CIENCIAS

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ABSTRACT | This work was developed with six SEN students, aiming to develop a mechatronic system based on the *Arduino* microprocessor and sensors that measure abiotic factors, such as temperature, light, air humidity and moist soil. This system was used in combination with ICTs as a didactic tool. The students identified some environmental characteristics of a greenhouse, selected several plants and created and installed a sensor circuit, using the *Arduino* platform connected to a computer. This device collects data and activates a water pump to irrigate the plants whenever necessary, and allowed to register whether or not the plants were in the ideal cultivation environment, according to the specifications of their species. Research data was collected through audio recording, photographs, tasks and notes taken by the teachers. This approach allowed a higher level of participation and autonomy of students in the performance of tasks related to the curricular topics of Natural Sciences.
KEYWORDS: Arduino, Sensors, ICT, Environment education, Learning Motivation.

RESUMO | Este trabalho foi desenvolvido com seis alunos com NEE, com o objetivo de desenvolver um sistema mecatrónico baseado no microprocessador *Arduino* e os sensores associados que medem fatores abióticos como a temperatura, a luz, a humidade do ar e a humidade do solo. Este sistema foi usado em utilizado em combinação com TIC como ferramenta didática. Os alunos identificaram algumas características ambientais de uma estufa, selecionaram várias plantas e criaram e instalaram um circuito de sensores, usando a plataforma *Arduino* conectada a um computador. Esse dispositivo coleta dados e aciona uma bomba de água para irrigar as plantas sempre que necessário, e permitia registrar se as plantas estavam ou não no ambiente ideal de cultivo, de acordo com as especificações de suas espécies. Os dados da pesquisa foram coletados por meio de gravação de áudio, fotografias, tarefas e anotações feitas pelos professores. Esta abordagem permitiu um maior nível de participação e autonomia dos alunos na realização de tarefas relacionadas com os tópicos curriculares das Ciências da Natureza.
PALAVRAS-CHAVE: Arduino, Sensores, TIC, Educação ambiental, Motivação de aprendizagem.

RESUMEN | Este trabajo fue desarrollado con seis estudiantes NEE, con el objetivo de desarrollar un sistema mecatrónico basado en el microprocesador *Arduino* y sensores que miden factores abióticos, como temperatura, luz, humedad del aire y humedad del suelo. Este sistema se utilizó en combinación con las TIC como herramienta didáctica. Los estudiantes identificaron algunas características ambientales de un invernadero, seleccionaron varias plantas y crearon e instalaron un circuito de sensores, utilizando la plataforma *Arduino* conectada a una computadora. Este dispositivo recolecta datos y activa una bomba de agua para regar las plantas cuando sea necesario, y permite registrar si las plantas se encuentran o no en el ambiente de cultivo ideal, de acuerdo con las especificaciones de su especie. Los datos de la investigación se recopilaron a través de grabaciones de audio, fotografías, tareas y notas tomadas por los profesores. Este enfoque permitió un mayor nivel de participación y autonomía de los estudiantes en el desempeño de tareas relacionadas con los temas curriculares de Ciencias Naturales.
PALABRAS CLAVE: Arduino, Sensores, TIC, Educación ambiental, Motivación de aprendizaje.

1. INTRODUCTION

The practices developed throughout this project occurred under a partnership established between a polytechnic institute's school of education and a 2nd and 3rd cycles of education school within the county of Porto, in Portugal. The project itself is funded and promoted by the city council named "Projeto SEI" – or Project SSE (Society, School and Innovation) – with the mission of promoting knowledge and scientific literacy. In specific terms, the Project has the objective of (1) promoting the access of children and teens to scientific production and research; (2) promoting greater dissemination of science and research carried out in the city; (3) promoting projects / actions that stimulate education / training throughout life; (4) stimulating close relationships between different entities; and (5) contributing to educational success. This way, a group was formed by trainee teachers and their supervisors, from the polytechnic institute, and a sciences' teacher, from the 2nd and 3rd cycles of education school, which carried out the sessions that were ensued throughout the project.

The group of pupils encountered within this setting were composed of six, mostly SEN (Special Educational Needs) students, from twelve to fifteen years-old, from different school classes of the same school, that were enrolled in a Science Club-like extracurricular activity, in a formal educational setting, although not directly contributing to the science curriculum. The interventions started in the beginning of the term and occurred once a week, over 6 weeks, until the end of the second term, which meant that there were not possible to continue or evaluate the effects of the intervention both with the students and the project itself.

The interventions carried out in the educational context were planned in order to approximate the contents of the students involved to the curriculum contents related to abiotic factors, as well as to the use of technologies at the service of academic research. The problem that proved to be the motivation for the project's implementation was identified as the need to link technologies with the abiotic factors present in the science curriculum to promote learning in both aspects: the manipulated resources and the explored curriculum contents. From the identified problem, two questions arose: the first, "Is the *Arduino* platform, combined with computers, an epistemic resource when working with middle school students?"; and the second being "What contributions can this contextualization of ICTs bring to students' involvement in science classes?".

The project presented in this text had the aim to avail the existing technological resources in the educational setting and to make progress of the "already existing student's skills within these resources" (Silva, et al., 2020) and put them to use within a problem identified by the students in their educational context: the need to irrigate plants in the pedagogical garden when there isn't no one around to do it taking, for example, during the school breaks and during the summer holidays. This objective emerges as there is an increasing need to promote scientific literacy, computational thinking as other skills concerning technological research and advancement in order to ensure that students "acquire a wide range of tools or capabilities that will allow them to thrive in an increasingly complex global job market" (Milligan, et al., 2020).

2. FRAMEWORK AND CONTEXT

Sensors are typically used as an extension of human senses (Magnani, 2004) and ubiquitous electronic sensors of our everyday devices influence the way we feel and understand the world. *Arduino*, created in 2005, became popular for its features as an open-source prototyping platform based on easy-to-use hard-ware and software (Arduino, 2018) that allows easy and accessible use of electronic sensors.

A Scientific and Technological context is a learning environment in which we can use a daily situation to be reconstructed in the classroom, or observed in the field (Redish, 2003). When students work in learning environments close to the real world, we are creating conditions that allow them to establish the connection between real concepts and simple phenomena (Lopes, et al., 2009). Considering all the environmental problems arising in our society, it is important to connect scientific and technological education with environmental awareness (Santos, 2008). The main objective of this work is to research and create instruments closer to the students' reality, that combine a significant scientific education with the use of ICT, namely with *Arduino* and electronic sensors, to monitor some of the abiotic parameters that affect plant growth.

The teachers involved in the project came across a group of students with Special Educational Needs (SEN) who were described by the teachers as lethargic and / or apathetic. It became a real challenge to motivate this group of students as they were not interested in the themes and subjects that they were learning at the time. Regarding this situation, Gibson's words (in Rowan & Bigum), "the future is here. It's just unevenly distributed" (Rowan & Bigum, 2012), captures the scenario in which some students are seen as disengaged and left feeling alienated by a world that has been greatly altered by computers, but "unchanged in the ways in which factors such as gender, economy, culture identity, disability and location continue to impact educational success or failure" (Rowan & Bigum, 2012). As the world changes around computers, these technological advances must meet the needs of this same world and, in this case, the needs of education. As novelty serves to attract students' attention, the primary approach was to try to instil the feeling of curiosity and the need to experiment with the gadgets that teachers would bring to the classroom. The second stage would be to try to connect an existing problem with the resources that would be manipulated, integrating knowledge, values and actions from different domains to innovate (Larkley & Maynhard, 2008).

Innovation requires creativity, resources and variety and implies interdisciplinarity and transdisciplinarity for success (Larkley & Maynhard, 2008). This became a key factor for the progress of the project, regarding the diversity of learning opportunities that were given to students throughout the various sessions. The previous one implied that the project should have a contribution from several disciplines, from science and mathematics to the arts and design, oral communication and other areas of knowledge, while the students did not know that they were, in fact, using these subjects in service the type of problem-solving situation they faced. The aim would be to build a kind of "cat and mouse" game in which students constantly try to find answers to the problem they are facing, as well as to the subsequent problems that arise soon after, to continue to feed their curiosity and, consequently, the willingness to actively participate in the project.

The activities mentioned are needed to develop problem solving skills and to enhance the mental ability to make logic within the various problems that should arise in the future, bringing children closer to the capability "oriented to the understanding of how the world works" declared by the values of computational thinking referred by Denning & Tedre (2019). These skills ought to prove to be useful in the future when facing the "challenges of the job market of tomorrow [with future workers having to] relate a set of skills that, interconnected, will develop an appropriate posture towards the problems that are yet to emerge (Silva, et al., 2020).

For this to happen, Brito & Suárez (2001) state that one must develop "practices that suit the curriculum and promote learning improvements in students" being that from "problematization" and "reflexive strategies to answer various problems". This leads to the reflection of the teacher's role in the succession of tasks and activities leading to the contribution of promoting the skills referred. In that way, the teacher has the task of involving the students and bringing them closer to "stimulating elements [that] awaken the students' interest not only to the discussions regarding the specific Sciences' subjects, as for being aware of the necessity of its continuous development" (Malheiro, 2016).

3. EDUCATIONAL PRACTICE'S DESCRIPTION AND ITS IMPLEMENTATION

Having previously outlined the main objective of these interventions among the teachers involved, introductory sessions were held where students could get in touch with simple circuits, constructed with a 9v lamp and a 9v battery to light the lamp to measure the energy capacity of the batteries used in the previous exercise, a voltmeter was used, which allowed us to compare the voltage in the battery information and the output that was given. At the end of this session, students were shown the *Arduino* sensor, as well as some of its components, light emitting diodes (LED) and resistors, to mimic the lamp circuit. With the support of the official Arduino software, and simple code provided by the teachers, the participants were able to manipulate the LEDs and to turn them on and off in a certain period of time.

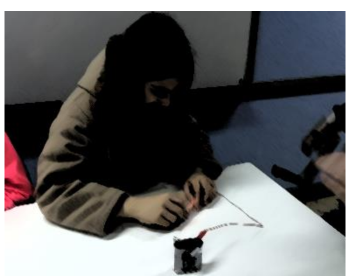

Figure 1 Turning on a lamp with a 9v battery (simple circuit)

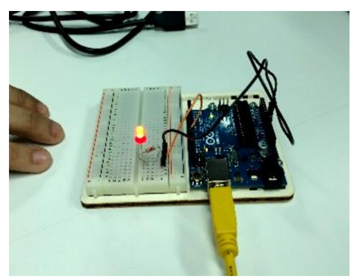

Figure 2 Turning on a LED with the *Arduino* board

In the 2nd session, the teachers brought some inexpensive light and soil moisture sensors, consisting of two nails for the humidity sensor and a photoresistor for the light sensor and a model plant for testing purposes, a bonsai plant elm tree, which would later be added to the project as a control subject. For these sensors to work, it became necessary to build and connect some extra components, composed of a test plate and jumper wires that allow the sensors to be connected to the Arduino board, without having to solder. With teacher supervision and guidance, students were able to create a simple circuit board to start connecting the sensors. The Light Dependent Resistor (LDR) sensor was attached to the top of the bonsai plant and the nails (soil moisture sensor) were attached to the soil of the plant's pot. With the sensors and the Arduino board connected to the board, the Arduino was then connected to a computer, in which, with the aid of the Arduino software and a code pre-configured by the teachers, the students were able to evaluate the results provided by the monitoring soft-ware. At the end of this session, the students were taken to the pedagogical garden, located in the school itself, in order to measure abiotic factors with sensors in different types of plants, which would lead to the main theme of the project.

As the students understood the subjects related to electricity and circuit connections, a debate was triggered with the whole group, in order to start the construction of the self-monitoring central mechanism. The group then decided to use three *Arduino* boards, which would be used to connect seven analogue sensors: three light sensors (photoresistors), three soil moisture sensors and a humidity and temperature sensor (DHT22). For the information provided by the sensors, it was decided to use three RGB LEDs (red, green and blue) for the light sensors, three yellow LEDs for the soil moisture sensors and an LCD for the humidity and temperature sensor. The water pump would be added later, so that it could be used as an automatic watering can, supplying water when necessary to the plant. The group decided where the sensors would be placed and how the information would be provided to the user. The students had access to the components and started to connect them, without worrying about coding yet. The only thing

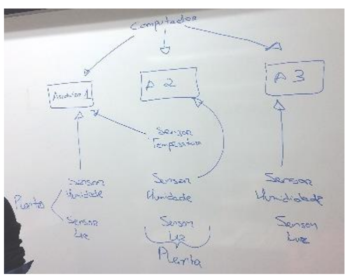

Figure 3 Project's schematics drawn on the board

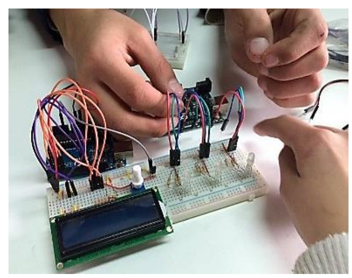

Figure 4 Connecting the LEDs to the LCD

left to complete the first stage of the project was to designate the two plants to monitor abiotic factors (the third being the elm bonsai). This was done with another visit to the pedagogical garden, where the group chose a water demanding plant, a plant that requires water, and a cactus, a plant with little need for water.

After making the connections inside the test plate, the students then proceeded to fix the sensors on the plants, following the same procedure as in the 2nd session: fixing the LDR sensors on top of the plants and the soil moisture sensors fixed to the soil of the plant pots. The DHT22 sensor was connected directly to the assay plate, as it could measure air humidity and

Figure 5 Building the circuit board on the breadboard

Figure 6 Measuring soil humidity with two nails

temperature in the area where the plants were placed. The water pump would be added later, after the construction of the box where the *Arduino* boards and their components would be placed, to make it easier to organize. The box was made with coloured popsicle sticks, cork for the bottom and acrylic for the top, so that the components could be seen by the user. The water pump was then placed inside the box with a water reservoir on the outside, completing the 2nd stage of the project.

The 3rd and final stage of the project would culminate with data entry on the computer, using the official *Arduino* software, where students were guided through-out the process, understanding the code and what purpose it would serve, although more complicated parts of the code had been written by teachers. The code was then calibrated to meet the needs of the light and water plants.

In the last session, with the completion of the project, students were able to explore the information provided by the sensors, manipulate and examine, concluding the effects that abiotic factors have on each plant, given their needs.

4. IMPLEMENTATION'S EVALUATION OF THE PRACTICE AND MAIN RESULTS

Considering the fact that the research took place in a school where there is a pedagogical garden, students felt a very clear and understandable concern about how they would irrigate their plants during summer holidays. They were, therefore, aware of the existence of the problem and interested in contributing to the creation of a solution. Their interventions were adequate and appropriate and a stimulating knowledge sharing environment was created.

In the scope of the first two sessions, students were able to understand, with some experimental activity, how simple electrical circuits work and how to use *Arduino* software to create a similar circuit that can be programmed. This first approach to this software was important so that students could observe its potential, as well as the ways to interact with it and allowed students to realize how easy and exciting it is to use this software.

The next task was to understand the importance of collecting data on abiotic factors, such as water, light and soil moisture, in order to develop a technology mechanism that solves the irrigation problem. Therefore, in the second session, it was proposed to the students to verify, using a plant, the data collected by placing some sensors. This activity made the students understand that using sensors in plants was simi-lar to "having plants with a USB port that allows talking to the computer", as evaluated by one of the students.

In the fourth session, the students were excited to create a tool that would allow them to understand when they should open the windows to increase the luminosity collected by the plants (this would be necessary "as soon as the light (RGB LED) turns red the plant is in the dark and cannot grow", concluded some students), when they should irrigate, the moment the humidity sensor in the soil turns on the yellow LED and to know if the greenhouse was too hot or too cold. In the meantime, the group could also experiment with the response that the LEDs gave by blocking the light manually and assessing that the lights turned blue, as one student stated "Light! Blue, ok! Blue, ok!", followed by another colleague that suggested "If you cover here, it becomes red.". Having done the experiment, the first one concluded: "Yeah, now it's red!".

In the last session, all students seemed anxious to create an “electric water can” that would not turn on at the scheduled time, but when the plant needed to be watered. Concerning this event, a student asked the group if she could “go on vacation and water the plants at distance”, which was promptly answered by another student that it would be possible, as that objective was the very reason why they were doing this project. This is an example as to why establishing a connection between school-based projects and real-life problems, creates meaning in the student’s minds. The students were also able to experience first-hand how the signals changed when per-forming actions that would alter the plant’s state. In one instance, a student asked: “I want to see the lights! If we water it (the plant), will they (the LEDs) change?”, having the teacher answered positively, as “when the plant does not need water anymore, the light would turn off: “And it only comes back on when it (the plant) needs it (water) again.

Even though none of the students or the even the project teacher had ever come in contact with the *Arduino* software before, all of them seemed to enjoy the activity and easily understand the relationships between the data collected by each sensor, the message sent to the programmed software and the “reaction” seen in the box where the lights were installed and connected to the software.

Although there is still some resistance in schools to use technological resources, either due to lack of economic resources or because the teacher is not comfortable with the use of ICT software, it was noticeable that students became more interested in learning, experimenting and reflecting on the themes and ideas arising from this work. It was perceptible that students learn more easily and significantly when the subject is close to reality and related to their lives and problems and when the subject is ad-dressed from a perspective of experimentation and validation.

The main objective of this sequence of sessions was to respect the students’ learning time in order to increase their instant span and attention. Regarding the students' involvement, it was clear that their interaction was fluent and frequent and they al-ways appeared to be focused and committed to the project and its purpose.

5. CONCLUSIONS AND IMPLICATIONS

Considering that students in this project were considered unmotivated and not participating in the classes, and that they, on the other hand, were so predisposed to learn new technologies and to program some software to achieve their goals, it is possible to realize that the *Arduino* software, together with some field work, promoted interest, motivation, involvement, participation and attention on the whole group. There seem to be numerous advantages to using *Arduino* software in classes for teachers and students, as it can provide teachers more diverse and motivational strategies or methods that increase student involvement in the learning process. All students were interested and motivated to learn curricular content, such as abiotic factors and plant needs meanwhile checking the objectives defined for a good learning environment within a science classroom, “to scientifically explain phenoms, to evaluate and conceive scientific investigations, to scientifically interpret data and evidences” (Lourenço, et al., 2019).

As for the project itself, it seemed that the use of the chosen software made way for children with SEN, especially with attention deficit disorders, to become more interested, motivated and, above all, focused on the learning process with a desire to be part of it. They always wanted to do things by themselves, especially when connecting wires or sensors or when watering was involved. Classroom environment was clearly one of true knowledge sharing, thoughts or beliefs and all students always seemed to want to share their conclusions with their classmates, in order to demonstrate knowledge on the subject. Teachers and students had an active participation in the teaching and learning process. It was easily understood that the use of an interactive program with children with SEN, and probably also with others, results in a better learning and sharing environment.

Regarding our first research question, "Is the *Arduino* platform combined with computers an epistemic resource when working with middle school students?", it becomes understandable that, both the teacher and the students have understood the potential of this technology, regarding the use of *Arduino* Software to solve daily problems encountered and brought to class by students. As said before, there was even a student who defined the project's objective as "to develop a plant with USB input in the roots, leaves and flowers, transmitting the needs of the plant to a talking computer".

Concerning the second question mentioned, "What contributions can this contextualization of ICTs bring to students' involvement in science classes", fun and astonishment regarding the participation of students in the project was constantly observed during the sessions, using their restricted knowledge in ICT and his knowledge in science to develop a procedure to solve his problem, which was like watering his green-house plants during the summer holidays.

With all of the above, it seems obvious that by investing in classes with more diverse resources and creativity, it is possible to involve students in their learning experience. The results led also to the assumption of the importance school principals and education ministers have, in supporting and financing these activities and to value all the positive, diverse and dynamic aspects of classroom work. It is possible to confirm that the use of ICT with students with SEN will provide them with greater involvement and wisdom.

Projects like the one described here, allow students to communicate, share ideas, plan, deal and solve detected problems. *Arduino* software proved to be a good un-structured ICT resource that complements and facilitates the promotion of academic skills in children with or without SEN. This software and science project promoted interaction and autonomy, increased students' attention and concentration and facilitated a better contribution to problem solving, leading to the reflexion that "to do, to teach, to learn and to communicate within science implies the use of technology" (Paiva, Morais, & Moreira, 2015).

Finally, with regard to the fun and enthusiasm of students described by teachers as lethargic or disinterested, it showed us that teachers must always develop new strategies that "encompass various strategies or resources to purposefully motivate and further promote knowledge production" (Stroupe, Moon & Michaels, 2019). In order words, to face the fear of failure to innovate and produce knowledge, so that children and students look forward to going to the classroom in order to maintain and develop their projects and enhance shared knowledge.

Within this context, ICTs present themselves as an axis connecting different curricular subjects (Flores, Peres & Escola, 2010), which are fundamental to the teaching and learning process, namely the learning by learning - since these epistemic tools act as mediation instruments to the construction of knowledge. These tools, digital and interactive, are familiar to the 21st century generations, used not only as an end, but as a means for the acquisition and development of skills (Cachapuz, Sá-Chaves & Paixão, 2004). In addition, it shows itself as an integral part of everyday life, solving problems and opening opportunities, so they are indispensable tools for the teaching and learning process, encouraging motivation and changing the ways of learning, thinking and modelling to learn (Flores, Escola & Peres, 2009).

As Nóvoa (2007) emphasizes, technologies should reinforce the role of the teacher and its ability to respond to unforeseen situations in school daily life, assisting the search for new pedagogical conceptions and practices, keeping teaching alongside the advancement of his own society and the children themselves. ICTs then reveal themselves as a pedagogical tool that provides an interactive environment, helping the teacher to create a practice that is both more dynamic and conducive to the construction of knowledge.

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