Bridging the gap between school and out-of-school science: A Making pedagogical approach

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***Abstract*— Making provides a beneficial learning environment that requires skills and knowledge from the areas of science, technology, engineering, and mathematics to design and construct a product or an artefact. In this paper the maker approach reflects on the pedagogical potential of learning through the design and deployment of an automated system that monitors and records environmental parameters in lakes and rivers. IoT technologies are used to connect schools with natural ecosystems, providing the opportunity to students to be actively involved in designing and developing technology artefacts to experiment with, and further, in the formulation of research questions, and in the processing and interpretation of research results and measurements. The study contributes to the research literature on bridging the gap between the school and out-of-school science.**

Keywords: Making, education, IoT

I. Introduction

At the beginning of the twenty-first century, educators scrutinize the content and pedagogy of science learning and teaching and propose new standards that intend to shape and rejuvenate science education. Research in the field of education suggests that students are called upon to develop new knowledge and skills, such as problem-solving, critical and creative thinking, and collaboration. For this to happen, beneficial learning environments are necessary, associated with progressive pedagogical approaches that engaging students in design-build activities, allow them to explore ideas, develop skills, understand concepts, and build a wide range of learning dispositions and capacities.

In recent years, mainly from advances in technology and new digital fabrication technologies, the Maker Movement has flourished. The definition of Making is very broad and gathers individuals that create things, the “maker”. A Maker integrates digital technologies into practices of designing and constructs physical, and sometimes virtual, objects. Through this process, several abilities are fostered, such as innovation, creative thinking, develop and design products and the spirit of challenge.

In this regard, there are many studies who argue that formal education [3,4] could benefit from “making” approach and that is time for innovative pedagogies to move into the classroom. As PEI [38] suggests “*making develop the ability to discover problems, analyze problems and solve problems, but also make it easier to maintain the passion of learning and enhance the confidence of learning, while all these qualities are important components of students’ creativity*”. As science educators consider ways to make their instruction more stimulating and inclusive, more rich in STEM practices, and more culturally responsive and relevant to a broader number of students, there is growing interest among educators in bringing making into formal school curricula.

However, the way to successfully apply educational interventions inside schools is still an open question.

II. REAL-WORLD DATA IN EDUCATION

A. Literature review

The Internet of Things (IoT) is a network of several devices which are attached with miscellaneous software, electronics, and network connectivity, aimed at exchanging, and compiling of any kind of information [1]. Several work focus on IoT applications into education process in university that leverage a learning-by-doing and hands-on approach [7,11,20,23,36], while the implementation of IoT-enabled educational scenarios in schools is less investigated.

The UK, Open University offers a learning infrastructure that allows students to experiment with, and learn about, IoT technologies by engaging in a range of activities that include collaborative and collective programming of real-world sensing applications [17]. Complete novices use SenseBoard networked sensor device and Sense visual language and programming environment, based on Scratch, to design and build technological systems that reflect expectations of openness and participation.

Along this direction, Porter [24] argue that the lack of students' engineering experiences in primary and secondary education is in part of teachers’ lack confidence in their ability to teach technology and engineering approaches. Darling [27] argues that most teacher candidates have not had the opportunity to witness deep integrations of digital technologies for learning purposes in their careers as K-12 students. And continues, that the “*problem often surfaces in complaints that teacher education is too theoretical, by which teachers often mean that they have not learned about concrete tools and practices that let them put into action the ideas they have encountered*”.

Gianni [15] reports on the usage of a toolkit [34] for rapid IoT application prototyping with a group of high school students. Mavroudi [5] has expend the work to lower secondary school students that undertook the role of designers of IoT applications in the contexts of education and smart cities. In Make2Learn workshops, Divitini [30], supports that making IoT artefacts enable children to foster co-creativity and joy in learning processes and to construct knowledge that lead to STEM concepts.

UMI-Sci-Ed project proposed an educational framework leveraging ubiquitous, mobile and Internet of Things technology for science learning in high schools, while also investigating students' stance on IoT-enabled education activities [12].

European research project GAIA - Green Awareness in Action (http://gaia-project.eu) has developed a real-world multi-site IoT deployment, comprising 19 school buildings, aiming at enabling IoT-based energy awareness and sustainability, promoting energy-saving behaviors supported by IoT data. Temperature, humidity, luminance, motion, and noise level sensors have been installed in classrooms and so the infrastructure is monitoring in real-time, the electricity consumption as well as indoor and outdoor environmental conditions, using heterogeneous hardware and software technologies, including different commercial hardware/sensor vendors, as well as open-source solutions [18].

However, although IoT technologies can reshuffle the geographical location of an individual providing more transformations in the education sectors, (there has been little focus so far on) little part of investigation has focused exclusively on connecting schools with out of schools environments (e.g. natural ecosystems) and the opportunity studying those environments leveraging real data. As classroom-science is often contrived and unreal, and cannot hope to replicate real processes, whereas monitoring a natural ecosystem and actively participate in the formulation of research questions, in the design and development of experimental and technological products as well as in the processing and interpretation of research measurements, can contribute much to explain science as it is practiced. Real research projects with meaningful outcomes have been shown to engage students, especially when real ways in which science is conducted are been used. Context sets science in the real world of the student, enabling a better appreciation of complex scientific and social relationships.

III. Environmental Water Projects

The European Union (EU) has defined in "Europe 2020" Strategy (COM/2010/2020/FINAL, 03.03.2010) two mutually reinforcing priorities: a) smart growth based on education, knowledge and innovation, and b) sustainable growth promoting a more resource efficient, greener and more competitive economy.

The approach of promoting a sustainable behavior among young people regarding the environmental resources and supporting a better understanding of the factors affecting ecosystems, is key to changing their behavior towards achieving a sustainable planet. Moreover, reinforcing the educational community on educating new generations has a multiplier effect for understanding the resources and for reducing our environmental footprint.

The work presented here focuses on raising awareness for water pollution since about 79% of Earths' surface is covered by water. Water has multiple importance as source of life while provides the ability to produce food, minerals and energy, is a key factor for the renewal of the planets' oxygen, and the means to transport goods (trade, energy transfer/information). However, in order to achieve a better understanding of the potentials of water, its uses, and at the same time to effectively protect it, several educational activities come under the scope of various research programs.

Donahue [35] supports that too often, what student learn in school has relevance only in a school context and creates the perception that school is unrelated to life as it exists outside of school. Suggests the Global Rivers Environmental Education Network, Thornton Creel Project, and Harpeth River Environmental and Educational Project as authentic and real-world contexts, in which students from passive organizers of detached data become active investigators of contemporary issues within their community. In those projects, students explored rivers' hydrology, tested water quality, and identified point sources of pollution. Through student-based scientific research and the development of innovative tools and partnerships for environmental investigation and education, students develop and apply science skills and knowledge in the service of their communities.

In order to support STEM training, National Science Foundation (NSF) funded through the Innovative Technology Experiences for Students and Teachers (ITEST) the SENSE-IT (Student Enabled Network of Sensors for the Environment using Innovative Technology) project, in which students design, calibrate and use a series of sensors to monitor the quality of aquatic ecosystems [28]. Utilizing the materials offered by the program, students construct, program and test sensors and digital circuits to record physical parameters such as temperature, conductivity, turbidity, and depth. As part of the project implementation, sensors technology material for secondary education was developed, their data were used for teaching technology, engineering, mathematics and science, students were encouraged to explore any local environmental issues related to quality of water bodies and, finally, an effort was made to make more attractive for pupils the choice of employment in relevant career areas.

Take into consideration that the deterioration of the quality and quantity of surface water is one of the biggest environmental problems today while it is expected to intensify due to climate change and the incorrect management of stocks [22, 26], we propose to leverage a making approach with IoT technologies to investigate environmental water issues, in classrooms. This project includes the development of an innovative system for monitoring the quality of rivers and lakes and the use of relevant measurements to study the natural ecosystems and physicochemical concepts that describe them.

Monitoring the quantity and quality of water is essential for the complete management of water resources, environmental protection as well as the reduction of natural hazards (floods/droughts) and anthropogenic disasters (water pollution). One of the preventive measures is the monitoring of the water situation using conventional means (e.g. water sampling, spot measurements) but also innovative tools (telescoping, automatic monitoring stations, etc.). However, the level of information provided to date is not satisfactory and prevents the design and implementation of appropriate water management and rehabilitation measures [32, 6]. Therefore, the development and installation at key points of rivers and lakes, automatic environmental monitoring stations, which are economically affordable and easy to use, is a necessary approach that if combined with participatory processes of the wider educational community can contribute to a sustainable solution for effective water monitoring.

About 60% of surface water bodies in the European Union are classified as moderate or of poor quality and therefore immediate protection and rehabilitation measures should be taken [14]. Therefore, water monitoring at European level, using modern equipment that allows continuous recording and timely updating of key quality and quantity indicators is necessary, on the one hand to facilitate immediate intervention and mitigation measures to mitigate the effects of natural and man-made disasters, on the other hand, for the correct design of long-term measures and infrastructure projects. However, the installation and operation of a National or European network of automatic water monitoring stations is still a difficult process as the cost of acquiring and maintaining automatic stations is still high, while the bodies responsible for their operation are inevitably far from most of the network, which makes it difficult to respond directly to equipment repair and maintenance needs. However, with the use of low cost and open source hardware and software (e.g. Arduino - IoT), the cost of building automatic water monitoring stations is rapidly declining and modern participatory practices such as Citizen's Science facilitate the installation and operation of these stations [10].

IV. PROJECT DESCRIPTION

The project aimed at students aged 16-17, from general and technical schools. As part of the program, students undertake solutions to how they could monitor the quality and quantity of surface waters for environmental protection. First, students undertake to design, construct, and deploy an automated system that monitors and records environmental parameters (such as temperature, dissolved oxygen, total dissolved solids, and pH) in lakes and rivers, using IoT technologies. For that, they follow the eight-step engineering design process [31] in Massachusetts Department of Education curriculum framework for science: a) identify the need or problem; b) research the need or problem; c) develop possible solutions; d) select optimal possible solution; e) construct a prototype; f) test and evaluate the prototype; g) communicate the solution, and h) redesign the prototype. Then they interpret the physicochemical measurements to study the ecological system through appropriately designed lesson plans.

The process of learning is a socially organized action that is assembled in the real world through a process of participation in communities of practice [13]. This requires offering students opportunities to participate actively in formulating and evaluating problems, research questions, assumptions, conclusions, arguments [21]. Student engagement in an authentic learning framework has proven to be an effective educational approach. The basic concept of authentic learning is based on the perception that pupils may be more interested in what they are learning if that reflects in real life, is practical and useful and address issues that are important and applicable to non-school life [2]. It is a way of teaching science thought and work in which students make assumptions after observation, design and implement experiments and confirm or reject their affairs, and finally present the results of their investigation. Students apply knowledge or skills, such as problem solving and critical thinking in situations that represent real-life situations. To investigate any pollution problems in water bodies located in their area, students plan their own study which follows the scientific method and tries to answer inquiry questions by collecting and analyzing data, concluding conclusions, and making recommendations.

V. PARTICIPATORY SENSING

Considering the physicochemical concepts included in science curriculum and that the cost of equipment must be affordable for schools, we came up with the choice of five sensors: temperature, dissolved oxygen, conductivity, and pH. The first edition of the device was tested in a marine environment and had one more sensor, the turbidity sensor which rusted very quickly.

The design of the device is based on the open-source (hardware and software) Arduino platform. The Arduino platform has been chosen as it is well-established electronics prototyping platform and offers multiple variations that provide us with the appropriate core components for building sensing devices with the lowest cost and effort [29]. The goal has been to develop a small, relatively inexpensive, portable device that can easily be deployed.

The first trial was a short hands-on IoT sensing attempt, conducted in three islands of Cyclades, at Aegean Sea. Due to the area of our test, open sea and island beaches, we wanted an easy way to collect measurements without the need of a deployed communications infrastructure (e.g., a mobile data network connection) and the device was designed to submerge only the sensors in order to collect measurements. An Arduino device equipped with an SD card reader module was used, that allows to store the measurements collected in each session. After the data collection, the SD card was removed from the Arduino and the measurements had been transferred to a laptop or a smartphone. The Arduino program follows an extremely simplified approach to collect the measurements. As soon as the device is powered a file is created in the SD card to append new data. Each sensor is polled sequentially and once data are retrieved from all sensors, the collected data are appended to the file together with a relative timestamp, that shows the time since the devices power on time (as the device has no real time clock or battery to maintain a constant time reference) [9]. It is therefore important to store the measurements after each sampling session and properly tag them for location and time manually.

In the second step the device had been installed for two days in Pikrodafni river stream (3755’7.05”N, 2342’9.02”E) after automated the process by transmitting the data via GPRS to a database accessible via the Web (http://netmon-noc.ath.hcmr.gr/pikrodafni), including time stamp and deep sleep operation. For the power supply of the devise a power bank has been used.

At the final edition the power supply problem has been solved with a solar panel that charge a 12 Volt battery, and Hellenic Centre for Marine Research (HCMR) team, installed the devise in Koumoundourou Lake, at the same location with HCMRs’ research station, so it could operate and send data seamlessly for a long period of time (https://grafana.ath.hcmr.gr:8080/d/KrpT3r8Zk/koumoundourou2-station_final-real-time?orgId=1&refresh=1h&from=1581443286788&to=1581616086790).

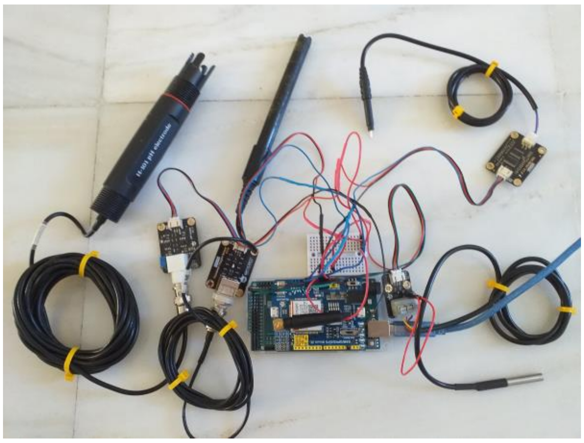

Fig. 1: The Arduino-based water sensor kit, that was used for the education activities.

The sensors that have been tested with the device are the following:

- DS18B20 Digital Temperature Sensor for measuring the water temperature at the sampling location.

- Total Dissolved Solids Meter for measuring the soluble solids dissolved in the water at the sampling location.

- Analog Dissolved Oxygen Meter for measuring the oxygen available in the water at the sampling location.

- Analog pH Meter for measuring the pH value at the sampling location5. In the improved version of the device as an automated telemetry station, the pH sensor has been replaced by a sensor with an industrial electrode, suitable for long-term online monitoring.

- Analog Turbidity Sensor for measuring the suspended particles in water by measuring the light transmittance and scattering rate which changes with the amount of total suspended solids in water. As the TSS increases, the water turbidity level also increases. This sensor was used in a series of samples in sea water and rusted in less than a week from salt.

The next step is to compare the values that the sensors will record with those of the HCMR research equipment in order to ascertained lacking in accuracy and potential slack between the measurements produced from the IoT sensors, that are inexpensive and are not meant as scientific measurement tools.

THE STUDY

The main goal of this study is to develop, implement, and assess a framework for making activities in the context of high school curriculum. More specifically, the objectives of this study are as follows:

1. What aspects of Making can be effective in formal education and with which students?

2. What are the factors that influence what and how much school students' do and learn through making activities?

3. How do influence students' perceptions and attitudes about science?

4. How could be designed and implemented to better achieve important learning goals?

5. How might be integrated into the formal curriculum?

The findings will ultimately allow us to form best practices and a unified framework for guiding/ assisting educators who want to adopt this teaching approach.

The Design-Based Research (DBR) methodology has been chosen with emphasis on the qualitative method for data collection as suitable to both research and design of technology-enhanced learning environments. Qualitative measures have special value for investigating complex issues, such as children's attitudes to computer science, mathematics, and engineering, topics such as self-efficacy [8], and general impressions about the process of making activities [25]. Wang [16] defines DBR as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories." Researchers suggest DBR as suitable method for real-world educational context while focuses on the design and testing of interventions, uses mixed methods and is concerned with an impact on practice. On the other hand, we have to mention that DBP is not so strong method to capture students nonverbal thought processes.

A video camera will record the students' classroom behaviors. In addition, the researcher will record field notes to observe student participation in the learning activities. At the end of the project a series of interviews with students and teachers will take place. For the protocol analysis of the video will be used Razzouks' hierarchically arrayed set of variables from the design thinking competency model [33]. The model allows to collect data on the educational activities that could be used for diagnostic and assessment purposes as well as review learned skills.

VI. DISCUSSION

This research further supports that education-focused real world IoT deployment can help to form a better understanding of our environment and promote sustainable activities, starting at a school level. By using inexpensive and easily available IoT infrastructure to measure, and then visualize and reflect on the data combinations, a more meaningful understanding of our environment is informed. At the same time provide an opportunity to perceive school science as relevant and practical, to make links between school science and everyday life and to involve students with hand-on/ practical nature experiments.

Most research work on utilization and application of IoT technologies in educational practice remains untheoretical, especially when it comes to selecting an appropriate evaluation methodology for school learning. In this paper, we try to lay the ground for other researchers, by searching for, selecting and validating a suitable evaluation method. Such evaluation efforts can help similar research in an effort to integrate STEM learning approaches and IoT sensing to formal school education.

While scholars and educators have good reasons to believe that making learning experiences can enrich school science and offer a much quicker response to new discoveries than is possible in the formal sector, we have to invest more how these experiences can best be integrated into school curriculum.

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