Internet of Things in Education for Sustainable Development

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Abstract. Education for Sustainable Development (ESD), as stated by UNESCO, should empower learners towards new ways of thinking and acting for a more sustainable and just society for all. However, it is often narrowly interpreted and taught as scientific knowledge about the environment, failing to trigger relevant social changes. In this preliminary study, we visit the computer science literature to analyse some potential roles of technology, more specifically the Internet of Things (IoT), with a human-centred design perspective to be applied in ESD. Through these lenses, we propose some preliminary guidelines to apply IoT-based projects to educate and empower students related to environmental Sustainable Development Goals.

Keywords: Sustainable Development Goals · Education for Sustainable Development · Internet of Things · Human-Centred Technology

1 Introduction

As a critical enabler for progressing towards the Sustainable Development Goals (SDGs), education is at the centre of the United Nations 2030 Sustainable Development Agenda [22]. For decades, UNESCO has been at the forefront of Education for Sustainable Development (ESD), supporting strategies and articulated actions to address sustainable development in education policies, teachers training and curricula across the world [20].

The current view of ESD encourages changes in knowledge, skills, values and attitudes to enable a more sustainable and just society for all [10]. However, as reported in [20], frequently ESD is still interpreted with a narrow focus, mostly associated with the teaching of scientific knowledge of the environment. This approach is rarely enough to empower learners towards new ways of thinking and acting, thus failing to reveal the real transformative power of education [20].

In this paper, we discuss some potential roles of user-centred technology, more specifically of Do-It-Yourself (DIY) projects, to empower learners while enabling them to better understand their own contexts regarding specific Sustainable

Development Goals, in particular those related to the environment, relying on data as evidence.

Commonly applied in DIY projects, the Internet of Things (IoT) consists of connected objects (*things*) embedded with sensors, software, and other technologies [12]. IoT provides, among other features, 'simple' and affordable alternatives to sense and measure characteristics of the physical world, transforming aspects of the environment that are usually abstract into data, or even further, into a knowledge base. Beyond the most typical applications on environmental monitoring, i.e. measuring characteristics of water, soil or air, smart cities [7, 15], healthcare [14], or smart home [17], IoT has also being applied in educational contexts in different ways [16, 12].

In the next sections, we first introduce the concept of Education for Sustainable Development as adopted by UNESCO. Then, we present relevant characteristics of IoT, followed by an overview of IoT-based projects related to the environment being used in educational contexts. We analyse some potentials and challenges of applying this technology in ESD aiming at boosting learners' transformative power.

2 Education for Sustainable Development

Beyond addressing key related concepts of Sustainable Develop Goals (SDGs), such as climate change, biodiversity, poverty, among others, ESD also aims at equipping learners with competencies to think and act as informed citizens towards a more sustainable society. As a holistic and transformational education, ESD shifts the focus of education from teaching to learning. It embraces elements such as collaboration, problem-orientation, inter and transdisciplinarity, self-directed learning, as well as the link between formal and informal learning. The ESD framework addresses pedagogy, learning environments, educational content and outcomes [10]. Other concepts intrinsic of ESD relevant to this research are:

Humanist view. Although education is typically connected with generating opportunities for economic development and employment of students, as highlighted in [19], for building the knowledge and skills needed for sustainable development, a more humanist vision of education that promotes inclusivity and universal ethical principles towards a common good is essential.

Competences. In [13], Rieckmann proposes approaching ESD with a competence perspective aiming at enabling individuals to participate in socio-political processes. Among other key competencies, the author highlights the importance of *problem-solving* to deal with complex sustainability problems, *self-awareness* as the ability to reflect on one's own role in the local community and (global) society; and *critical thinking* as the ability to question and reflect on values, norms, practices and opinions; and take a position in the sustainability discourse. Critical thinking is related to exploring and questioning 'the experts' views' and experimenting with the complexity and contradictions of sustainable living.

Engaging the youth. For [23], typically, young people are not engaged as collaborators in decision making at political and policies levels. To change this, the engagement of young people with ESD and the SDGs has to foster reflexive, socially relevant and contextually situated learning and action, also helping learners to distinguish utopian perspectives from research-backed responsible actions.

For disseminating and boosting ESD worldwide, plentiful resources are currently available to support policy makers, educators or community leaders [21]. Yet, in academic research, contributions to ESD merging computer science and education are still emerging. This transdisciplinary perspective oriented by principles of human-centred design, socially-responsible technology and participatory design involving youth can potentially lead to technology-based educational projects suitable to different learning environments, respecting local and diverse cultures and values, and more effective in empowering learners towards transformations.

3 Internet of Things (IoT) for Education for Sustainable Development

3.1 IoT Technical Possibilities

The open-source platform Arduino [1] is the most popular for building electronics projects nowadays. First developed in Italy in 2005, it became popular due to its low cost, for running on different platforms (Windows, Mac, Linux), simplicity for programming it, and open-source extendable software and hardware. Arduino consists of both a physical programmable circuit board and an Integrated Development Environment (IDE), a software application for programming based on a simplified version of C++ programming language providing a standard way to perform micro-controller features, such as communicating with sensors and controlling hardware. There are a lot of Arduino clones boards in the market that support development with the Arduino IDE.

Raspberry Pi [3] is another popular platform created specifically for promoting computer science teaching to elementary school students. Until 2020, it was exclusively a Linux small single-board computer that boots up into a full operating system. In January 2021, the Raspberry Pi Foundation introduced the Pico version, a new form of the Raspberry Pi ecosystem which is itself a micro-controller, similar to Arduino.

In Table 1 we compare some characteristics of the two most popular platforms, Arduino and Raspberry, considering their cheapest boards with USB connection, which facilitates the development in practical aspects. There are many Arduino boards below US$10.00 but without a USB port. The new Raspberry Pi Pico has better hardware and lower cost, thus it is more suitable to enhance the ESD in developing economies. As it is more popular worldwide, there are more DIY tutorials and projects available online for Arduino. However, with Arduino official support to the new Raspberry Pi RP2040 chip, much of this online material can now be ported to this version of Raspeberry Pi [4].

Table 1. Characteristics comparing Arduino and Raspberry Pi Pico

	Arduino	Raspberry
Board	NANO EVERY	Pi Pico
Microcontroller	Atmel ATmega4809	Raspberry RP2040
Architecture	AVR RISC 8-bit	Dual-core ARM Cortex-M0+ 32-bit
Speed	20MHz	133MHz
Data Memory	6KB SRAM, 256B EEPROM	256KB SRAM
Program Memory	48KB Flash	2MB Flash
Communication Ports	8	22
Dimensions	18 x 45 mm	21 x 51.3 mm
Price	US$10,9	US$4.00
Programming Language	C/C++	C/C++/MicroPython

There are many sensors compatible with both platforms including: ambient light, motion, temperature, magnetic fields, gravity, humidity, soil moisture, vibration, pressure, electrical fields, current, sound, position, smoke (MQ-2 gas), alcohol (MQ-3 gas), methane (Q-4 gas), toxic gases (MQ-135), ozone (MQ-131 gas), air quality level (PM2.5), flow, PH sensor, turbidity sensor, total dissolved solids, to name a few [5]. The number of available sensors extends the application range to be used in educational context, and the possibilities to match different SDGs, such as SDG 6 for treatment of wastewater or SDG 11 referring to the concentration of PM2.5 in the air.

4 Samples of actual research

Aiming to find actual and representative examples in the literature on the topic of Internet of Things for Education for Sustainable Development, we searched for publications from 2016. The following keywords were used: kids, children, education, students, primary school, secondary school, elementary school, high school, low-cost sensors, eco-sensors, electronic sensors, Arduino, Raspberry Pi, IoT, water quality, air quality and environmental health. Searches with different sets of these keywords were made on Google Scholar and ranked in order of relevance.

From the selected articles in this first search, an iteration of backward snowballing [24] was performed to identify other relevant works. In this section, we present some of these works grouped according to the environmental aspect they address.

Air pollution. Measuring the air quality was the target in [7, 8, 6]. Dutta et al. [7] investigated sensing air quality indoors and outdoors in an opportunistic approach, while people are on the move. The AirSense platform consists of the Air Quality Data Management (AQDM) circuit, a mobile application and cloud services to put data in a map named AQImap. The use of the solution can be made personal and collective. The authors argue the solution is low cost, low power and low weight to favor mobility.

Fjukstad et al. [8] adopted a citizen science approach with Norwegian students in secondary school (17-18 years old) using Arduino and the air:bit programmable sensor kit [2]. Researchers offered a two-day workshops to teachers and provided a web application for the students and general public monitor the data collected over a 2 months period. According to the authors, the students enjoyed the interdisciplinary nature of the project and coding was considered the most difficult part.

Chen et al [6] involved students in a 2-month voluntary monitoring campaign in schools in Las Vegas in the United States. Eight students of an environmental club performed indoor and outdoor measurements with a personal PM2.5 sensor. The initiative revealed the need to reduce both outdoor and indoor PM2.5 sources in the schools, as they can contribute significantly to the schoolchildren's exposure and health risks. According to the authors, low-cost sensors can be seen an an opportunity to offer air quality monitoring into many schools by integrating the sensors into science projects with primary and secondary school students.

Water quality. Tziortzioti et al [18] proposed a set of game-based educational activities for primary and secondary students on aspects related to environmental impact of water usage. The games could be played individually or in teams. The activities involved measuring water temperature, acidity, alkalinity and turbidity observation, among others. The toolkit included Arduino Uno, a mobile application and cloud services. The study revealed issues with the low accuracy of the sensors.

Energy. Mylonas et al.[11] explored gamification and competitions to engage with teachers and students in order to perform energy-savings activities. This work uses the GAIA framework which includes and IoT plataform, a web application builder, an app to access data among others systems. The competition themes addressed activities to reduce energy consumption in class and at the school. Thirty educators from more than 20 schools in Greece and Italy observed that the competition approach increased the student's engagement.

Temperature and humidity. Ga et al [9] have adopted Arduino-based devices to deal with the monopoly in the process of data analysis in the school environment. According to the authors, particular groups of students can take advantages of their competence with technology and privileged access to data. The authors argue that low-cost boards may optimize measuring methods and stimulate procedures for authentic scientific inquiry, i.e. getting closer to procedures that scientists engage in while conducting research.

5 Discussions

Although restricted, this literature reviewed illustrates a range of possibilities for adopting IoT in primary and secondary education as part of citizen science initiatives [8, 6, 9], extended with game or gamification features [18, 11], or as initiatives to measure and analyse their environment as part of sciences education [7]. These researches bring into discussion the adequacy of the IoT platforms and types of sensors, accuracy of the data collected, and some aspects of participants' engagement. However, studies with an educational and/or technology design perspective that also analyses the educational and technical resources for teachers, adequacy to specific age groups, and development of competences expected in ESD are still lacking.

Therefore, from this analysis we suggest a set of socio-technical aspects to be considered to properly address strategic competences for ESD such as critical thinking, problem-solving and self-awareness, described as follows:

- **Hardware choice:** Level of technical background and programming skills required; price and affordability in the context; availability of additional hardware resources; availability of supportive resources online.
- **Relevance of the data collected in the context:** Consider different possibilities to experiment with the data collection within the context, such as trying different situations, locations, times in the day, etc. that could lead to a better understand of actual circumstances and possibilities to change towards SDGs; adequacy of the data visualisation; possibilities to contrast the data collected with other scenarios.
- **Project design:** Level of complexity or 'readiness' of the technical and educational resources provided tailored to age groups and typical skills within the groups; strategies to democratise the hardware development, preventing that only students with more technical skills monopolise the activity.
- **Engagement:** Strategies to engage the students and their communities (family, friends, neighbourhood, etc.) with the initiative to discuss the impact related to SDGs.

6 Conclusion and Future work

In this paper, we reviewed the literature on IoT projects within educational contexts through the lenses of human-centred technology and Education for Sustainable Development Goals. This preliminary analysis led to an initial set of guidelines for choosing the right hardware platform, analysing the adequacy of the data collected to the context, and for designing strategies to engage students and to democratise the hardware development. Although this analysis focused on environment-related SDGs, we envision great potential to connect DIY technology with the education towards other SDGs, for example, related to health and digital access. As future work, we intend to expand this review to deeper analyse the literature towards addressing themes and competences related to ESD, and propose strategies to evaluate studies regarding the potential to empower students.

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