Smart Objects in Education: An Early Survey to Assess Opportunities and Challenges

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***Abstract*—Smart Objects are computationally enhanced versions of everyday objects such as shoes, coffee makers, pens, and more. They have the capacity to process information, sense and act on their environment and interconnect with each other and the Internet, creating an Internet of Things (IoT). IoT and Smart Objects technologies have been adopted in industries such as transportation and healthcare, however few implementations exist in the educational domain. This article presents a survey of Smart Objects applications in learning environments and explores the opportunities that exist in this domain and the main challenges that hinder the adoption of IoT in education.**

I. Introduction

The ever decreasing size and power consumption of microcontrollers and radio transceivers, as predicted by Moore's law, have enabled the creation of miniature, battery operated computing devices. These devices, when embedded in everyday objects such as fridges, shoes, key chains and watches, are able to interact with their surrounding environments while connected to the internet, creating an Internet of Things (IoT) [1], [2].

A computationally enhanced version of an everyday object, a "Smart Object", has the unique capabilities of sensing and collecting information about its use or environment to then process or transmit this information and finally act upon its user or environment based on this information or an external command [3]. Smart Objects are the constituent elements of IoT and, if well designed, have the potential to empower its users by augmenting their understanding and control of their environment [4], [5]. These Smart Objects, and IoT in general, have found applications in industries such as transportation, entertainment, health care, utilities and more [6]. Whereas an extensive body of research exists on the use of mobile devices (often conflated with Smart Objects) on learning environments [7], education is a relatively underexploited application domain for IoT.

The main purpose of this article is to survey the stat-of-the-art in the use of Smart Objects and IoT in the educational domain. This survey will enable the classification and analysis of current applications to identify the opportunities and challenges of the introduction of IoT in education. This article is structured as follows: section II summarizes the methodology used in this survey, section III presents the surveyed articles classified in three application domains, section IV discusses the main challenges encountered in the literature and our conclusions are presented in section V.

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II. Methodology

In this survey, we searched for articles that discuss the implementation of IoT technologies in the education domain in scientific search engines such as Google Scholar and ScienceDirect. For IoT technologies we used keywords such as *Internet of Things/Everything*, *smart objects*, *wireless sensor networks* and *cyber-physical systems*; while for the application domain we used *learning*, *learning environments*, *education* and *training*. We selected articles starting from the first implementations of Smart Objects in the early 2000s up until now and excluded articles that present applications that use exclusively mobile devices such as smart phones and tablets as we prefer to keep those devices in a separate category. Additionally, when we found several articles discussing very similar projects, we selected only the most representative for brevity.

III. How Smart Objects are used in Education

We found three main uses for Smart Objects in education: as enhanced user interfaces to bridge the gap between the virtual and physical world, as a tool to foster exploratory learning and as sensors to gather data in a learning environment.

A. Enhanced User Interfaces

Information and communication technologies (ICT) such as Learning Managing Systems (LMS), simulations and multimedia resources are increasingly becoming an indispensable tool in education and are widely regarded as beneficial to learning [8]. In this context, Smart Objects have the potential to enhance how we interface with ICT in learning environments by exploiting two technologies: Tangible User Interfaces and Augmented Reality. These two paradigms enhance education by augmenting and encouraging the use ICT during the learning experience [9].

1) Tangible User Interfaces: Work with smart objects and Tangible User Interfaces (TUIs) started in the late nineties at the MIT Media Laboratory with devices such as FlowBlocks and SystemBlocks. These devices, developed by Mitch Resnick and his research team, were digital toy blocks equipped with sensors and actuators designed to interconnect and interact with each other [10]. Parallel to this work, at Osaka University, Kishino and his group developed the TSU.MI.KI interactive blocks [11] and Peta Wyeth at the Queensland University of Technology created Electronic Blocks [12]. All these projects were examples of digital manipulatives: physical objects designed to foster learning [10]. These objects allowed children to explore complex abstract concepts while playing with digitally enhanced toy blocks. FlowBlocks, SystemBlocks and TSU.MI.KI allowed children to explore concepts in dynamic systems and probabilistic behavior with simulated scenarios such as filling a bathtub or growing a bank account. Electronic Blocks were focused on allowing pre-school children to learn programming concepts such as logic connectors and code reuse.

Resnick classified digital manipulatives into two categories: “Froebel - inspired Manipulatives (FiMs)” and “Montessori-inspired Manipulatives” (MiMs). FiMs are analogous to LEGO bricks, physical objects that enable the design of countless forms with few constraints (Figure 1), while MiMs are constrained physical objects designed to guide the learner towards a “correct” configuration or model [10], [13]. Both types aim to foster learning by using augmented sensory stimulation: tactile, visual and auditory [13].

While the FiMs developed by Resnick, Kishino and Wyeth lacked wireless connectivity, Pattie Maes and her group explored this feature of Smart Objects with the Sifteo cubes: smart interactive cubes that wirelessly communicate with each other to create Sensor Network User Interfaces (SNUIs). These cubes had small LCD screens, several sensors, a wireless radio and an infrared transceiver to interact with each other and their environment (Figure 2). They functioned as a blank programmable physical canvas where concepts such as mathematical operations or music composition can be explored [14], [15].

Another project that explored early the wireless capability of Smart Objects was Sensetable at the MIT Media Laboratory. Sensetable was a tabletop interface that tracked smart objects on its surface. These objects had wireless connectivity and were used as input devices and as representations of digital information displayed on the table. A user could manipulate and move these objects over the table and interact with the information they represented. Sensetable was used to display simulations of molecular interactions and dynamic systems where users could literally touch the simulated objects and alter their parameters while viewing in real time how the simulation reacted [16].

With smart objects acting as TUIs, learning material that was exclusively virtual can become tangible. Students can physically interact with simulations of abstract concepts while exploiting the educational benefits of hands-on learning [17], [9].

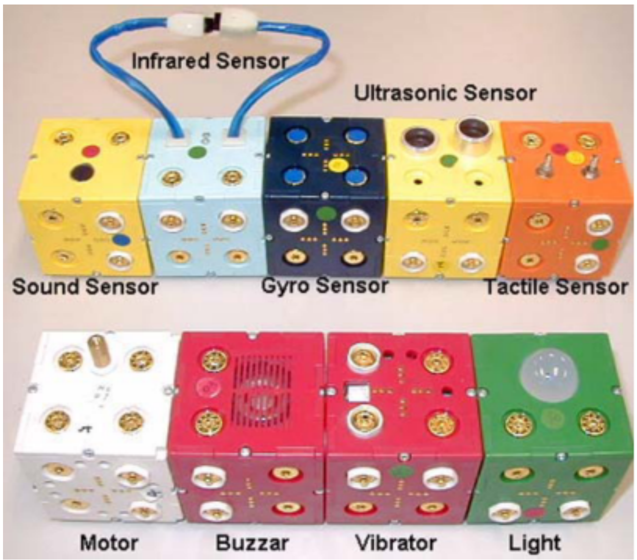

Fig. 1. TSU.MI.KI ActiveCubes were digitally enhanced toy blocks equipped with sensors and actuators that allowed children to learn while playing. Source: [11]

Fig. 2. Sifteo cubes used for problem solving with games. Source: [15]

2) Augmented Reality: Augmented Reality (AR) is the overlaying of interactive information on top of lenses or live video feedback in devices such as mobile phones or head-mounted displays. One of the earliest examples of using AR to interact with Smart Objects is UbiVisor, from the CICESE Research Center in Mexico. They presented a proof-of-concept prototype that uses QR codes to uniquely identify Smart Objects with a phone’s camera. Their prototype overlays graphical information of the object’s collected data while on their field of view [18].

The most salient example of using AR to interact with Smart Objects is the OpenHybrid project from the MIT Media Laboratory. OpenHybrid provides a framework for interacting with Smart Objects based on the Vuforia AR software, the Open Sound Control (OSC) protocol, and the Arduino YUN [19]. A common demonstration of OpenHybrid is using a tablet to control a smart radio. The tangible user interface of the radio is enriched with a more elaborate "virtual interface" on the AR plane. This virtual interface allows a user to perform complex tasks on the radio such as programming a playlist, setting an alarm or outputting the audio to a remote smart speaker. This last task illustrates another capability of the OpenHybrid framework, the ability to use AR to interconnect and provision Smart Objects, in this case to visually connect a Bluetooth enabled radio with a Bluetooth enabled speaker. There are no applications yet of OpenHybrid in learning environments, however the authors in [19] mention education as a possible application scenario.

A company based in the United States, called EquipCodes, is currently using AR to overlay assembly, maintenance and training information on real industrial equipment [20]. They provide to their customers an AR-enabled mobile app that displays information labels and assembly instructions on top of a machine's parts.

By combining AR with smart objects, learning material that was exclusively tangible can now interact with the virtual world. Physical objects in training environments and laboratories such as tools, equipment and machinery can be augmented with a rich virtual layer with tips, help or information about its use or state.

B. Exploratory Learning

Exploratory learning is an approach to teaching that lets the student experience, explore, reflect and test the concepts presented on a learning environment [21]. Smart objects are well-poised to encourage exploratory learning because they can provide real-time information and feedback to students during learning activities.

Researchers at the University of Córdoba in Colombia created a learning environment for an engineering course where physical objects, in this case computer parts, had a QR code or a NFC tag that provided contextual and interactive information about itself. Students interacted directly with these objects using their mobile phone. The researchers were able to demonstrate that this learning activity helped students reach the course learning goals [22].

At the University of Kaiserslautern in Germany, researchers used head mounted displays to let high school students explore in real-time the results of physics experiments. They created a mobile app, gPhyscis, that runs on Google Glass to assist the students on acoustics experiments. The students had to explore how the acoustic resonance of a glass changed as it was filled with water. The app let the students visualize with AR the appropriate water levels and the sound frequency of the glass as it vibrated. The students were able to explore different configurations of the experiment and react accordingly. The researchers demonstrated that using this technology helped students reach the activity learning goals and improve their motivation [23].

C. Data Gathering

Smart objects are normally equipped with different types of sensors to collect data about its environment or usage. Data collection within a learning environment can be used directly by the student to augment her understanding of the process being learned or by the teacher to understand the learning experience.

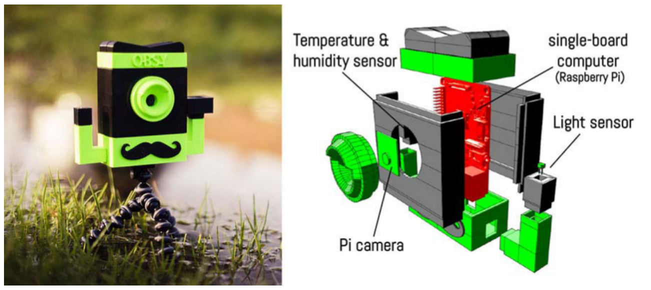

Fig. 3. OBSY: A Raspberry Pi based Smart Object is used in Thailand to collect environmental data for science courses in rural schools. Source: [28]

1) Learning Analytics: Learning Analytics is a new paradigm in learning technologies. Its goal is to measure and analyze student data in order to understand and optimize their learning process [24]. Smart Objects can be used inside Learning Analytics studies as devices to capture student actions. They had been used to analyze student-teacher interactions in face-to-face classrooms. Wearables such as EEG sensors and eye-trackers were used by researchers at the CHILI Lab of the EPFL to extract teacher actions during student-teacher contact sessions [25]. In [26], the authors proposed a device, called Multimodal Selfie, that sits on top of the students desk and records the student's notes together with multimodal sensory data such as video, audio and temperature. In both cases, the objective was to analyze and optimize the learning process in an environment, the classroom, that had been until now noisy and cumbersome to record [27].

2) Real-time data collection: Researchers at the Mae Fah Luang University in Thailand developed a device, called OBSY, based on the Raspberry Pi to perform high school science experiments in rural areas [28]. The device has a camera and multiple sensors (temperature, humidity, light) and connects wirelessly to mobile phones and the Internet to allow students to watch in real-time a video feed and live data of their science experiments (Figure 3).

In a similar fashion, a project led by the Arizona State University, called Connected Gardening, lets high school students monitor environmental and plant growth parameters using smart devices in gardens and farms [29].

The SUPPRESS research group at the University of León in Spain developed an IoT solution that allows students to interact remotely or in the laboratory with a physical system that controls and monitors a DC motor position loop. Electronic engineering students can use the data collected by the system to learn concepts such as sampling or system identification. They connected an Arduino to a DC motor and used the MQTT protocol to distribute the collected information in real-time. The researchers claim that this solution allows students to plot and analyze the collected data; providing more flexibility to a hands-on learning task. They also envision this solution

TABLE I
USES OF IOT IN EDUCATION

Educational Use	Projects
Enhanced interfaces	FlowBlocks, SystemBlocks [10], TSU.MI.KI [11], Electronic Blocks [12], Sifteo [15], UbiVisor [18], OpenHybrid [19], Sensetable [16], EquipCodes [20]
Exploratory Learning	University of Córdoba [22], gPhysics[23]
Data Gathering	Teaching Analytics @ EPFL [25], Multimodal Selfie [26], OBSY [28], Connected Gardening [29], University of León [30]

TABLE II
EDUCATIONAL SCOPE OF IOT AS MENTIONED IN THE LITERATURE

Educational Scope	Projects
Pre-school	Electronic Blocks [12], TSU.MI.KI [11], SystemBlocks [10]
K12	TSU.MI.KI [11], FlowBlocks, SystemBlocks [10], gPhysics[23], OBSY [28], Connected Gardening [29]
Higher Education	Sensetable [16], University of Córdoba [22], Teaching Analytics @ EPFL [25], Multimodal Selfie [26], University of León [30]

as part of a remote laboratory platform [30].

IV. CHALLENGES

IoT technologies have yet to be fully exploited in education. There are still several barriers and challenges for educational institutions, teachers and learners to start using IoT and Smart Objects in learning environments.

The first barrier is that IoT is still a nascent technology with unsolved problems: battery life is insufficient, sensors and miniature computers are still relatively expensive, wireless coverage is not adequate everywhere and coexistence with other wireless technologies creates interference and noise [14], [2], [31]. Moreover, a new technology often brings new ethical concerns about its use, specially when one of its main features is its capacity to record and collect data everywhere [32], [26].

Another barrier is the expected reluctance and pushback of educators and students alike to adopt new technologies and learning methodologies [8]. Educators fear introducing new distractions into the classroom [33] and, when using IoT for exploratory learning, they also fear that measured results will differ from theory and therefore introduce uncertainty in the learning process [34].

Early on, there was some skepticism from researchers on whether TUIs and Smart Objects were actually beneficial for education and the evidence presented by the scientific community was regarded as inconclusive [16], [17]. However, this skepticism was not observed in the latest literature on the subject.

V. CONCLUSION

Smart Objects and the Internet of Things are technologies that are coming into maturity and their potential to enrich learning environments has yet to be fully exploited. While we identified applications of IoT in learning environment ranging from pre-school to higher education (Table II), the instances were few. However, in this survey we identified three ways in which IoT has been used to improve education: as enhanced interfaces of physical learning objects, as conduits to exploratory learning and as systems to gather data about the learning process (Table I). The future of IoT in education lies within these three forms of augmenting learning environments.

The remaining challenges that hinder the adoption of Smart Objects in learning environments are mainly due to the lack of readiness of some IoT technologies, causing poor battery life and high implementation costs, and the fear of uncertainty when introducing new technologies to a well established field. We believe that these problems are only temporary, the same technologies that are used in Smart Objects are also found in mobile phones and the immense pressure that exists in this market will undoubtedly push costs down and improve power efficiency in the near future.

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