Development of IoT applications in civil engineering classrooms using mobile devices

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Abstract

This paper presents academic efforts aimed at integrating methodologies associated with the use of mobile devices, the potential of the Internet of Things (IoT) and the role of experimental education in civil engineering. This integration is developed by encompassing the use of sensors, microcontrollers, civil engineering problems, app development and fabrication. The proposal provides an explorative way of approaching the numerous possibilities that arise in civil engineering when it comes to IoT, automation, monitoring and control of civil engineering processes. The used tools represent accessible and affordable ways for application in classrooms and in educational laboratories for beginners. The initial explorative approach implies the fusion of three realms: i)the phenomenology and mathematics of varied civil engineering problems, ii) the systematic use of digital fabrication technologies and electronic prototyping platforms and iii) the creative and visual way of developing codes provided by block-based development platforms. This integration of perspectives is an attempt of approaching civil engineering mathematics to technology and arts with a rigorous scientific approach. A set of different examples is presented with the corresponding findings in educational terms. These examples are developed in a constructive, scaffolding-based way and may contribute as a potential alternative in the development of open-source teaching labs in civil engineering schools.

1. Introduction

The connection between the physical- (nature, people, cities, industries, etc) and the virtual-worlds (internet, computers and mobile devices) relentlessly brings new ecosystems at all levels of society. Automation, the Internet of Things or ubiquitous sensors in cities are only a fraction of those ecosystems. This has profound consequences for new generations and as a result, in education, trends and schools of thought are emerging particularly in the realm of robotics and control engineering [31]. In the construction industry, the level of automation and infrastructure monitoring and control is also increasing thanks to these trends. Civil engineering curricula, though, are seldom infused with commonplace strategies related to automation, physical-to-digital bridges and the systematic use of monitoring devices and human-computer interfaces.

Traditionally, civil engineering problems are described in classrooms by using classic theory involving a considerable amount of mathematical background as well as a deep understanding of the phenomena. Classic theories have generally been derived from experimental observations from laboratories or from nature. Historically, the development of single or multivariable experiments associated with these fields is still one of the greatest experiences for students at bachelor and master levels. Similarly, numerical simulations are increasingly used in education. However, in spite of the direct link between the physical and virtual realms in which the curricula are based, for the best of the authors' knowledge, few educational programs found in universities provide bridges between the existing gap between both worlds.

Therefore, educators in the field of civil engineering are starting to face a complex challenge. On the one hand, the relentless trends in automation, monitoring, control, the construction of intelligent cities and the Internet of Things (IoT) that will eventually shape the professional sector in the following years. On the other hand, the lack existing in civil engineering classrooms when it comes to infusing the use of sensors, electronics, programming and other technologies that represent the cornerstones of this transformation.

This paper proposes a simple, scalable, scaffolding methodology in which both sides are brought together in the same space. The paper deals with the development of physical-to-digital interfaces in simple yet real usual problems of civil engineering using mobile devices. These problems are reproducible in educational facilities typically found in civil engineering schools worldwide with additional layers of open-source Hardware and Software. Real data is gathered by means of sensors and microcontrollers and real -time visualization of this data is created in the form of apps as graphical user interfaces. For the former, the Arduino platform [36] for prototyping electronics is chosen whereas for the latter, the development environment platform MIT Appinventor [37] is used. Both platforms are chosen due to their accessibility, price and popularity but also, those platforms are connectable one to another via BT protocols straightforwardly. As a consequence, these tools provide an affordable, open-source environment for creation. This layer of information may be added to all theoretical, experimental and numerical educational environments currently used in civil engineering classrooms and/or educational laboratories. For the sake of illustrating the educational potential of this proposal, a problem-based, scaffolding method is presented.

The organization of the paper is as follows: Section 2 provides an overview of educational academic studies related to multidisciplinary developments in civil engineering education as well as a brief overview of the actual trends in automation in construction. Sections 3 provides a succinct presentation of the Hardware and Software used in this research. Section 4 and 5 present the developed learning environment and the educational methodology proposed in the form of workshops for civil engineering students and educators. In addition, section 5 includes some of the examples (mobile apps) developed for/in these events. Remarks and observations performed during the development and application of the proposal are provided at the end of the paper.

2. Review of the earlier work

In the years to come, the vast majority of processes related to industries and cities will experience an exponential growth when it comes to data-gathering. Considerably connected and networked sensors in a plethora of applications will be ubiquitous. Industrial automation and in a broader sense, automation of processes involving all societal actors lead to an overall thought of great advances in “Cyber Physical Systems” and the Internet of Things IoT [1]. Cyber Physical Systems (CPS) are the result of providing to physical components both computational and communicational capabilities. The use of CPS in industrial sectors such as manufacturing, logistics, data or city management may have a considerable economical, societal and environmental interest since these systems may generate pivotal opportunities in several fields such as energy, transportation, logistics, infrastructure and more broadly, in new generation human-environment interfaces [27]. The Architecture, Engineering and Construction (AEC) sector has traditionally used a slower gear compared to other more automated and industrialized fields when it comes to the Internet of Things and Automation. The adoption of such technologies has been rather low-paced. All key actors of AEC acknowledge the tremendous margin of improvement that exists in various fields such as sustainability, risk management, clean energy or infrastructure management. Similarly, innovation in automation is recognized as one of the greatest opportunities for growth in civil engineering [9].

The use of sensors embedded within city or rural infrastructures is in advanced ages in some fields but in its relative infancy in others. Numerous experiences of integration of physical/chemical sensors are available in water management, energy efficiency, or transportation [35]. Nonetheless, automation of construction processes or sensor embeddedness in structures is far from ubiquitous. Use of sensors within structures are limited to specific (though numerous) cases of highly controlled and rigorous experiences of Structural Health Monitoring [34]. It can be stated that the massive gathering of data coming from sensors in structures is still in its infancy.

When it comes to education in civil engineering, very few experiences in which these technologies are used can be found in the literature. In civil engineering education, courses and curricula are related to a varied array of fields such as mechanics, hydraulics, geosciences, topography or biology that are subsequently linked to highly professional subjects such as the design of structures, water supply, the foundations of buildings, transportation or water treatment. Figure 1 illustrates some of the core fields of study in which curricula are based upon.

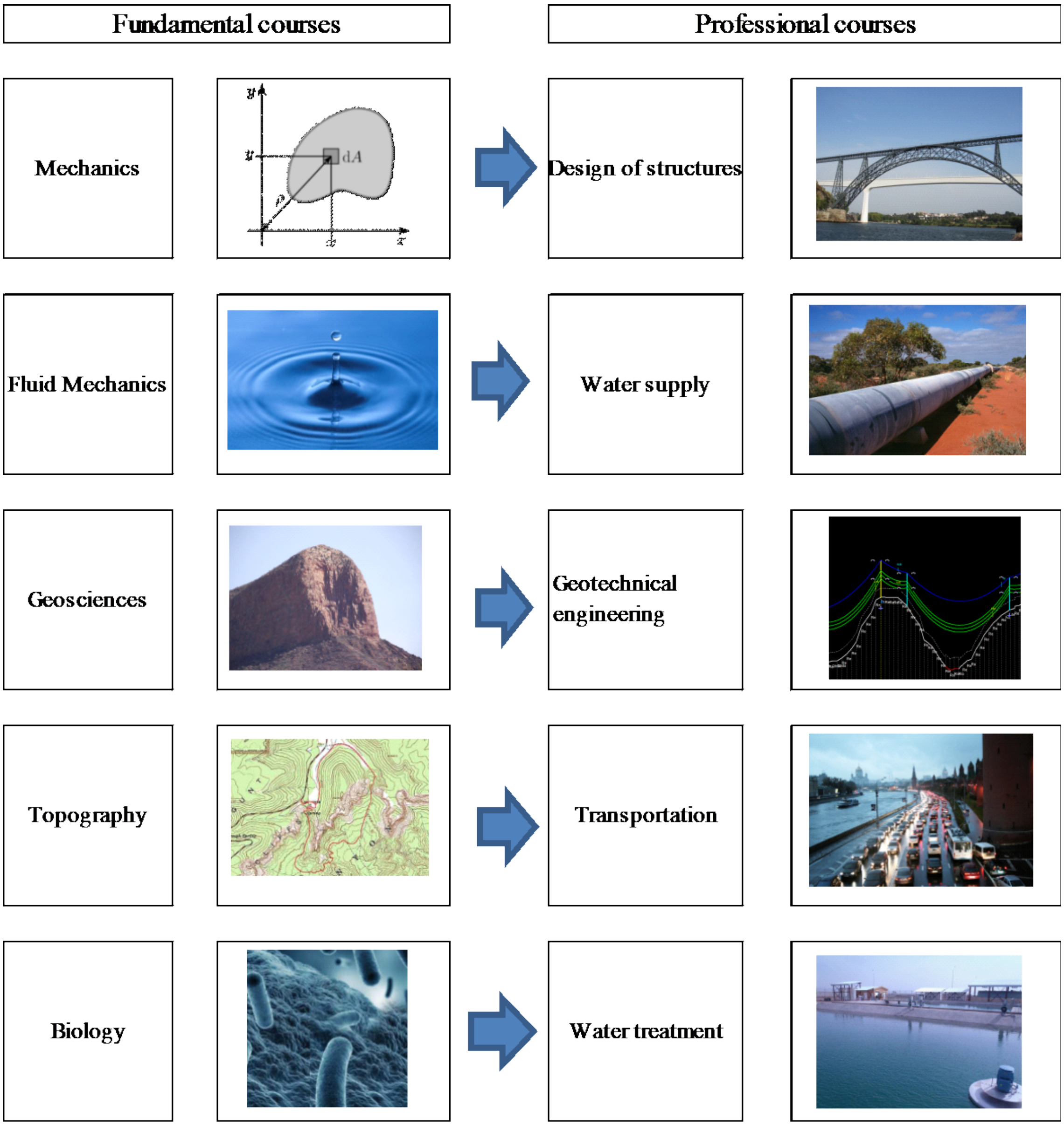


Figure 1. Some of the civil engineering core courses from the basis to the professional sector (source images [39])

One may found a considerable amount of research associated with the separated parts of the present paper, i.e., automation, civil engineering, experimental education, electronics, fabrication, coding or app-development. Multidisciplinary approaches encompassing automation, control, coding and civil engineering are available but to a considerably lesser extent. The focus of this review is on the latter level of educational research.

2.1 IoT, Construction and Civil Engineering Classrooms.

Automation in construction and infrastructure control are terms with a vast scope. Cutting -edge automation technologies developed in other industries are increasingly permeating the construction of major infrastructures at several levels (energy, transportation, sustainability, safety). Increasingly, the close links between civil engineering and the development of new digital environments in cities are bridging the gap between the Internet of Things (IoT) and Construction [4]. Nevertheless, civil engineering schools worldwide has not yet massively integrated automation in construction and infrastructure control within formal curricula.

Laboratory-based education in science and engineering is uncontested [11]. Real experiences foster cognition and provide effective skill acquisition. Likewise, educational experiences in interactive virtual laboratories are effective and may be used also in distance learning [2][24]. Hybrid learning environments which mix real complex simulations, experiments and desktop or mobile devices have been presented in mechanical [16] and aerospace engineering [14]. In civil engineering, academic examples of laboratory-based learning environments can be found in structural engineering [32] and in hydraulics [7]. Systematic use of virtual laboratories in structural engineering classrooms are also available [26][29] [33].

The particular usage and development of physical-to-digital interfaces in civil engineering and construction education is, however, less abundant. In a comprehensive attempt of bridging the physical-to-digital gap in the design of buildings using kinetic architecture, Kensek [18] proposes the use of sensors and microcontrollers for providing real-time data to BIM (Building Information Modeling) environments. The data-acquisition is performed with prototyping electronic boards and the data visualization is displayed in 3D modeling Software. Intermediate visual programming languages are needed for connecting both realms. The development of several physical-to-digital (and viceversa) links is addressed in architecture classrooms and workshops. Other experiences that are particularly worth pointing out have been developed in Taiwan by Huang et al [17]. These authors deploy a fully constructivist course for civil engineering students in which hands-on projects involving design, electronics, automation and modelling are blended together with a great success.

The development of physical-to-digital educational interfaces using Processing [38] (a sketchbook and a language for learning how to code within the context of the visual arts) and prototyping boards in structural engineering has been published recently by the authors [5]. In the context of structural dynamics, a set of physical experiments with their corresponding digital replica (pendulum, springs, frames) were developed and presented [6]. In the latter, the concept of digital twin (of great interest in the 4.0 construction industry) is addressed with civil engineering students. Other IoT-related educational papers related to health and safety training have been published [25]. Virtual and augmented reality have gained momentum in this particular field and research and development on this topic increases rapidly [21].

2.2 Mobile devices in the classroom.

Mobile devices have become a potential tool in classrooms and a subsequent set of various academic educational experiences may be gathered from the literature. Academic experiences ranging from educational approaches for implementing development and coding skills to systematic usage of mobile devices in active learning evolve rapidly [12][15][8]. In a comprehensive study developed in Taiwan, Liu and co-authors [22] developed a four-semester long course with students using mobile devices enriched with applications for scientific modeling. In this particular case, the focus was on the systematic use of the data and its corresponding scientific treatment rather than the development of the interfaces.

Likewise, among the academic studies related to coding skills and app-development, research related to the use of visual programming and learning is available. Scratch and MIT Appinventor are increasingly present in elementary and high schools curricula [26] [16] [10]. The complexity of problems that may be solved and addressed with these platforms is reduced when compared to other coding platforms. However, the visual features that provide these coding tools facilitate the development of artistic versions of the interfaces.

2.3 Fabrication and creativity in engineering education.

Another aspect that is gaining momentum in the educational sector is the use of constructivist environments for fabrication, creation and hands-on activities in the engineering classrooms. Constructivist problem-based methodologies in education are plentiful and have been studied for decades. Fabrication using 3D additive and subtractive technologies is nevertheless a rather recent alternative. When designing experiments or when designing auxiliary tools for the developments of such experiments, fabrication technologies (such as 3D printers) become powerful, affordable and accessible tools. As a result, the fabrication and "making" of the interfaces becomes a holistic project that may be performed entirely by students with creative open-source tools. In a book published some years ago, Pearce [23] debates on the endless possibilities students and educators alike may use in the development of open-source labs. These possibilities are also particularly interesting for civil engineering schools that have not benefited from the development of industrial sectors and consequently, are not equipped with adequate facilities [13]. Nowadays, the integration of digital fabrication technologies in the classroom, coupled with open-source Hardware (electronics) and Software (coding) has been considerably used using the terminology related to the Maker Movement and the Maker Education [20]. Some authors pinpoint how these technologies can be used holistically in science education [3] with a particular focus on design thinking [30].

3. Hardware and Software

The Arduino platform and MIT Appinventor were chosen as the Hardware-Software combination for the development of the educational experience due to their availability at the school, their open-source nature of both and their increasing popularity worldwide. Arduino is an open hardware-prototyping platform with capabilities for connecting analog sensors and peripherals as INPUT as well as digital sensors and actuators as INPUT/OUTPUT. Connection to computers is performed via USB (for uploading programs or providing power). Power supply can also be provided independently. Any program following the Arduino syntax can be uploaded/modified as needed. Add-in peripheral Bluetooth (BT) shields can be added easily (other more sophisticated boards have BT capabilities embedded) as well as other modules for connectivity such as WiFi module, Xbee protocols or similar. The most basic board of the Arduino platform is called UNO, with a 10Bits Analog-Digital Converter but more powerful boards (DUE, 12 Bits) are also available.

MIT Appinventor is a block-based coding platform for developing applications for Android devices. It consists of an intuitive, visual programming environment (IDE) that includes block-based functionalities. The user drags functions that enable compatible methods and variables that are connected visually. Coding within the platform is thus based on a block-based visual programming paradigm, which has gained popularity among primary and secondary schools students. As a result, some students are fairly acquainted with the platform at the moment of starting their bachelor degrees. One of the key aspects for the selection of both platforms has been the straightforward BT connectivity between Arduino and MIT Appinventor using BT shields.

4. Development of IoT civil engineering interfaces

Traditional civil engineering experiments developed in labs include the measurement of pressure, water levels, acceleration, material characterization, pressure, deflection of beams, etc. In research labs, these magnitudes are often measured with great precision by means of specialized equipment. Sophisticated user interfaces that are typically developed by the hardware providers allow gathering and visualizing information in a meaningful way. Due to the cost of Hardware and Software and to the limitation of facilities, research labs are, however, not available to the vast majority of students in the form of educational tools.

Moreover, costs and technical accessibility of electronics have decreased considerably in recent years. There is available technology that may facilitate the reproduction of traditional laboratory experiences by a greater amount of students to a reasonable extent in terms of accuracy and precision. Namely, in some courses, it may be an ideal scenario the one in which student develops IoT applications from scratch with correct use of sensors, microcontrollers and visualization.

There are, however, educational gaps related to basic electronics and programming that need to be addressed in civil engineering students before tackling the development of such applications:

- First, a vast array of sensors are available and accessible both technically and economically. Distance, light, temperature, humidity, pressure noise, or acceleration are, among others, some of the physical magnitudes that can be measured with these devices. Civil engineering students are seldom acquainted with how these devices transform the variations of physical magnitude in variations related to electricity. Thus, the behavior of analog and digital sensors need to be explained theoretically and practically.

- Second, prototyping electronic boards have become very popular devices that provide an Integrated Development Environment (IDE) for beginners. Even if these prototyping boards may not provide the same performance that professional equipment used in laboratories, the mechanics of the interfaces are quite similar. However, in general terms, civil engineering students have seldom been exposed to practical experiences involving electronics. Basic concepts of electricity and signals (such as Analog-to-Digital conversion (ADC)) need to be described beforehand.

- Third, once data from sensors is adequately gathered in computers, the information can be stored, transmitted, visualized or transformed in many forms. For this purposes, coding skills are required. Civil engineering students are generally acquainted with functional programming. However, they are less acquainted with treatment of data between devices. Basic concepts and applications on the use of communication protocols (serial port, Bluetooth, JSON, synchronicity, data types) are also needed.

Thus, it has been found that introductory courses encompassing the concepts depicted in table 1 are necessary for students with little- to no exposure to electronics:

Sensors	**Microcontrollers**	**Simple GUI**
Concepts	Concepts	Concepts
Analog sensors	ADC - DAC Converter	Data Transmission
Digital sensors	Resolution	Synchronicity
	Data loss	Data types

Table 1. Basic concepts to be covered in introductory sessions before the development of IoT apps.

From an educational perspective, IoT applications may involve endless combinations of such parts as well as a wide variety of existing Hardware and Software. Many different sensors and actuators related to a vast array of applications can be nowadays found at affordable prices. Several prototyping platforms with educational targets (or not) are emerging. These boards nowadays include different types of connection and data transmission such as the Serial port, Wifi, Bluetooth or other networks such as XBee. The form in which data can be visualized or used is also vast. Graphical user interfaces can be developed for desktop computers, for the cloud or for mobile devices.

In this paper, the development of IoT applications is chosen by encompassing the use of civil engineering, sensors, microcontrollers (the Arduino board) and mobile devices for visualization. Thus, one may standardize the different parts of one particular project:

- A given civil-engineering experiment is briefed to students (or proposed by them).
- The project involves the measurement of one- or several magnitudes with available sensors.
- Microcontrollers (the Arduino UNO board) provided with ADC provide real time data that has to be understood and thus transmitted via BT to the connectivity modules of the coding platform.
- These variables are then either stored or used graphically and visually by using the MIT Appinventor platform capabilities. Figure 2 illustrates these parts visually for better comprehension.

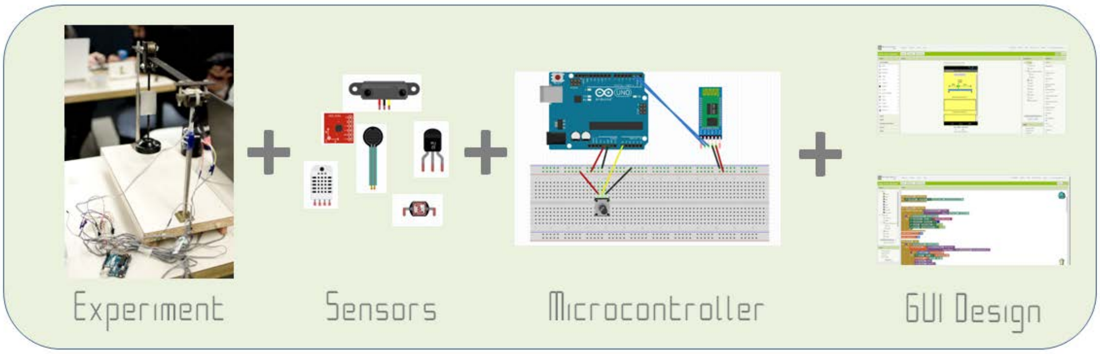


Figure 2. The flow of information from the sensor to the mobile device.

With the basic concepts depicted in table 1 and the chosen tools illustrated in figure 2, a hands-on learning environment for IoT applications in civil engineering is proposed.

5. Design of a learning environment of civil engineering IoT applications using mobile devices.

The main *objective* of the proposed learning environment is to facilitate the closure of the existing physical-to-digital gap among civil engineering students. This environment is conceived as a hands-on experience in which all students are provided with a brief, with the necessary tools and with a collaborative working space. Educators and technicians are available for help at particular pre-scheduled hours for any enquire students may have.

The educational *methodology* for the sake of achieving this objective is workshop for students at two levels:

- The fabrication level, in which participants create and develop physical-to-digital interfaces following a tutored path, a set of lectures and a briefed project.

- The analysis level, in which students develop IoT mobile applications that are subsequently assessed and tested following a collaborative peer-review.

The necessary *resources* for an adequate deployment of the environment are:

- A room provided with electricity, tables and internet connection.
- Personal computers for the students
- A fabrication starter kit including sensors, microcontrollers, servomotors, LEDs, a BT shield, cables, resistors and a protoboard.
- An Android-based mobile device with a Gmail account synchronized to the MIT Appinventor platform.

The result is a project-based, hands-on, peer-reviewed short course that is developed in two sequential parts. The methodology has been implemented with varying groups in the last two years with positive feedback from students.

In the following, a brief description of the workshop levels are presented. The present form of the educational environment comes as a result of several editions in which some aspects have been tuned iteratively.

5.1 The fabrication level.

Firstly, a sequential set of lectures and a given project are presented as the educational vehicles for achieving the first results. The lectures consists of a sequential tutorial related to the use of the platforms. The main parts of the level are: i) the Arduino platform, ii) MIT Appinventor and iii) their connectivity via BT. Table 2 shows the organization of this part of the workshop with the corresponding time proportions, the addressed concepts and the needed tools. As the starter example, in these hitherto performed editions, the workshop has included the physical and digital fabrication of an automated solar panel whose inclination is defined by the position of the sun. Other different examples of automation can be used following a similar approach as a tutored project. In this particular case, the project has been chosen as a meaningful example of civil engineering studies: the construction of clean energy infrastructure. It has been observed that the subject of the given project should be related to a civil engineering topic. These engineering problems are familiar and meaningful for these students. As a matter of fact, in other more specific courses provided by the first author (Experimental Techniques in Construction at Master Levels), students are free to choose their project provided it fits in the vast realm of civil engineering.

Arduino (40%)	MIT Appinventor (40%)	BT Connectivity (20%)
Concepts	**Concepts**	**Concepts**
The Arduino syntax How to blink a LED How to measure light with a LDR How to move a servomotor with a knob How to program automated tasks (IF-THEN)	The Canvas Drawing lines Using pictures Moving lines with a slider How to program automated tasks (IF-THEN)	The delay in Arduino. Data acquisition frequency The clock in AI. Event handlers Synchronization between Arduino and AI
Project	**Project**	**Project**
1 or 2 students	Individual submission	1 or 2 students
Fabrication of an automated solar panel whose inclination is defined by the sun position using Arduino	Development of an app in MIT Appinventor. A solar panel whose inclination reacts to a slider position	Development of an app in MIT Appinventor. A solar panel whose inclination reacts to the real measurement from sensors
PDF Tutorial | Starter Kit | Lecture	PDF Tutorial | Mobile device | Lecture	PDF Tutorial | BT shields | Lecture
Necessary tools	Necessary tools	Necessary tools
A board, LEDs, LDR, cables, breadboard, servomotor, knob and a computer	A Android mobile device a computer	A board, LDR, cables, breadboard, servomotor, BT shield, Android device and a computer

Table 2. Design of a learning enviroment. The fabrication level

Some observations related to this level are worth pointing out:

- It is worth noting that the workshop is separated in three parts. The first part correspond to an entirely automated physical object, the second part correspond to a mobile application and the third part includes both realms and BT connectivity.
- Physically, the size of project is scaled to laboratory facilities. The starter example is easy to reproduce and the sunlight is mimicked with flashlights.
- Digitally, the solar panel is drawn using MIT Appinventor capabilities and the sunlight is mimicked using a slider tool.
- In past editions, this level has been satisfactorily performed with a total duration of 10 hours (which in European standards represents 1 European Credit Transfer System ECTS).
- Groups of 1 or 2 are effective. A starter kit with electronic equipment, a computer and a mobile device with a Gmail account are needed for each group.

Figure 3 shows some images captured during the hands-on experiences at this level in different editions: circuitry, physical objects and graphical visualizations.

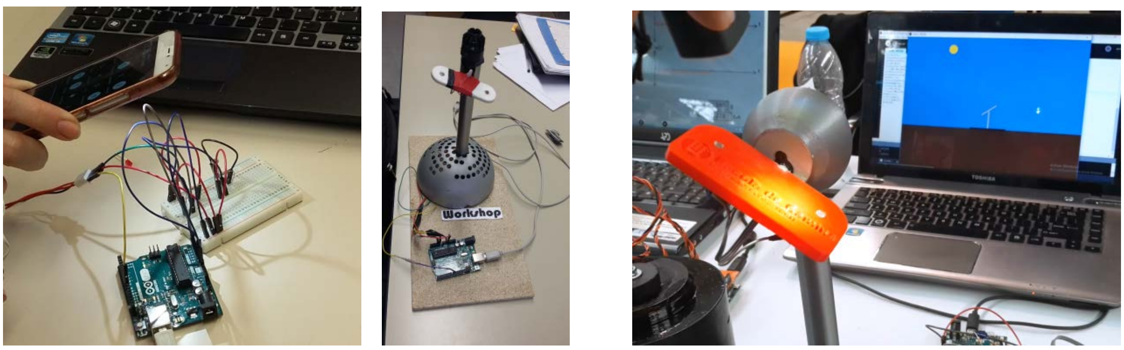


Figure 3. Hands-on connections, physical objects and simple GUIs

The development of the set of lectures is uneven since the level of electronics and programming in students is generally heterogeneous. Results are, however, similar at the end of educational experience. Practically all students are able to reproduce the briefed project. Among the encountered difficulties, one may pinpoint:

- From the perspective of electronics, students need particular guidance with the use of resistors, protoboards, LEDs and other simple components. For instance, the color code of resistors in unknown for most of them. This has been solved by printing posters with basic information that is available within the room. On the other hand, the default initial conditions of BT shields include a name that is identical among them. All BT shields need to be named differently by the users in order to avoid interferences.
- From the perspective of the graphical user interface, frequently asked questions are related to the organization of the canvas (the screen). Students are generally oblivious to the need of responsiveness of the screen and tend to provide absolute coordinates to elements such as text, figures, arrangements or sprites. MIT Appinventor allows to design mobile applications that adapt to the size of any device by defining the option “fill parent”.
- From the perspective of data transmission, one of the most discussed topics is related to data types. The measurements can be sent from Arduino to MIT Appinventor in the form of *strings* that need to be parsed or in the form of *bytes* (which stores an 8-bit unsigned number, from 0 to 255).

Some results related to the evaluation of this level have been obtained. From the students’ perspective, a simple evaluation of the methodology and the subject is performed. Students answer a single qualitative and quantitative survey in which some single questions are addressed.

The level of satisfaction of students after completion the briefed project is high. Table 3 shows average qualitative results of student satisfaction and comprehension (the course has been hitherto delivered in four editions with a total sample of 78 students). The scale is from 1 to 5 being five the highest. It is fair to point out though that these students did not belong exactly to the same cohort when performed the workshop. Some of them were at Bachelor while some others at Master level.

Answer	Satisfaction	%	Comprehension	%
1	1	1%	0	0%
2	0	0%	0	0%
3	8	10%	1	1%
4	34	44%	31	40%
5	34	44%	45	58%
Total	78	100%	78	100%

Table 3. Students’ satisfaction and comprehension after completion the fabrication level

On the other hand, from the educators’ perspective, several remarks related to the results obtained are pointed out:

- During the development of the workshops, it is observed that students present difficulties in electronics. The mechanics of analog sensors need to be explained in detail. The question of how a physical magnitude alters an electric current needs to be asked and answered by facilitators during the set of lectures. Consistently, question immediately arises during the development of the workshops.

- Likewis, the mechanics of Analog-Digital converters (ADC) are worth detailing theoretically. A key aspect of the system is the overall resolution, which partly depends on the available ADC in the used microcontroller. Consistently, questions regarding the resolution of the system as well as other linkable features such as accuracy or precision appear.

- In order to motivate groups and foster collaboration between students, it has been found that collaborative makerspaces equipped with digital fabrication technologies and open-source low-cost electronics are an interesting experimental environment for infusing progressively IoT and automation within classical subjects in civil engineering. The use of sensors, microcontrollers and block-based programming platforms represent a challenge since students have unevenly distributed traces of training in these fields. This methodology has been found also interesting for the development of the second level, which is presented in the following.

5.2 The analysis level

The second (and sequential) level of the workshop is related to the evaluation of civil engineering projects in which a scientific appraisal and a critical assessment of the components of the designed artifacts is addressed. In the development of the first level, the attendees should have measured analog magnitudes with a particular sensor. The given board should have transmitted data to the developed interface and a simple visualization is expected.

In this particular level, they are entitled to apply this methodology in the development of a personal project with a particular focus in scientific training and engineering. The project is proposed by students and few conditions are established. The limitations provided so far are:

- The project needs to be a meaningful example for civil engineering.
- The students are shown the available sensors in the laboratory facilities (if other material is desired, an approval from the educators is necessary).

Thus, students must develop a project related to civil engineering (structures, hydraulics, geotechnical engineering, transportation, water treatment). The project should include the measurement and transmission of analog signals associated with a physical magnitude such as temperature, pressure, distance, humidity, light within the frame of civil engineering. The level of sophistication of the project should be adapted to the existing laboratory facilities and may range from simple scale-reduced projects to a more elaborated laboratory-sized design.

The development of this level is conceived as follows: up to 6 hours tutored lectures and up to 14 hours autonomous work for the development of the artifact and for writing an academic report. In European standards, it represents approximately 2 ECTS. In this case, the design of the MIT Appinventor application has not particular conditions and thus it is set entirely open to creativity and exploration. Table 4 shows the organization of the workshop and the topics that encompass the educational experience. Closer inspection of table suggests that students require performing a deeper analysis of the developed application

Measurements	**Signals**	**Microprocessor**
Compare the measurements with known values	Provide a statistical assessment of the signal noise	Detect how many values per second can be measured with no loss of information
Data transmission	**Resolution and accuracy**	**Presentation**
Study how to synchronize the acquisition rate in Arduino with the refresh rate of the mobile application	Analyze which are the maximum and minimum measurable magnitudes and relate them to the maximum amount of values provided by the microcontroller	Present the artifact and write a scientific report with the scientific conclusions related to the system

Table 4. Design of a learning enviroment. The analysis level

Figure 4 shows some images related to the development of projects at this level. A civil engineering problem is proposed by students and a starter kit is provided to them. In this case, the exercise consists of visualizing in real time the deflection of a miniature truss loaded at mid-span. The deflection is measured with an ultrasound sensor whose circuitry and GUI are also shown. Generally speaking, it is observed that the nature of problems proposed by students so far is quite straightforward (linear problems whose analytical solution is well known). The results obtained are, however, remarkably meaningful for them since it generally represents the first IoT experiences during their studies.

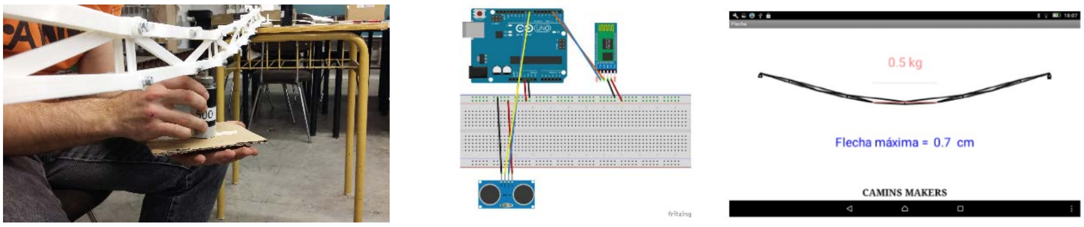


Figure 4. Deflection in 3D printed truss, circuitry and simple GUI

Some results related to the evaluation of this level have been obtained. From the students' perspective, the evaluation of this level has been hitherto done as peer-reviewed. DThe final day of the workshop (typically a 3 hours session), all students present their work to their peers. During this presentation, they ask pre-established questions one another. These questions are then answered and submitted personally by all of them to the evaluators. Typically, these questions and/or remarks include technical aspects but also, suggestions for improvements.

From the educators' perspective, it has to be said that this part of the workshop has been performed in three editions only with Master students. The results at this level and the gained educational experience suggests the following conclusions:

- Varied topics are proposed by the students. The level of realism and applicability of the proposed projects is initially uneven. Some of the proposed projects needed adaptation to the capabilities of this type of equipment (non-existing sensors or unfeasible).
- The autonomous work was difficult to achieve initially for some students and additional time for consultation has been requested.
- MIT Appinventor represents a very satisfactory platform for the fabrication level but not as satisfactory for the analysis level. Other programming languages may represent a better alternative for developing complex applications as GUI.

5.3 Examples

A set of straightforward examples with basic interfaces is presented. The chosen apps have been developed by students for the sake of illustration during the development of the learning activity. The sample shows a variety of problems that can be solved by students within some of the aforementioned civil engineering fields. Figure 5 displays simple interfaces for the cases presented in Table 4, in which key aspects of each case are depicted. The apps range several fields within the broad spectrum of civil engineering (the design of structures, water supply, geotechnical engineering, transportation and water treatment). The chosen interfaces show that values can be visualized in MIT Appinventor not only numerically but also pictorially. A brief explanation of how information flows from reality to the visualization screen is included. Some hints provided for the sake of calibrating the system rigorously are also added.

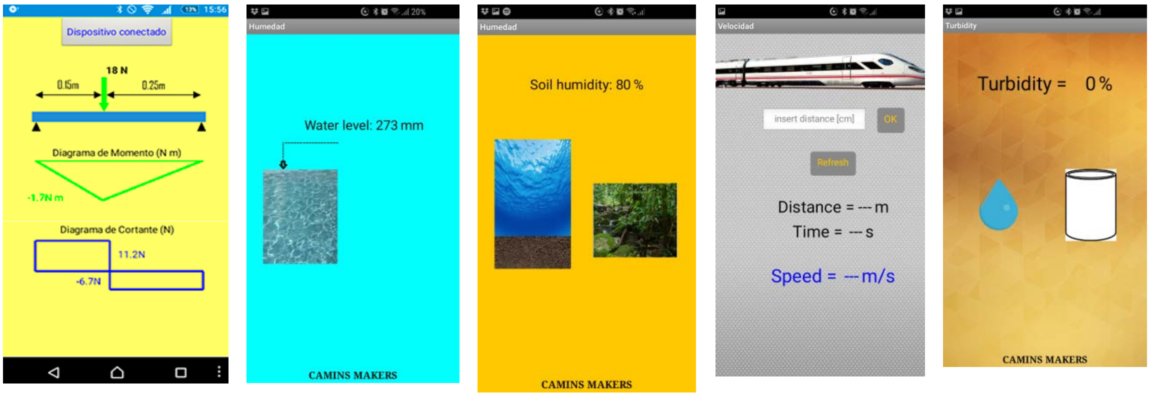


Figure 5. Examples developed for illustrating the potential of the learning experience in civil engineering.

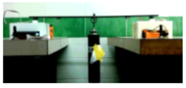
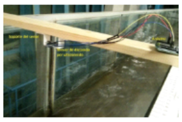
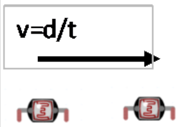
Field	Physical	Flow of information	Sensors	Calibration
Design of structures		The measured pressured value is sent to the app. Shear and bending moment diagrams are visualized in real time. The coordinates of the end point of the lines are defined by the measured pressure	Simple circular pressure sensor	The pressure sensor is calibrated with known weights. A simple correlation between the measured value and the applied weight is used as a calibration basis
Water supply		In a flow chanel, the measured distance defines the height of the water level pictured on screen. The pictures changes its size as a function of the distance	Ultrasonic distance sensor	The level can be measured with traditional devices and values can be compared. The variation of the water level may also be a source for statistical analysis
Geotechnical engineering		In several soil samples with varying humidity, a sensor is placed and values are sent to the app. The measured value alters the selection of an image (a dry soil, saturated) and the proportions between brwon and blue rectangles' size	Simple soil humidity sensor	The soil humidity sensor may be calibrated with different samples whose humidity is analyzed with traditional methods (weigh-dry-weigh method)
Transportation		Moving bodies trigger a time counter by surpassing two light-dependent sensors separated a certain known distance. Bothe the amount of bodies and their speed are shown	Indirect measurement of speed using light dependent resistors and time count	No analog magnitude is measured for calibration
Water treatment		In several water samples with varying amount of pigment, the absorbtion of light is measured. The values alters the selection of an image (cristal water, dirty water)	Indirect measurement of water turbidity using light dependent resistors	An artificial correlation between turbidity and amount of pigment can be indirectly established

Table 5. Examples developed for illustrating the potential of the learning experience in civil engineering.

6. Conclusions

The main contribution of this paper is to present a learning environment for civil engineering schools in which digital technologies related to IoT, automation and monitoring together with classical experiments in the field are blended together in a single educational experience. The learning environment consists of a constructivist hands-on short course, in which interfaces between data coming from sensors are visually displayed by Android-based applications developed by students. In this visualization, these simple yet meaningful artifacts including sensors, microcontrollers and app development are encompassed to the classical needs associated with these civil engineering problems. Several conclusions from different perspectives are pointed out:

- From the perspective of civil engineering, students and educators alike may found an interesting approach for introducing the use of sensors and microcontrollers and visualization. Automation in construction as well as infrastructure monitoring may be some of the greatest sources of innovation in civil engineering for the next decades and consequently, new professionals will need to bridge this physical-to-digital gap naturally.

- From the perspective of engineering education, students and educators alike may found an interesting approach for encompassing science, technology, engineering, arts and mathematics in one single project. App-development as well as digital fabrication technologies provide endless possibilities for fostering meaningful creations.

- From the students' perspective, in the hitherto developed editions, the level of satisfaction and comprehension of students is high. The evaluation of the educational experience by means of a peer-reviewed demonstration of the results devices has been particularly pinpointed by students as an interesting activity in which all students learn from all projects. The constructivist approach and the perception of achievement has been pinpointed by students in qualitative appraisal of the methodology.

- From the perspective of educators within the civil engineering field, it is interesting to point out that this type of learning environments may also be used in particular topics within civil engineering such as structures, water supply and treatment, geotechnical engineering, transportation, coastal engineering, etc. Specific laboratories within these schools with particular research applications may also benefit. The methodology is not limited to mobile interfaces with block-based coding but can be extended to other more sophisticated coding platforms typically found in civil engineering development.

- From the perspective of the used tools, low-cost sensors and microcontrollers are versatile technologies that can be brought to the civil engineering classroom for numerous applications. MIT Appinventor represents an interesting way for deploying straightforward connections from sensors and microcontrollers in a creative way. For more complex visualization though, other programming platforms may prove more robust.

As a final remark, it is stated that encompassing sensors, signals, statistics, physical phenomena and mathematics intertwines several engineering aspects in a single real problem. Addressing these problems scientifically by students may provide a sound environment for meaningful discovery and creation.

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