A PBL-Based Methodology for IoT Teaching

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The authors present a three-phase teaching methodology that relies on the project-based learning approach and make use of a six-layer IoT Open Reference Model that covers all aspects of an IoT solution, from sensors to the end-user interface. The proposed methodology focuses on a complete understanding of the business behind the application and on the end-user needs.

Abstract

The Internet of Things has dramatically expanded its scope of applications in the last few years, reaching all areas of human activities, from biology to technology to social sciences. In the same way, IoT applications are becoming a driving force in the economy, playing a central role in many businesses. This scenario presents challenges in the teaching and designing of IoT applications due to its inherent multidisciplinary nature, with areas of knowledge ranging from electrical and computing engineering to those related to the target application to the business itself. In this article, we present a teaching methodology that relies on the project-based learning approach and makes use of a six-layer IoT Open Reference Model that covers all aspects of an IoT solution, from sensors to the end-user interface. The proposed methodology focuses on a complete understanding of the business behind the application and on the end-user needs. Following a top-down approach, from the business to the devices required to collect the necessary information, the approach allows students to have a complete view of all components involved in any IoT application. The proposed methodology has been applied in graduate and extension courses at the University of Campinas and has proven extremely useful.

Introduction

The Internet of Things (IoT) is certainly a reality. Its applications, though, are not as widespread as predicted or even desired, but its growth potential is rather impressive. Reports indicate that billions of objects will be connected in the coming years, exchanging information and interacting with the environment in a smart way. On the other hand, the training of professionals to work with IoT remains a concern, mainly due to the multidisciplinary nature of the system itself. IoT involves diverse fields of knowledge, including computing, communications, energy, data analysis, microelectronics, and others. Additionally, IoT applications have been used to solve problems in a variety of areas, from biology to technology to human behavior sciences. In this sense, it is imperative to recognize any IoT application as part of a business plan and of a larger system, with its own rules and peculiarities. Accordingly, appropriate design of IoT solutions requires expertise in a number of different fields, limiting its widespread use.

The first step toward teaching IoT is to recognize its multidisciplinary nature. On the other hand, educational institutions face an additional challenge as follows. A quick survey of the IoT market shows an incredible number of available technologies from numerous manufacturers, each with its own attributes and, most of the time, tailored to a rather particular application. The multitude of products and technologies makes the teaching process intricate, because if any particular system is adopted in an IoT course, its scope becomes limited. Ideally, training courses should prepare professionals to develop solutions regardless of the technology employed.

This article presents an IoT teaching methodology using project-based learning (PBL) in connection with a three-phase cycle:
- *Understanding the Business*
- *Requirements Definition*
- *Implementation*

This teaching methodology, named the three-phase methodology (TPM), focuses on the IoT design process and aims at addressing the issues, as pointed out above, concerning the intrinsic complexity of an IoT solution and the need for a manufacturer-independent design approach. As discussed in the following sections, a detailed understanding of the business behind the intended IoT solution is an essential part of the design process proposed in the TPM. Also, the TPM makes use of an open source reference model for IoT applications, which is manufacturer-independent and can model any IoT application through six layers, from the things that monitor the environment (i.e., sensors) to the interface to the end user.

The remainder of the article is organized as follows. We briefly review the concepts of PBL and IoT. We present the structure of TPM and its key concepts.The three phases of TPM are thoroughly described. We present some details on the application of the proposed teaching methodology in graduate courses at the University of Campinas, Brazil. Finally, we conclude the article.

Basic Concepts of PBL and IoT

In this section, we review the basic concepts of the PBL methodology and discuss some intrinsic characteristics of the IoT field that motivate the development of the learning process presented in this work.

Project-Based Learning

PBL is an active teaching methodology that motivates students to gain knowledge and skills by

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solving real-world problems [1]. The principles of the PBL methodology are based on the concept of learning by doing, an idea first outlined by John Dewey in his book *My Pedagogical Creed* [2], published in 1897. Roughly speaking, PBL integrates know-how and practice, with emphasis on the development of critical thinking and problem-solving skills. Accordingly, the learning process is guided by the problems presented to students, who are led to solve problems autonomously. In this sense, the role of the instructor in this process becomes fundamentally that of an advisor [3].

PBL works across subjects, involving competencies and skills from several areas. This particular characteristic is one of the main reasons for its choice to be employed for teaching IoT.

Another feature of PBL that justifies its choice is the fact that this methodology encourages students to develop self-learning skills. This is a highly desirable craft when working with fast-changing technologies, such as computing, wireless communications, and data processing.

In its standard format, PBL follows seven steps [1]:

- Nomenclature: Words, expressions, technical terms, and concepts related to the problem with which students are not acquainted must be identified and explained.
- Problem definition: A list of challenges to be addressed while solving the problem must be created.
- Brain storm: A discussion using students' previous knowledge and background is carried out, aimed at finding a solution to the problem at hand.
- Summary: The main takeaways from the previous discussion are listed, recalling the problems and hypotheses identified and the contributions based on previous knowledge, with a list of pros and cons.
- Formulation of learning objectives: Based on students' previous knowledge, a list of obscure points is created, that is, topics that must be studied in more detail.
- Search for information: The sources of the knowledge needed to solve the problem are found.
- Reporting, discussion, and solution: All the pieces of information gathered to solve the problem are integrated.

It should be mentioned that PBL in IoT teaching as presented in this work makes use of its very basic principles, so not all of the steps listed above apply. The primary attribute borrowed from the traditional PBL methodology is the use of the problem definition as the starting point of the project development. In this sense, the seven steps are replaced by three phases. The details of the proposed teaching methodology are presented later.

(Readers interested in more information about teaching experiments based on PBL and active teaching methodologies in the context of IoT are referred to [4, 5].)

Internet of Things: Challenges and Issues

IoT technologies allow things or devices to act intelligently and collaboratively [6]. In the IoT context, things no longer make decisions individually, but they do actively and ubiquitously communicate and collaborate in order to carry out critical decisions [4]. An IoT technology, along with cyber-systems, cloud computing, and machine learning, forms the basis for the so-called "Industry 4.0" [6].

Despite the remarkable advances that have been made in recent years, IoT still faces many challenges to become a widespread technology. One of these challenges relates to the lack of standards for the design and implementation of IoT applications, combined with the multitude of technologies and products from numerous manufacturers. This scenario creates barriers to its widespread dissemination, particularly in small to medium-sized enterprises. A typical business in this market does not have the necessary financial resources to acquire the solutions offered by larger IoT manufacturers, and often lacks personnel with the specialized knowledge required to create alternative IoT solutions at lower costs.

As already mentioned, another critical issue in this scenario concerns the training of professionals. Several IoT solutions are offered, each one focusing on a particular application and with distinct features. This variety of products hinders the training of professionals since no methodology allows for the use of these solutions within a standardized and systematic context.

This scenario has motivated the development of the teaching methodology proposed in this article and presented in the following section.

PBL for IoT Teaching: The Three-Phase Methodology

The teaching of IoT has attracted a great deal of attention in the last few years due to the peculiarities and multidisciplinary nature of the systems involved [4, 5, 7]. The TPM proposed here differs from other methodologies found in the literature. This methodology is based on a technology-independent open source IoT reference model. With TPM, students are provoked to question and propose ideas about a chosen project. Instead of using the classical approach of PBL, TPM follows well-defined steps as a guide to design, specify, and implement IoT solutions in general. These three steps are:

1. *Understanding the Business*
2. *Requirements Definition*
3. *Implementation*

TPM is based on the premise that there is always a well-defined problem to be addressed by an IoT solution. The reasons for a company to seek a solution based on IoT include adding value to a product, improving an existing process, and offering a new service, among others. Therefore, the understanding of the business related to the problem to be solved may provide important guidelines when designing an IoT solution. The process of *Understanding the Business* is the first phase of the TPM methodology and aims to collect the customer needs and expectations. This step must precede any technological choice.

In this sense, the role of the specialist emerges in the process. The specialist is a professional with knowledge of the business who is responsible for providing the designers with detailed

The reasons for a company to seek a solution based on IoT include adding value to a product, improving an existing process, and offering a new service, among others. Therefore, the understanding of the business related to the problem to be solved may provide important guidelines when designing an IoT solution.

The business rules are premises and restrictions applied to the operation of any business. Therefore, these rules should be taken into account throughout the solution development process. The business rules can be determined by analyzing the target scenario in which the IoT solution will be employed. It may also be necessary to study regulatory issues related to the respective activity.

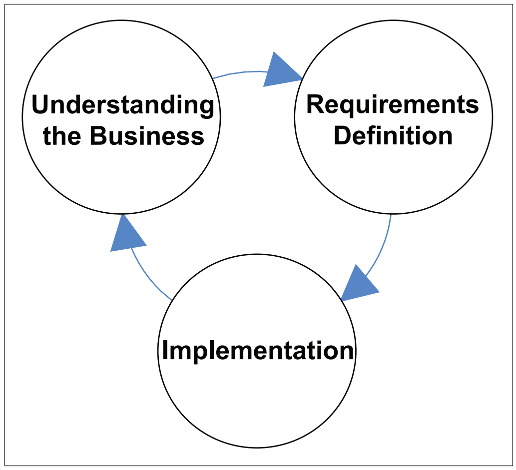

Figure 1. The three-phase methodology.

information about the problem to be solved. For instance, if the business is in the area of agriculture, a professional in this field is required to yield theoretical and practical support for the choices to be made in the development of the IoT solution. This specialist may be someone from the company itself or somebody else hired for this purpose.

After the connection between business and things is understood, the requirements for the solution can be defined, based on the objectives established in the previous phase. This process is carried out in the *Requirements Definition* phase when the components of the IoT system are defined as well, although no technology choice is made yet.

The last phase in TPM is the *Implementation* phase, when the technologies that best meet the specifications defined in the previous steps are investigated and the solution is implemented.

These three phases are iterative and incremental (Fig. 1), such that during the solution lifespan, the three steps can be repeated to meet new business demands or to correct failures.

In the following sections, the three phases of TPM are described in the context of the teaching process.

Understanding the Business: Phase 1

The Business

The purpose of TPM is to connect the business to things through IoT, using business rules and specialized knowledge, as illustrated in Fig. 2.

As discussed in the previous section, the details of the business associated with the IoT application in mind may provide the guidelines of the project by identifying priorities, operational conditions, and the type and format of the information to be provided to the customer by the IoT application.

At this stage, students are presented to the problem to be solved, when they are encouraged to raise questions about it and are expected to understand the demands from the IoT application. This stage comprises the main PBL characteristic borrowed by TPM since students are supposed to build knowledge from the problem presentation down to the solution specification.

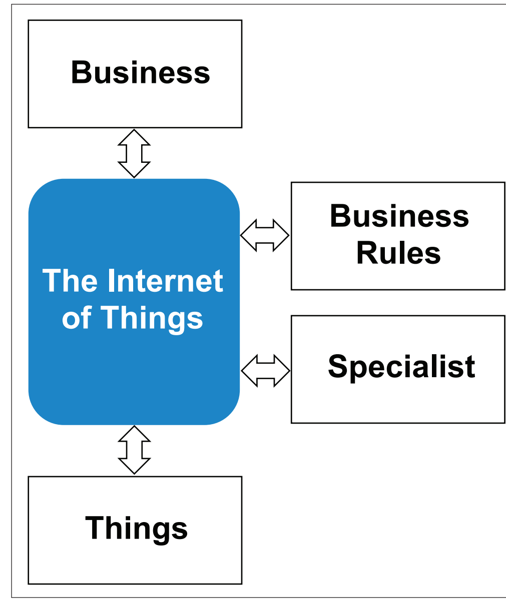

Figure 2. The business-thing connections.

The type of business behind the IoT application varies from project to project, even when dealing with projects in the same area of activity, as each project may have its peculiarities. Therefore, the business phase is of paramount importance. If not well delineated, the final solution may not satisfy the end user.

The Things

Things are entities needed to achieve the purposes of the business. These things can be physical entities, such as temperature, humidity, and luminosity, or electronic devices (e.g., relays and cameras). In this step of the methodology, students are supposed to define the type of things to be employed in the IoT solution, and this definition will guide the processes of specification and implementation of the sensors/actuators to be used in the project.

The Specialist

As already mentioned, the proposed teaching methodology requires the involvement of specialized personnel, who will provide information to support the decision making processes found in different phases of the methodology. This professional can be someone directly connected to the business or explicitly hired for that end.

The Business Rules

The business rules are premises and restrictions applied to the operation of any business. Therefore, these rules should be taken into account throughout the solution development process. The business rules can be determined by analyzing the target scenario in which the IoT solution will be employed. It may also be necessary to study regulatory issues related to the respective activity.

In the process of learning about the business rules, the following issues must be considered:
- The relevance of the IoT solution in the business process and the respective added value
- The execution flow (inputs, processing, and expected outputs)

The development of an IoT solution begins with a clear understanding of the business rules, which should be consistent with the needs of the company.

Requirements Definition: Phase 2

During the Requirements Definition phase, students are encouraged to discuss the problem, aiming to define the requirements of the IoT solution, and document the corresponding specifications of the system to be implemented. TPM deals with the design of solutions that connect the business to the things. It is based on a top-down approach, starting at the business level and flowing down all levels, as far as the one where sensors and actuators (things) are located. This top-down approach is based on a six-level *IoT Open Reference Model* proposed in [8], shown in Fig. 3.

Accordingly, the discussion carried out in this phase leads to the definition of the tasks to be performed at each level of the Reference Model. It should be noted that this discussion does not involve any technology choice, but only how the solution in mind should work. The use of a PBL-based methodology motivates students to come up with new ideas and to develop skills to work in a team environment, essential for professionals in any field nowadays.

In the following section, we present a brief description of each level of the IoT Open Reference Model as shown in Fig. 3.

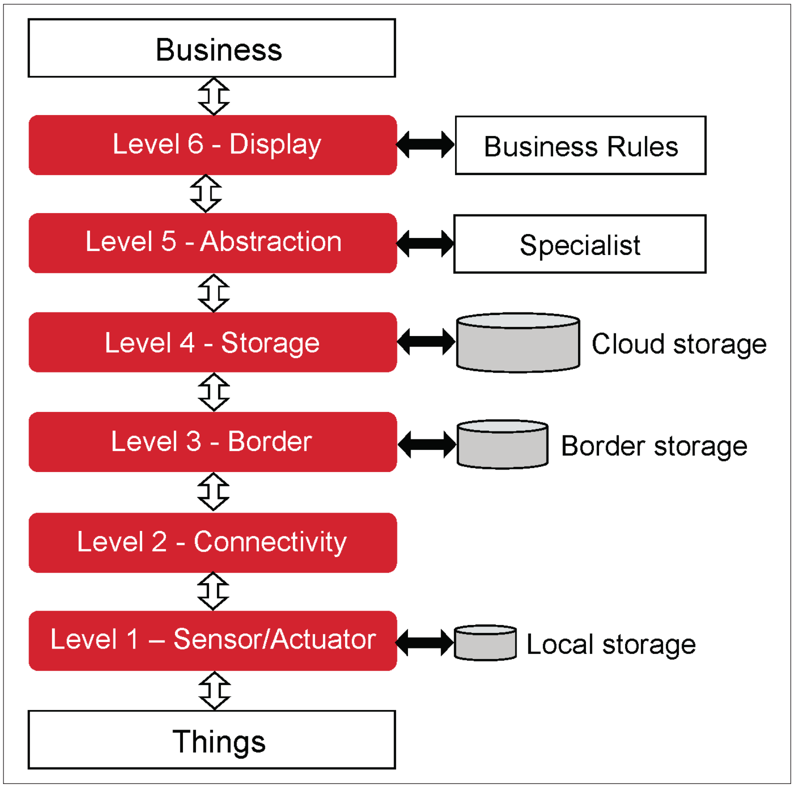

Figure 3. The IoT Open Reference Model.

Level 6: Display

The Display level covers the way information is to be depicted to assist the end user in the decision making process. This information can be presented, for example, through charts, graphs, and numbers. Emergency and other actions necessary for the business are signaled and dealt with at this level.

Level 5: Abstraction

At the Abstraction level, the stored data is used to transform information into knowledge. It is at this level that a specialist's expertise is required. Students, with the assistance of the specialist, analyze the scenario and propose an appropriate way to accomplish the abstraction from the available information. Students can make use of techniques including artificial intelligence, data mining, and machine learning, among others.

Level 4: Storage

The Storage level defines how the collected data is to be stored. The storage can be in the cloud, in the client's system, or in both. The decision regarding data storage depends on issues such as the required level of availability and security and the amount of data. At this point, students are prompted to discuss issues related to redundancy, data security, and storage location. These issues may require special attention if the IoT application in mind involves a large amount of data.

Level 3: Border

This Border level defines the characteristics of the element that connects the IoT solution to the Internet, the so-called *border element*. This element operates on both the IoT local network and the Internet, providing the connection between these two worlds. Therefore, the border element must always be present in the system. Also, this element may be required to perform network functions using more advanced strategies, including software-defined networking and network function virtualization. In this sense, it should be emphasized to students that the Border level embraces items related to the network infrastructure of the IoT solution, which may account for a large portion of the operational cost. Students are expected to specify the border element, taking into account issues such as processing capacity, storage, baud rate, and costs.

Level 2: Connectivity

This Connectivity level deals with the connection between things and the border element. This connection may be provided through wireless or wired links or by a hybrid solution. Wireless technology is typically employed in the IoT context, mainly when a large number of sensors/actuators are distributed over a large area. However, the decision about the type of technology to be employed must take into account several other issues, including costs, things to be monitored/controlled, operating environment, required capacity, and reliability of the transmission system, among others. Students should discuss all these issues in light of the project needs and requirements in order to define the technology to be adopted.

Level 1: Sensor Node/Actuator

The Sensor Node/Actuator level concerns the devices responsible for collecting data or acting upon the environment. At this point, students decide on sensors or actuators to be be used, based on the type of data to be collected or on

Figure 4. The open source IoT development kit used to illustrate the presentation of the implementation phase.

the action to be taken. Typically, the raw data collected by sensors must be processed to extract useful information or to remove redundancy. Several data processing strategies can be employed, including:
- Local processing, to reduce the amount of data transmitted
- Cloud computing, for resource-intensive applications
- Fog computing, for resource-intensive applications with stringent latency requirements

The first strategy is implemented at this Level 1, whereas the last two are typically performed at the border element or beyond. Another important issue to be discussed and decided regards the degree of autonomy of the devices. For instance, the devices can be configurable by entities located at other levels in order to adjust their operation according to decisions made at these levels. Alternatively, devices can operate autonomously, when their operation does not depend on the decisions made at other levels.

The discussion carried out within each level should lead to a document describing the requirements and specifications of all devices and entities of the system, which will guide the implementation phase, discussed next.

Implementation: Phase 3

Once the system specification phase is concluded, the technological choices are made and the implementation begins. Students start by assessing the technological options available in the market and choosing the ones that best fit the specification established in the previous phase.

A bottom-up approach is used in the implementation phase, since it is first necessary to define how things are monitored/controlled and how that information reaches the business, following the specifications defined on the previous phase. Thus, the implementation starts at Level 1 (sensor/actuator), through the higher levels, until it reaches the business. The Implementation phase then follows the opposite direction to the Requirements phase.

In the next sections, we revisit all six levels of the IoT Open Reference Model, now from the perspective of the Implementation phase.

For better understanding of the Implementation phase, we illustrate the implementation process using an open source IoT development kit specially designed and built by some of the authors for teaching purposes. This development kit, shown in Fig. 4 and presented in detail in the next sections, follows the IoT Reference Model discussed earlier and has been employed in graduate and extension courses offered at the University of Campinas, Brazil.

Level 1: Sensor Node/Actuator

The development kit contains two local nodes, a sinking node, and a mini-computer equipped with a screen, a mouse, and a keyboard.

The local nodes employ the DK107 development board [9], along with a communication module, denoted BE900, which is implemented using an ATMEL ATmega328 microcontroller and a Texas Instruments CC1101 RF transceiver.

Students are instructed on how to use the development kit through practical experiments. In addition, they are motivated to survey products available in the market that can be used as local nodes. Arduino is an option that has become attractive, offering, for example, the Arduino IoT Cloud [10], which is a set of tools for creating IoT applications. Intel has an Arduino-based solution, called Arduino Create [11], which enables simplified prototyping of commercial applications based on Intel architecture. Sigfox has a set of sensors, called the IoT Sensor, which is prepared for transmission to the cloud through the Sigfox network [12]. By analyzing these products from the point of view of the Reference Model, students can easily identify where and how to use them within an IoT solution.

Many products offer an IoT service, but most of them work only at some levels of the Reference Model, leaving the other levels to be implemented using other technologies. Providing students with skills to evaluate the IoT products found in the market, from the perspective of the Reference Model, is a paramount target of the teaching methodology proposed here, as these skills help them spot the most suitable technology for the project at hand.

Level 2: Connectivity

The open source IoT development kit uses the CC1101 transceiver with the Radiuino communication protocol [9].

Students may run several experiments using this transceiver in order to have a better understanding of the mechanisms and techniques involved in wireless communications, such as antenna gains, propagation environment, modulation format, and transmission bit rate, and their effects on the system performance. The instructor should guide students through these experiments and point out the main takeaways of each one.

Students should also be introduced to alternative solutions for connectivity in the context of IoT available in the market, such as LoRa, Sigfox, Bluetooth, WiFi, and LTE.

Level 3: Border

The open source IoT kit employs a Raspberry Pi computer loaded with a Linux-based operating system, with scripts written in Python to automate processes, and Zabbix [13] for data management

Questions					Yes	No
Did you have any previous experience with IoT?					35%	65%
When proposing the initial project, did you miss a methodology to follow?					70%	30%
Did you already know any methodology for teaching/developing IoT solutions?					0%	100%
Has the course achieved its goal?					97%	3%
Assessment – Please Rank	**1**	**2**	**3**	**4**	**5**	
The ease of understanding the methodology	0%	0%	5%	30%	65%	
The effectiveness of the methodology in helping design your project	0%	0%	5%	40%	55%	
The level of difficulty in applying the methodology	5%	20%	20%	30%	25%	
The effectiveness of the methodology in helping understand IoT	0%	0%	5%	35%	60%	
Your willingness to use this methodology again in future work	0%	0%	15%	15%	70%	
The usefulness of the teaching resources (practical experiments, IoT development kit)	0%	0%	7%	23%	70%	

Table 1. Questionnaire applied to students.

A number of projects were proposed in several areas of applications, including environment audible noise monitoring, solar energy monitoring, energy consumption in households, restaurant queue length monitoring, etc. The proposed methodology has then been successfully applied to all projects and all of them were fully functional at the end of the course.

and storage. Students are instructed on how this edge element works by running tests and trying different configurations. Students should also discuss the protocols used to connect the IoT network to the Internet, such as MQTT, CoAP, REST, and web sockets. These protocols are responsible for communicating with the TCP/IP protocol stack.

Students should survey alternative combinations of hardware and software that can play the role of the edge element. The Arduino platform, for example, has made available the Arduino Pro Gateway for Lora solution, which plays the role of an edge element with transmission support using Lora. The use of Raspberry Pi for this function has been well documented in the literature, as there is a wide range of possibilities for operating systems and communication interfaces.

Level 4: Storage

At this level, Zabbix is used again, now along with a MySQL database. Students must test different configurations, including local storage, cloud storage, and a hybrid solution. As already mentioned, issues such as cost, data volume, redundancy, and required level of security must be taken into account when designing the storage system.

There are several options for storage in the cloud, such as Tago [14] and ThingSpeak [15], which offer online platforms for managing and storing data. A possible alternative is the use of a storage server with a conventional database management system, such as MySQL, Oracle, and Time Series Data Bases.

Level 5: Abstraction

At Level 5, students experiment with data abstraction by extracting useful information from the raw data collected by sensors. In the open source IoT development kit, Zabbix combined with the Grafana plugin is used for the abstraction. The Tago and ThingSpeak platforms offer this functionality as well. There is also the possibility of using other programming languages for more specialized data processing, such as Phyton, Matlab, R, and Scilab. Students can also try other data treatment strategies, such as artificial intelligence, machine learning, and data mining.

Level 6: Display

Zabbix is once again used, now to display the information extracted from data through charts and tables. As mentioned before, different strategies for displaying the information can be used, including alarms and graphs showing the correlation among different data.

Application of the Methodology

The TPM approach has been applied in graduate (60 hours) and extension (32 hours) courses offered at the School of Electrical and Computer Engineering and the Institute of Computing, both at the University of Campinas. Students enrolled in these courses were divided into groups and asked to propose and implement IoT applications following the TPM strategy. Instructors with expertise in sensors, wireless communications, and network management introduced key topics in their fields and were available during classes to guide the discussions proposed in the strategy. Students were also encouraged to seek assistance from professionals working in the field of the concerned IoT project, who would play the role of the specialist as foreseen in the strategy. A number of projects were proposed in several areas of applications, including environment audible noise monitoring, solar energy monitoring, energy consumption in households, restaurant queue length monitoring, and so on. The proposed methodology was then successfully applied to all projects, and all of them were fully functional at the end of the course.

Students were then asked to respond to a questionnaire designed to assess the effectiveness of the TPM approach and to evaluate the students' experience when applying the methodology and the use of the development kit. The main questions and a summary of the outcomes are presented in Table 1. (Around 60 students responded to the questionnaire.)

In Table 1, 1 and 5 correspond to lowest and highest scores, respectively. As can be seen in the upper and lower part of the table, the great majority of the audience had had no contact

In order to support the application of the proposed teaching methodology, an open source IoT development kit was created, which has also been tested in these courses. The proposal is promising as it employs non-proprietary solutions that meet the various levels of the Reference Model and can be a standard for the teaching of IoT.

whatsoever with the IoT subject. The results show that the use of the methodology greatly facilitated the accomplishment of the course target, which was to have the IoT applications fully functional at the end of the course. In fact, this is also attested by the students themselves who nearly unanimously approved of the use of the methodology as well as the use of the proposed development kit. Another important remark extracted from the table is that the students showed their willingness to use the proposed methodology in their future work.

Even though no formal survey among instructors was carried out, it was a common understanding among them that the TPM strategy offers students a more structured and systematic approach to implement an IoT solution, based on a broader view of the context within which the IoT solution is to be inserted. This broader view was shown to be very beneficial during the process of selecting technological solutions. Instructors also noticed that the proposed methodology encouraged students to take part in class discussions, which had a direct impact on the quality of their final reports. The fact that the methodology splits the project design into three distinct phases directly leads to this full and thorough class engagement since each phase demands its own considerations and discussions.

As a follow-up to the courses, the students have been motivated to proceed with a view toward entrepreneurship having their projects as flagship products.

Conclusion

This article presents a PBL-based methodology for IoT teaching following a three-phase methodology for IoT design. This design methodology relies on three well-established phases, namely Understanding the Business, Requirements Definition, and Implementation. The IoT Open Source Reference Model was used to guide the proposal.

The proposed methodology has been applied in graduate and extension courses at the University of Campinas, and a survey carried out among attendees showed the effectiveness of the methodology. We do recognize that this is just a preliminary assessment, but hints that it is a promising methodology. Of course, only thorough and further application of it and by different players will attest to the effectiveness of the proposed methodology.

In order to support the application of the proposed teaching methodology, an open source IoT development kit was created, which has also been tested in these courses. The proposal is promising as it employs non-proprietary solutions that meet the various levels of the Reference Model and can be a standard for the teaching of IoT.

Future work will focus on the development of a software framework to be used together with the IoT kit to assist in the development of TPM.

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