Analysis and Discussion of Recent Initiatives on Teaching Internet of Things Concepts

Luiz Carlos B. C. Ferreira, Pedro R. Chaves, Raphael M. Assumpção, Omar C. Branquinho, Fabiano Fruett e Paulo Cardieri

***Abstract*— The teaching of IoT has brought about new challenges due to its inherent multidisciplinary nature. Also, this training must consider the particularities of wireless communications, as it is essential to guarantee communication in any IoT solution. In this article, we present and discuss part of the recent work on IoT teaching carried out by a team of researchers from the School of Electrical and Computer Engineering at the University of Campinas, Brazil. The group has been active since 2017 and its effort resulted in training projects, extension and postgraduate courses, and articles published.**

***Keywords*— Education, Teaching, IoT, Internet, TpM, Distance Learning.**

I. INTRODUCTION

Recent reports indicate that billions of objects are going to be online in the coming years, smartly interacting with its surroundings [1][2]. IoT Analytics [3], a German company specialised in IoT market information and business intelligence, reported in its March 2022 edition that companies' expenditure on IoT grew 22.4% in 2021 to US$158 billion. The company forecasts the market value for IoT, including software, hardware, security, and services to grow to US$525 billion by 2027.

However, according to the report *Why IoT Projects Fail* [4], a survey showed that the higher level of knowledge in design and architecture required in the development of IoT projects was a major hindrance. This survey was conducted with 250 companies distributed across 42 countries. The report also stated that often the definition of the business associated to the IoT project, its objectives, and expected returns are not taken into account, contributing to the failure of IoT projects. The report concludes that focusing the solution only on technology is a mistake.

Also, according to Jha [5], "80% of IoT projects fail before they are rolled out". The author adds that companies are developing solutions first and then searching for the problems for them to solve.

These facts are forcing educational institutions around the world to modernise and offer training consistent with the challenges of our times. In Brazil, federal law No. 9394, from 1996, established the bases and guidelines for a more flexible and innovative educational model, the National Curriculum Guidelines (DCN) [6]. Also, the National Workgroup for the Strengthening of Engineering, created in 2016, now also dedicated to science, technology, engineering, the arts, and mathematics (STEAM), has contributed to the publication of the new DCN for Undergraduate Engineering Courses, in force since in 2019. These guidelines emphasise competence development, project-based learning, and better communication with society. The DCN proposed that engineering courses should be based on practical and active learning experiences, in a process in which the students are fundamental agents. The DCN also endeavour to modernise the assessment process from a generic evaluation process to a continuous, diversified one, in tune with academic activities, based on competencies. This assessment process should reinforce what has been learnt while promoting feedback from teachers [6].

Furthermore, the National Internet of Things Plan [7], from June 2019, encourages the development of programs, methodologies, and tools for the teaching of IoT. The plan is an initiative of the Ministry of Science, Technology, and Innovation and the Brazilian National Development Bank, and aims to improve the quality of life and promote efficiency and productivity gains through IoT. The plan's objective is to implement and develop IoT in the country and integrate it into the international IoT scenario.

The projects, courses, and articles presented in this paper follow the DCN and are aligned with the main objectives laid down in the National Internet of Things Plan. These constitute part of the original work on IoT and science teaching carried out by researchers, graduate and undergraduate students from the Departament of Semiconductors, Instruments and Photonics, and the Department of Communications of the School of Electrical and Computer Engineering at the University of Campinas (UNICAMP), Brazil.

The main contributions of this paper are:

• A literature review of some recent teaching initiatives on science and IoT at FEEC;

• An analysis and discussion regarding these works' main contributions.

The rest of this article is organised as follows: Section II brings some recent original research carried out at FEEC, while the discussions are presented in Section III. The article ends with the conclusions in Section IV.

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II. Research Initiatives

Since 2017, there has been a concentrated effort by some researchers at FEEC to develop teaching initiatives that follow the DCN and adhere to the National Internet of Things Plan, oriented to academics and industry professionals. This effort resulted in two teaching projects:

A. The Project School 4.0

This project aimed to offer training to elementary and secondary school teachers in the use of accessible technologies. The objective was to allow teachers to explore and develop multidisciplinary skills with their students. To that end, there was a 60-hour, distance learning course entitled "Development of Maker Activities to Support the Teaching of Science, Technology, Engineering, Arts and Mathematics (STEAM) at Elementary and Secondary Schools"(FEE217). During the course, students used solely open-source software and hardware solutions developed to this end, which they were encouraged to modify, improve and create new components. This course was geared to use recycled materials including electronic scrap. There have been three editions of the FEE217 so far. The success of this initiative has led to the publication of an article entitled "A Contribution to the Training of Elementary and Secondary Education Teachers in the Development of Maker Activities Using STEAM", presented in the next subsection. The FEE217 is currently being reworked as a Massive Open Online Course (MOOC) to be offered at the Coursera platform. More information can be found at https://www.escola4pontozero.com.br.

B. The Project IoT Workshop School

The use of traditional teaching strategies, presenting content and then carrying out experiments, proved inadequate for IoT teaching. IoT solutions are multidisciplinary, which differs from the traditional ways that generally favour technologies. The IoT Workshop School follows a structured methodology along four axes, so to ease the understanding and development of IoT projects:

Conceptual – Theoretical and practical framework for the preparation and presentation of contents, with special attention to the learning process. This axis is subdivided into three parts: the Three-Phase Methodology for IoT, a Project-Based Learning (PBL) [8] based project, and planning and assessment.

Organisational – Structure how the contents are to be organised and how they are to be taught. The IoT Workshop School is organised into intermediate, professional, undergraduate, and graduate levels; courses and subjects; and workshops. In terms of disciplines, it follows a classic way of identifying themes and contents. However, the workshops follow a new structure, in which content and experiments are mixed.

Modalities – Identifies how the content is to be offered. Courses are offered through one or more disciplines, with each discipline comprising workshops. This is an important point, as the workshops employ PBL and Bloom's taxonomy [8] in their preparation. The strategy always seeks to involve the students in what is being treated. Courses can be on-site, distance, and blended learning.

Materials – Apparatus needed to support teaching and learning strategies. There are different materials, including customised kits. During the workshops, students have access to an IoT Platform. More information can be found at http://www.iotm3f.cc.

Building upon the expertise gained with these projects, three extension and postgraduate courses were created:

1) Fundamentals and Workshops on the Implementation of IoT Applications in Smart Cities (FEE215): this 24-hour, on-site extension course aimed to introduce students to theoretical and practical aspects of IoT applications, using the IoT Open Source Reference Model (IoT-OSRM). The objective was to present students to different technologies used in applications. The experimental part of the course used an open-source platform (software, firmware, hardware) for the project development. The codes were made available, allowing the students to develop their own IoT projects. During the classes, the following topics were addressed: collection and processing of data through sensors; wireless communication techniques, including signal propagation, antennas, media access control, routing, architecture, and network; management and connection to the Internet and provision of data in the cloud, with storage, abstraction and display, and business aspects. In the final part of the course, the students developed group IoT projects.
2) Introduction to Wireless Data Networks (INF505): the objective of this 24-hour, on-site extension course was to present the basic concepts of wireless networks and the main technologies that implement them. It provided the basis to design wireless networks while conceptually approaching the physical and MAC layers. The INF505 was also covered the analyse of antennas systems and propagation conditions in different environments. During the course, students carried out a link budget (power balance) for a network, considering antenna, modes of communication, transmission power, and sensitivity. The approach starts with the analysis of operating conditions and then the presentation of main over-the-air interfaces available on the market, covering the necessary concepts for the design of this type of network. The students also carried out experiments with laboratory networks and simulations.
3) IoT Fundamentals and Workshop - A Practical Approach Using the Flipped Classroom (IE309X): the objective of this 60-hour, remote postgraduate course was to promote the understanding of the principles governing wireless connectivity applied to IoT solutions, as well as its management and security, enabling participants to design and implement wireless connectivity in order to meet different IoT needs. The classes followed flipped classroom concepts for interaction, discussion, and knowledge sharing. The course sought to enable the students to: (i) Employ the IoT Reference Model to identify the parts that make up an IoT application; (ii) Discuss the nature of transducers and signal condi-

tioning for IoT applications; (iii) Learn how to choose antennas and understand the conversion of guided into non-guided signals and vice versa; (iv) Discuss some data transmission techniques, among the many used in wireless networks applied to IoT; (v) Characterise signals using statistical concepts; (vi) Understand the phenomena inherent to the propagation of signals; (vii) Evaluate wireless network management concepts; (viii) Design and prototype wireless solutions applied to IoT. The IE309X proposal was of a course where participants had the opportunity to run experiments to validate concepts. To that end, the Network Environment Workbench, presented in the next subsection, was made available. The study material for each meeting was made available the week before, giving students a week to familiarise with the content.

The successful outcome of these courses led to the publication of one master degree dissertation and six articles in international scientific magazines:

1) A Proposal of an Open Source Reference Model for the IoT [9] - This master dissertation, published in December 2018, presents the six-layered Open Source Reference Model for IoT (IoT-OSRM) applications development. The main focus was to create an architecture using only open source solutions, bench-marked by the reference model. The IoT-OSRM served the needs of small and medium-sized enterprises, as these, often, do not have the resources to invest in the costly solutions offered by large developers. Several paradigms about the adoption of IoT solutions were analysed, including the claim that IoT solutions are just plug and play. The work sought to combat this assumption, while at the same time, aimed to demonstrate that to succeed in the development of a platform, it is necessary to understand that IoT solutions need management since no solution is perennial, infallible, or foolproof. The IoT-OSRM was evaluated and tested in case studies. The results demonstrated the feasibility of the model in the implementation of IoT solutions in different scenarios.
2) A PBL-Based Methodology for IoT Teaching [10] - This article was published in IEEE Communications Magazine, in November 2019 and presents the Three-Phase Methodology (TpM), an IoT teaching methodology that relies on the Project-Based Learning (PBL) approach, and uses the IoT-OSRM to cover all aspects of IoT solutions, from sensors to end-user interfaces. The methodology focuses on the complete understanding of the business behind the application and on the end-user needs. Following a top-down requisite gathering approach, and a bottom-up specification phase, the TpM allows students to have a thorough view of all components involved in any IoT application. The TpM has been applied in graduate and extension courses at the University of Campinas and has proven extremely useful.
3) A Remote Emulation Environment for the Teaching of Low-Power Wireless Communications [11] - This article from February 2021 presents the Network Environment Workbench (NEWBen). The NEWBen is a remote, low-cost, open-source network emulation environment capable of reproducing the behaviour of non-guided, low-power links under different configurations. The NEWBen can be of great interest to education institutions, specially in poorer counties, as it can be replicated for around US$280,00. The emulation environment incorporates inductive approaches in the experimentation with wireless connectivity while following a consolidated project methodology. The environment was offered at the IE309X postgraduate course in 2020 and 2021. An end-of-course survey with the students indicated that the environment contributed positively to the comprehension of the principles governing the over-the-air connectivity. The evidence suggests that this remote environment is a useful tool for academic investigations of the particularities of low-power wireless channels.
4) The Integrated Digital Learning Environment for IoT [12][13] - This article, published in September 2021, presents the development of the Integrated Digital Learning Environment (IDLE-IoT), for distance teaching of IoT, based on the TpM and Bloom's Taxonomy. The IDLE-IoT offers an integrated hardware platform in which students can implement their IoT projects. Hence, the IDLE-IoT platform allows the thorough use of the TpM, access to an array of innovative IoT teaching techniques, and an environment where the creation and sharing of projects can be guided by TpM, i.e., a single environment for learning and project sharing.
5) A Contribution to the Training of Elementary and Secondary Education Teachers in the Development of Maker Activities Using STEAM [14]: training teachers to use digital technologies in the teaching environment has been an important task in the Brazilian education scenario since the introduction of the computer on education. It is important to prepare teachers to innovate and introduce new challenges in the teaching process. This article, from 2021, presents a systematic and structured approach to the training of elementary and secondary school teachers in the use of maker tools to assist in pedagogical practices, thus improving the teaching and learning process. The three basic premises are: low cost of implementation, no specialised technical knowledge required, and customised remote support offered. In addition, the article discusses the past three editions of the FEE217 course, presenting some preliminary results on both teachers´ training and in the interdisciplinary development of curricular content.
6) The Three-Phase Methodology for IoT Project Development [15] - This article, still under revision by the magazine, presents the Three-Phase Methodology for Project Development (TpM-Pro), originally developed as an IoT teaching methodology that proved ideal for solution development. It is a generic, agile, interactive, technology-independent, and incremental methodology that splits the development of solutions into three distinct phases: Business, Requirements, and Implementa-

tion. This segmentation has proved invaluable and can become a standard for IoT solution development. In this paper, the TpM-Pro is gauged against five other methodologies proposed for IoT solution development. The article also details a case study when the TpM-Pro was used on a corporate IoT project.

7) Advancing Engineering Education: Using the Three-Phase Methodology to Teach IoT [16] - This article, already accepted by a magazine to be published, presents a new learning approach that uses the TpM and the Flipped Classroom approach in a postgraduate course in IoT (IE309X) where students are introduced to the concepts required to design, build, and test IoT solutions. To evaluate the effectiveness of the proposal, the results of an earlier edition of the course (2019), when the learning approach was not used, are compered to two more recent ones (2020 and 2021) when it was. The same syllabus and rubrics were used in all three editions of the course. The final group projects' grades and satisfaction surveys were used to evaluate the students' performance and motivation. Findings indicate that the 2020 and 2021 classes performed better than the 2019´s, as their final group projects grades were considerably higher, indicating that the approach has an impact on the development of students' transversal skills.

III. Discussions

Several schemes have recently been put forward to tackle the deficiencies found in our teaching programmes at all levels. Studies, like the one from [17] concluded that STEAM education still lacks a clear conceptual framework with broad consensus within the scientific-educational community. Initiatives like the training of elementary and secondary school teachers to use digital technologies in teaching can be a game-changer for an entire generation. This can make the use of technology commonplace among our teachers, preparing the next generation of professionals that will develop the IoT solutions that we will increasingly be dependent on.

However, the IoT is a multidisciplinary and comprehensive area that involves concepts, techniques, technologies, and approaches from several areas of engineering. In addition, an IoT solution can be useful in any area of knowledge. Figure 1 presents an infographic that shows the variety of themes related to IoT.

The main difficulty often encountered in IoT teaching projects was the integration of these concepts, techniques, technologies, and approaches. We observed that, often, IoT courses offer content in isolation, without a direct relationship between them, consequently, failing to show how each discipline fits within the IoT concept. Another challenging aspect is that the professionals who will work in IoT have a variety of specialities, including computer and data scientists, electrical, mechanical, telecommunications, and computer engineers. This heterogeneous aspect of IoT professionals also influences the way IoT is taught.

Thus, we noticed the necessity of a way to structure IoT solutions in a systematic way, so that it is possible to link the

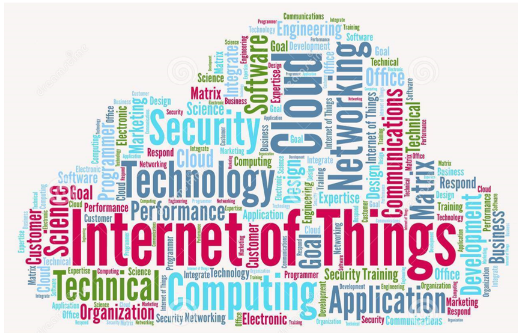

Fig. 1. Infographic.

necessary know-how for the development of applications and, consequently, consolidate the understanding of IoT.

The first move towards this goal was the work of [9], describing the creation of the IoT-OSRM for IoT solutions. The model has six levels, where each one is responsible for a specific function/component of the IoT application.

Any IoT solution can be divided into these six levels, regardless of the complexity of the solution. In this way, the OSRM is useful for structuring IoT solutions, linking the know-how by level.

Another concern regarding the IoT teaching process was how to present the specific contents of each level of the OSRM model in an integrated way, related to the IoT concept.

The answer was to resort to active teaching methodologies, such as PBL. The new DNCs for engineering and technology courses suggest using these approaches. However, PBL is a generic methodology applicable to a variety of scenarios. So, a specific methodology for teaching IoT could be an important contribution.

Therefore, the TpM was created in 2019. A methodology based on PBL but created specifically for IoT teaching. It incorporates the OSRM reference model but also includes an important feature, the need to define the problem/business to be addressed by the IoT solution. Figure 2 presents the TpM diagram.

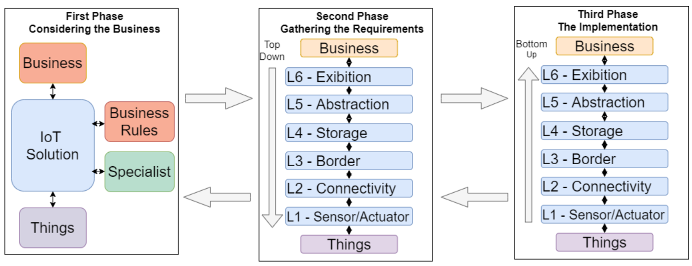

Fig. 2. The Three-Phase Methodology diagram encompassing the 6-level IoT-OSRM (adapted from [10])

The TpM was successful in treating IoT as a tool to achieve a goal, not just a technology. This approach proved to be efficient, as students understood what IoT offers to solve a problem. It is only after this understanding is consolidated that the technologies for implementation are discussed.

The areas involved in the creation of IoT applications are already consolidated and in full development by industry and academia. There was a need for a way to organise and systematise the role of these areas within the IoT concept. The TpM was a proposal that addresses this issue.

With the TpM, IoT courses can be offered with a focus on a certain area, emphasising specific contents, without neglecting the importance of other areas and other contents.

A practical example of this statement is the work of [11], where an emulation environment for teaching low-power wireless communications for IoT, the NEWBen, is presented. The author uses the TpM to contextualise the importance of this area in IoT, making it clear where wireless connectivity is in an application. In this work, there is an effort to offer students and educational institutions around the world, a low-cost alternative for wireless experimentation that can be replicated locally.

Also, to assist in the teaching process, a project development tool was developed using the TpM [13]. This system was improved and became a complete Virtual Learning Environment (VLE) based on the TpM, the Integrated Digital Learning Environment (IDLE-IoT) [12].

The TpM has been tested in courses for the last 3 years, in extension and postgraduate courses, with more than 100 students. The work of [16] for example, analyses three editions of the postgraduate course IE309X at FEEC. The work shows that the approach encourages active participation in the activities and facilitates the retention of the concepts studied.

Thus, considering the experiences presented in this paper, we offer some observations that can contribute to further research and guide new initiatives in the area of IoT teaching:

• We must prepare our students from the elementary years, allowing interaction with technologies an concepts. This should increase their interest in the areas of technology and engineering.

• For that, elementary and secondary school teachers must also be prepared. Methodologies, such as the TpM, can help in this process, as they deal with the subjects in a more conceptual way, focusing on the project/problem. This is a friendly approach to get into more complex topics.

• The IoT requires different skill sets to pull together, however, sometimes this can be difficult to coordinate. The methodologies and tools presented in this paper can help in this integration process. In addition, they can serve as inspiration for new proposals.

• We believe that the IoT will only fully develop when all these aspects have been considered.

IV. Conclusion

"The difficulty lies not so much in developing new ideas as in escaping from old ones"[18]. This sentence resumes what we encountered when proposing new ways to do something. It is clear that we need to investigate new ways to transfer knowledge, more in line with the new possibilities offered by new technologies. We hope that the initiatives presented in this paper contribute to changing the perceptions of science and IoT teaching. We believe that further research should concentrate on providing our education professionals with the tools to prepare our students to face the challenges the 21st century has to throw at them.

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