Learning Emergent Digital Technologies: The Experience in the Internet of Things Course Unit

Paulo Leitão*†, Luis Piardi*, Lucas Sakurada*, and André Mendes*†
* Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politécnico de Bragança,
Campus de Santa Apolónia, 5300-253 Bragança, Portugal,
Email: {pleitao, piardi, lsakurada, a.chaves}@ipb.pt
† Laboratório Associado para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC),
Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal

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***Abstract*—Industry 4.0 is re-shaping the way companies and individuals operate, but it is also introducing strong demands in education processes to train professionals with adequate competencies in emergent digital technologies, e.g., Internet of Things (IoT), Artificial Intelligence and collaborative robotics. In the last decade, innovative educational methods are being applied, e.g., problem-based learning and project-based learning, to move the traditional education approach into a more student-centric process where the student has a more active role. Recent studies point out that the combination of such educational methods is beneficial, each one selected according to the particularities of the learning subject and objective. Having this in mind, this paper describes the application of a learning methodology that combines different educational methods, namely face-to-face, problem-based learning and project-based learning, in a teaching course unit focusing on IoT technologies. The achieved results show an increase of the student's assessment performance, motivation and satisfaction, and the opportunity to consolidate their acquired knowledge with hands-on practice. This approach also stimulates the acquisition of soft skills, mainly teamwork, communication, creativity and critical thinking.**

***Index Terms*—Education, Internet of Things, Industry 4.0.**

I. Introduction

The digital transformation associated with the 4th Industrial Revolution is reshaping the way as companies and individuals operate, based on the digitalization of processes, machines and products. This paradigm is strongly based on innovative concepts like Cyber-physical Systems (CPS) and Digital Twins, and emergent digital technologies, e.g., Internet of Things (IoT), Artificial Intelligence, Big data and Collaborative Robotics. These technological trends are also changing the labor market as sustained by several reports, e.g., the Mckinsey Global Institute predicts that 75 to 375 million people worldwide can change their job category by 2030 due to the new job market scenario, and 8-9% of the 2.66 billion workers will have new jobs by 2030 [1]. This means that the adoption of these digital technologies is affecting the job profiles and skills required by the workforce, promoting the need for training programs better suited to upskilling [2], [3].

In this context, there is a need to consider innovative educational practices that promote the effective training of professionals to work in the Industry 4.0 (I4.0) environment, facing the requirements imposed by the society and market, i.e. professionals with technical skills in digital technologies and personal skills that will enable to develop and maintain such systems. A pertinent challenge is related to the design and implementation of learning programs that allow to training young students and active professionals in such emerging digital technologies, and particularly the selection of the best educational methodology to train these professionals to acquire the required technical and personal skills.

Several educational methods are being adopted, ranging from face-to-face, which is teacher-centered, to problem-based and project-based learning methods that are student-centered approaches, where the student has a more active role in the learning process [4]. These student-centered methods are being implemented individually, and in spite of being pointed out as the panacea to address the challenges of education, it is noticed that usually, they do not completely solve the learning needs. In fact, the selection of the educational method is dependent on the learning topics, the class typology and size, and the students' culture, heterogeneity and background. This means that combing educational methods in a harmonious way and according to the particularities of the learning demands will be beneficial and allow to cover the different learning needs to achieve the pre-defined learning outcomes.

Having this in mind, this paper describes the application of a learning methodology that combines different educational methods, namely face-to-face, problem-based learning and project-based learning, in the teaching of the "Internet of Things" course unit that is part of the bachelor of Informatics Engineering. The achieved results, in terms of the student's attendance, their feedback at the end of the semester and the performed assessment, clearly show that this integrated approach strongly contributes to improve the quality of the learning process, with students playing a central role in this process, and having the opportunity to consolidate and practice hands-on at their particular rhythm. This approach also stimulates the acquisition of transversal (soft) skills, mainly teamwork, communication, creativity and critical thinking.

The remaining of this paper is organized as follows. Section II discusses the related work and Section III describes the implementation of the proposed integrated educational methodology in the learning of IoT topics. Section IV analyses the achieved results, and finally, Section V rounds up the paper with the conclusions and future work.

II. Related Work

Over the years, educational methods evolved to adapt to the learning needs, particularly moving from a teacher-centric approach where the student has a passive role to student-centric approaches where the student has an active role in the learning process. This is complemented by the growing demand for the acquisition of hands-on competencies on practical issues that are usually addressed by implementing "learning by doing" methods.

The traditional teaching approach is the face-to-face method, where the teacher defines what and how contents will be learned, usually applied to expose and explain the theoretical topics or to provide an overall picture of a particular topic in the form of short presentations. In this method, the student has a passive role and is faced with the challenge of expanding the knowledge beyond the teachers' exposition, in addition to the difficulty of assimilating the content presented with practical problems. In another perspective, a multidisciplinary knowledge, solid academic background and hand-on practice are essential competences for some professionals. However, the balance between theory and practice is not usually ideal, with the time devoted to cover the theory subjects being longer than the time spent on laboratory practices.

With the Bologna process, the objective was to shift the teaching paradigm towards competency and outcome-based principles, where the student has a more active role in the learning process. Several educational approaches follow the learner-centred approach, e.g., project-based learning [5] problem-based learning [6] and research-based learning [7] methodologies, where students actively participate in the learning process by discussing and solving problems and questions, and working in teams.

In the problem-based learning, students use problem scenarios to define their own learning objectives, and increase knowledge and understanding of certain subjects. They subsequently perform the independent, self-directed study before presenting and discussing in the classroom, and later refining their acquired knowledge. The process is clearly defined, and the various variations follow a series of similar steps [8], which are characterized to introduce problems to students to activate their prior knowledge and motivate them to learn new things to solve the addressed problems. Usually, the complexity level of these problems increases with the student's maturity and feedback. When analyzing the problem, students generate hypotheses about possible solutions, and then, based on the hypothesis, they guide the studies to solve the problem. This procedure results in the capacity for abstraction, reflection, and self-search for knowledge to assess the applicability of hypotheses [9]. An example of this methodology is its application to software engineering students [10].

In contrast to the traditional education, project-based learning may be an indispensable way for students to acquire practical engineering knowledge and experience [5], [8], being enabled to improve their ability to think, analyze and solve problems [11]. This method organizes the learning process around the development of projects that involve the application of the acquired knowledge topics to develop the solution for a problem and will result in the creation of a final product. In this approach, students work in multi-disciplinary teams for a considerable period of time. An example of this learning approach is its adoption to teach autonomous driving in robotics [12], aiming to provide students with an opportunity to solve complex engineering problems in team work and to transfer the acquired theoretical knowledge in real-world practical problems.

The research-based learning method introduces the students to the research methodology, not only exposing students through the entire research process on the basis of developed research questions but also incorporating the research results, methods and processes into the learning process. As example, this approach was adopted by undergraduate engineering students to develop research skills in strategic exploration, e.g., search information in reliable data sources, design the sketch of research work and present the results to a jury [13].

The gaps between the expectations of industry and society and the competencies of graduates will be always a problem, since companies need students with the appropriate competencies to solve their specific problems, but universities should train students to acquire generic engineering topics and not to the specific company's problems. An effective culture of lifelong learning is crucial to ensure that everyone has the knowledge, skills and competencies they need to thrive in their professional lives and improve employability [14]. Thus, the concept of micro-credentials appears as a mechanism to warrant the results of short-term learning experiences, e.g., a short course or training. In addition to offer a clear, objective and flexible pathway in assisting the student who seeks to obtain the knowledge, skills and competencies, they need for their own development, especially at a professional level. This concept emerged in response to the demand for more flexible and learner-centered ways of learning and retraining, and has been spreading rapidly across the world. As a counted advantage, micro-credentials allow to reach a wider range of learners, including vulnerable groups, providing education and training opportunities for all. However, without common rules to ensure their quality, transparency, cross-border comparability, recognition and portability, micro-credentials cannot reach all their potential.

In spite of the potential benefits of each educational method, and particularly considering that project-based learning and problem-based learning methodologies are being pointed out, in the last decade, as good practices to address the challenges of improving the learning quality, the problems still exist and the discussion remains around the need to have innovative learning methods that properly provide efficiently the required competences to the students. This mean that these approaches have partially failed due to the inappropriate implementation and probably because their individual implementation can not solve the imposed challenges on learning demands. This problem becomes even most challenging when learning emergent digital technologies associated to I4.0 due to its multidisciplinary and interdisciplinary.

In this context, a proper solution is to consider the aggregation of different educational methods, as proposed by [4], which introduces the T-CHAT educational framework that considers 5 pedagogical methods, namely face-to-face teaching, perceptional learning, project-based learning, problem-based learning and research-based learning, to teach CPS topics.

III. Application of the Proposed Integrated Learning Methodology

Following the recent trends, a learning methodology that combine different educational methodologies was applied, during 2 years, in the teaching course unit "Internet of Things" that is part of the curricular plan of the Bachelor on Informatics Engineering. The adopted learning methodology considers three educational methods, namely the face-to-face learning, the problem-based learning and the project-based learning, as core of the learning process, as illustrated in Fig. 1. These methods are combined and articulated aiming to address the specific learning demands for this technological field, as well as to put the student in the center of the educational project, playing an active learning role. These three educational methods are complemented with an assessment methodology that ensures the continuous feedback on the students' learning progress, and allow the teacher and the student to adjust the rhythm and the way the learning plan is executed.

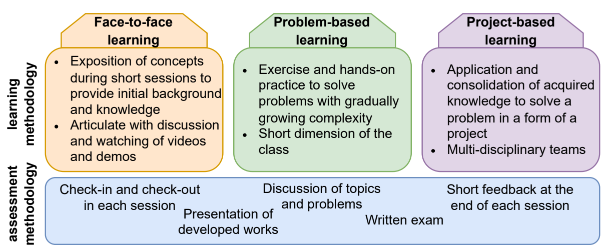

Fig. 1: Methodology integrating several learning methods.

This section provides details on the application of the learning and assessment methodology to the IoT course unit.

A. Characterization, Typology and Learning Outcomes

The objective of this course unit is to provide the students with the knowledge and hands-on practice on developing IoT applications. For this purpose, the expected learning outcomes (LO) at the end of the course unit are the following:

- LO1: Know the importance and role of IoT technologies in the context of the digital transformation.
- LO2: Know communication technologies for IoT.
- LO3: Use communication protocols for IoT.
- LO4: Develop applications using IoT platforms, e.g., Node-RED (https://nodered.org/).
- LO5: Know the problems associated to the security of IoT devices and platforms, and mechanisms to mitigate them.
- LO6: Understand and implement simple IoT integration scenarios using external services (e.g., RESTful APIs).
- LO7: Develop small IoT solutions to solve real problems.
- LO8: Develop transversal (soft) skills, namely team work, communication, creativity and critical thinking.

As pre-requisites, it is expected that the student be able to have basic knowledge of informatics and programming.

The course unit comprises four hours per week during a semester of 15 weeks, totalizing 60 presential hours (contact between the student and the teacher). These 4 hours per week are splitted in two sessions, the first one addressing theoretical-practical activities for the entire class, i.e. an audience of 80 students (average), and the second one addressing laboratorial activities. Aiming to reduce the dimension of the audience in each laboratorial session, five alternative shifts were considered, each one for an average of 16 students.

Following the Bologna principle, 102 non-presential hours are considered in the learning plan of the course unit, devoted to the personal study, the development of problems and projects aiming to consolidate the learned concepts.

B. Face-to-Face Learning Method

The face-to-face learning method is mainly used in theoretical-practical sessions to provide an initial background knowledge on the theoretical concepts, and an overall picture of a particular topic. Each session is devoted to one topic of the course unit and is organized in a way that the student can make a check-in procedure at the beginning of the session and a check-out at the end of the session, expressing respectively its expectation for the learning session and the feedback on the achieved accomplishments during the learning session, allowing to self-assess and monitor the learning progress.

For this purpose, and aiming to have a student-centered approach, the session starts with a short exposition and explanation, approximately 20 minutes, of the learning topics and concepts, complemented with the watching of videos and demonstrations that illustrate and provide more (technical) details on the exposed concepts. Note that video is usually more engaging than text materials and help students to retain the acquired concepts for longer time.

At this moment, students have the necessary background concepts and are ready for further stages in the learning process, particularly the discussion of the proposed topics and the realization of practical exercises, playing a more active role in the learning process, and stimulating the motivation to learn new concepts. As example, one session was devoted to learn IoT communication protocols, being initially presented the background concepts with a short presentation, complemented with videos that illustrate these concepts. During the discussion phase, students study and discuss the application of IoT protocols in different scenarios, e.g., to monitor health parameters of a patient, to monitor environmental parameters in a natural park or to monitor energy and operational parameters of a stamping machine in a factory plant.

In this context, the use of the flipped classroom approach [15] is particularly interesting and applied, with students learning new concepts pre-class by consuming instructional material at home, primarily through text and video materials provided by the teacher, complemented with other materials available to the student. In the class, students check their understanding on the studied topics by performing several class activities. In the case of the "Internet of Things" course unit, several sessions were implemented using the flipped classroom method, e.g., for the learning of the security issues. In this case, a brief introduction was initially provided, and the students studied the provided materials pre-class related to one security thread, e.g., Denial of Service (DoS), Man-in-the-Middle, Bots, and Malware. At the class, each group of students presented its point of view and a discuss arises to ensure the correct understanding of the learned concepts.

Finally, included in the face-to-face learning method, it was explored the use of field visits that allowed the students to leave the classroom and be exposed to the learned concepts in another perspective: seeing real applications using the concepts and technologies they are learning. In this case, students went to the CeDRI research center (Research Centre in Digitalization and Intelligent Robotics), where they were able to see and discuss with researchers and PhD students that are developing IoT applications for several application sectors.

C. Problem-based Learning Method

Problem-based learning was applied to teach the fundamental practical concepts of IoT and consolidate the previously acquired theoretical knowledge, being based on the principles of multidisciplinary team work, learning by solving problems, be exposed to IoT environments, and deploying the new knowledge in real applications. This approach was used in the first ten weeks of laboratory activities, divided into six sequential worksheets to construct knowledge and lead students to problem-solving. Table I summarizes the list of six worksheets that were provided as problems to the students.

TABLE I: List of problem-based worksheets.

#	Problem	Objective	Goals
1	MQTT protocol	Use of MQTT protocol to exchange messages between IoT devices	LO2, LO3
2	Computational platforms for IoT	Data digitization and communication via MQTT programmed with ESP8266 / ESP32 devices	LO3, LO4, LO8
3	Data manipulation and storage	Use of InfluxDB 2.0 to store and manipulate time series data	LO4, LO8
4	Data visualization	Develop user friendly data visualization and graphs with Grafana	LO4, LO8
5	Device integration in IoT	Integrate external API's in developed IoT solutions with RESTful	LO6, LO8
6	Security in IoT	Encrypt data, messages and certificates in data visualization platforms	LO5, LO8

The first four worksheets constitute the fundamental basis for learning IoT concepts, with two practical classes being dedicated to each topic (i.e., two weeks each, summing eight weeks in total). Therefore, at the beginning of each worksheet, the problem was introduced, and the students should work in group to find alternative solutions to be implemented. This study can be performed extra-class, e.g., by using forums and developer communities. For example, in worksheet 2, different IDEs, libraries, and code structures were found to program ESP8266 and ESP32 devices to monitor the classroom's temperature and humidity parameters and transmit this data via Message Queuing Telemetry Transport (MQTT). In the second week of each topic, the laboratory classes were used to complete the work and understand the approaches and solutions' strengths and weaknesses. For example, to face the problem addressed in the worksheet 4 that is related to the remote monitoring and visualization of temperature and humidity parameters, the student's solutions were based on the knowledge acquired in worksheets 1, 2, and 3 adopting the MQTT communication protocol, the IoT device programming, and the data manipulation and storage. In this context, the students digitized the temperature with the IoT device and the DHT22 sensor, and created a dashboard in the Grafana platform as a web application, as illustrated in Fig. 2, remotely accessible to monitor the environment conditions, and perform a statistical analysis over the last 24 hours.

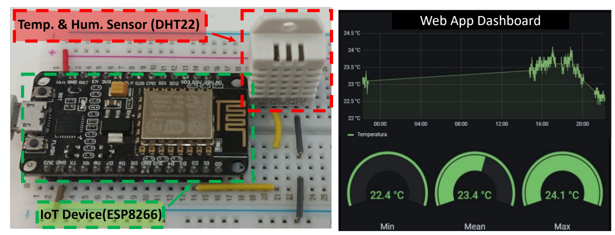

Fig. 2: Students' solutions with IoT device for worksheet 4.

The worksheets 5 and 6 were carried out in the last two weeks of the time period devoted to the problem-based learning. The worksheet 5 challenged students to integrate external applications that provide data related to e.g., environment, weather forecast, air quality, water quality, background noise and ambient radiation, through the use of the RESTful API. The worksheet 6 handles security problems in IoT applications, providing students with hands-on expertise with end-to-end encryption of communication contents when using MQTT.

The eight learning defined outcomes were addressed by using the problem-based learning approach in practical classes, enhancing the acquired learning with real applications.

D. Project-based Learning Method

Experimentation plays a significant role in understanding the learning concepts. Teaching in engineering, for instance, is always challenging as the theoretical study should be augmented with experiments and practical works, allowing students to get a feel of the real-life applications related to concepts they study [16]. In this way, a project-based learning approach was used in the last 5 weeks of the practical classes, where students, organized as groups, faced the development of a short project to improve their understanding of the subjects covered in the theoretical-practical classes. Table II summarizes a short list of projects that were proposed to the students, contributing to reach all defined learning outcomes but particularly LO7 and LO8.

TABLE II: Exemplary list of short projects.

#	Project	Objective
1	Internet of medical things	Develop a system to remotely monitor the patients' vital signals, using a patient app and a hospital's physicians and assistants dashboard
2	Smart parking	Develop a system for monitoring free parking spaces, using a driver app and a parking dashboard
3	Farm to fork strategy	Develop a system to monitor the traceability along the farm to fork chain, including primary production, transport and final consumer
4	Building automation	Develop a system to control the light, temperature and air quality of a room by using actuation on blinds and air conditioning system
5	Irrigation management system	Develop a system to monitor the temperature and humidity of the air and soil, to control the water irrigation of a crop
6	Transportation management	Develop a system to request the transport of products by forklifts trucks through a client-side app, and a forklift driver dashboard
7	Audio chat	Develop an encrypted two-way voice chat between two users

As example, considering the project #7 from Table II, students have created an encrypted voice chat between two users via the Node-RED embedded dashboard and, additionally, the messages were converted to text and sent via Telegram. This solution, shortly illustrated in Fig. 3, allows to select and listen the last 10 exchanged audios by using each user's interface. This project challenged students to capture audio from the computer's built-in microphone, process the data to transform it into text to send on telegram and be able to reproduce messages between users.

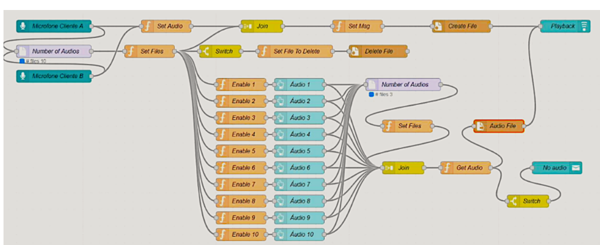

Fig. 3: Example of student development for audio-chat project.

E. Assessment Methodology

The assessment methodology is important to evaluate the acquired competencies, but particularly it should be used as a tool to guide the learning process, providing feedback on the student's learning progress. It is desirable that the assessment should be performed on a regular basis allowing teachers to get feedback to adjust the learning plan, and students to be actively engaged in their learning process (and allowing them to implement strategies to maximize their own progress).

In the case study course unit, several methods were used and combined, using different weights, to evaluate the student's progress and performance, being the primary objective to implement a continuous learning assessment of the students during the semester. In the theoretical-practical sessions, the participation in the several learning activities performed in the various sessions, and particularly the thematic discussions were particularly valuable. Additionally, at the end of several sessions, short assessments using the Kahoot! game-based learning platform (https://kahoot.com) [17] were performed, aiming to review the students' knowledge and increase engagement, motivation, and concentration of students to improve their learning performance and the classroom dynamics.

The technical quality of the developed practical works and projects was also evaluated, as well as the presentation elaborated by the students, on their developed solutions, to the class audience. In this context, the soft skills gained by the students, namely teamwork, communication (oral and written) and creativity, were also evaluated.

Finally, a written exam, including theoretical and practical questions, was performed aiming to assess the individual performance of each student, particularly the level of acquisition of the learning outcomes.

IV. Analysis of Results

At the end of each academic year, it is possible to carry out a statistical analysis of the evaluation results obtained in the curricular unit, whose results reveal the success/failure rate and allow to assess, in some way, the adequacy of the implemented learning methods. Table III summarizes the data obtained during the two years of operation of the curricular unit, comparing with the average of curricular units of the third year and of the entire bachelor course.

TABLE III: Statistical results of the IoT course unit.

	avg(IoT)	avg(3rd year)	avg(bachelor)
Enrolled students	106.5	113.2	150.8
Assessed students	72.5	80.6	85.7
Approved students	64.0	61.2	51.7
Assessed/Enrolled	0.68	0.71	0.57
Approved/Enrolled	0.60	0.54	0.34
Approved/Assessed	0.88	0.76	0.60

The achieved results of the two academic years presented above are globally positive, with high values for the ratio of number of approved students versus the number assessed students. This ratio drops a bit if the number of enrolled students is considered, which is due to a dropout rate in this context. However, this value is smaller when compared to other curricular units taught in this curricular year and in the entire bachelor course, which can be justified by the fact that students are more motivated to attend the curricular unit, mainly due to the learning of technological topics, the kind of adopted educational methodology and the possibility to exercise and consolidate their skills in real systems.

At the end of semester, students were invited to answer to a questionnaire survey aiming to receive feedback of the operation of the curricular unit. Fig. 4 summarizes the received feedback (40 answers), where a Likert scale is used to assess the level of agreement in different learning perspectives.

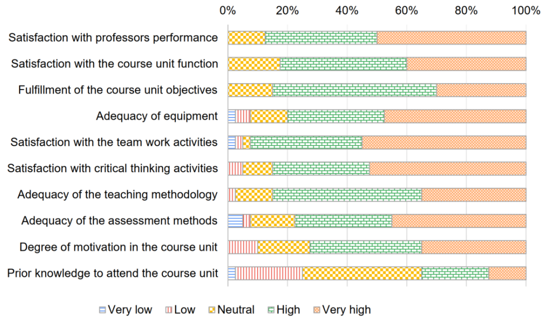

Fig. 4: Assessments of the participants' feedback.

Analyzing the achieved results, it is possible to verify that 73% of the students reported a high or very high motivation for the course unit, and 85% reported that the proposed objectives were completely achieved, in spite of about 25% of them reported having poor or no background in topics related to IoT. In terms of pedagogical feedback, around 88% of the students highly or very highly appreciated the teachers performance, with 85% highly approving the teaching methodology, 78% considering highly adequate the assessment methods and 80% considering the quality of the infrastructures and equipment used in the course unit outstanding. This means that the proposed integrated learning methodology applied in the IoT course unit was very positively appreciated by students, in particular, the self-motivation to find solutions to the challenges/problems offered by the worksheets and projects. These activities were performed in work teams, showing an overall positive reception by 93% of students and enhancing other soft skills like the critical thinking, which was recognized and valuated by 85% of the students.

V. Conclusions and Future Work

In the context of the 4th Industrial Revolution there is a strong demand for high-qualified professionals that exhibit competences in emergent digital technologies like IoT and AI. This strongly constraints the education and learning processes at the universities and vocational training centers, imposing the need to adopt innovative pedagogical teaching methods that allow the proper acquisition of technical and soft skills.

In this context, this paper discusses the application of a learning methodology that combines different educational methods, namely face-to-face, problem-based learning and project-based learning, in the teaching of the "Internet of Things" course unit belonging to the Bachelor of Informatics Engineering. The different methods were applied, in an integrated manner, in the teaching sessions according to the learning objectives and the particularities of each session.

The achieved results show an increase of the quality of the learning process and a higher motivation and satisfaction of the students to execute the learning plan, consolidating their competences by reaching the learning outcomes at their particular rhythm. This approach has also stimulated the acquisition of soft skills, e.g., team work, communication and critical thinking, as result of adopting different educational methods. This approach is more adequate for classes with a reduced number of students in the teaching class, e.g., practical classes with approximately 15 students. In case of classes with dimension 20+ students, there is the need to adapt these approaches or in alternative to split into several shifts, as implemented in the case study course unit described in this paper.

Future work will be devoted to extend the application of the proposed methodology to new editions of the "Internet of Things" course unit by combining other educational methods, namely the research-based learning and learning factories.

Acknowledgments

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