Hands-on Learning Modules for Upskilling in Industry 4.0 Technologies

Alexandre Oliveira Junior*, Heitor Assumpcao*, Jonas Queiroz*, Luis Piardi*, Javier Parra†, Paulo Leitao*
* Research Centre in Digitalization and Intelligent Robotics (CeDRI), Instituto Politecnico de Braganca,
Campus de Santa Apolonia, 5300-253 Braganca, Portugal, Email: {alexandrejunior, jpqueiroz, piardi, pleitao}@ipb.pt
† BISITE Research Group, University of Salamanca,
Edificio Multiusos I+D+i, 37007 Salamanca, Spain, Email:javierparra@usal.es

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***Abstract*—The Industry 4.0 (I4.0) advent is re-shaping the way systems and processes operate by considering Cyber-Physical Systems combined with a plethora of emergent Information and Communication Technologies (ICT), e.g., Internet of Things (IoT), Artificial Intelligence, Cloud Computing and Intelligent Robotics. However, the emergence of such disruptive technologies strongly establishes a demand for upskilling and requalification of active professionals and young undergraduate students. This means that the wide adoption of the I4.0 systems and related technologies is dependent on the efficient implementation of lifelong learning and training initiatives that address these challenges. Having this in mind, this paper describes the implementation of a series of short learning modules and hackathons that relies on a strong hands-on practical experimentation, regarding the upskilling in emergent ICT technologies, particularly focusing on IoT, mobile robotics and Multi-agent Systems. The preliminary efforts contributed to qualify undergraduate students and active professionals in disruptive ICT, with the attendees' feedback illustrating the importance of these kind of short and hands-on learning modules to address towards the continuous demands associated to the digital transformation.**

***Index Terms*—Education 4.0, upskilling, learning modules.**

I. Introduction

Industry 4.0 (I4.0) represents the current state of the industrial digital transformation process, transforming the traditional factories into smart factories [1]. Cyber-Physical Systems (CPS) act as the pillar of I4.0, which is complemented by the adoption of emergent Information and Communication Technologies (ICT), such as Internet of Things (IoT), Big Data, and Artificial Intelligence (AI), to develop the next generation of intelligent and distributed industrial systems. The confluence of these enabling technologies has led to the transition of the traditional industrial hierarchical systems into more flexible, modular, decentralized, and responsive automation systems, comprising a network of autonomous and interacting components supported by AI algorithms and communicating through the use of IoT technologies [2].

Besides impacting the production system dynamics and efficiency, the broad integration of ICT in the industrial sector is also responsible for several economic and social implications. For instance, the investments related to IoT applications in the global industry in 2020 were about US$ 77.3 billion, being expected to reach US$ 110.6 billion by 2025 [3], showing that companies are constantly adapting to the exponential emergence of disruptive ICT to remain competitive. Moreover, I4.0 is also causing several social impacts, e.g., regarding the jobs, where workers need to continuously develop their skills to work with the new digital technologies and changes that are affecting the industrial sector [4].

Similarly, the education sector has also to follow this challenge, offering new training programs to qualify the workforce with the necessary soft and hard skills required for I4.0 and related to disruptive ICT. For this purpose, new learning paradigms should be considered and learning actions should be the result of a co-design process that involves different stakeholders, namely learners, companies, and educators [5], preparing workers and academics for the digital transformation [6]. Additionally, I4.0 increased the demand for skilled professionals that did not exist before; in fact, several new professions arose with this new industrial revolution, e.g., data scientist and cloud services manager, for which there is still a shortage of training offers around the world. The Covid-19 pandemic has speed up this need to re-think and adapt the educational paradigms and pedagogical strategies.

In this context, the DISRUPTIVE project (disruptive.usal.es) aims to carry out a series of training actions consisting of learning modules, workshops and hackathons to assist the diffusion and training of workforce and undergraduate students in disruptive ICT, to improve the competitiveness of the social-economic system in the cross-board region of Portugal and Spain. For this purpose, a training plan was designed and organized in terms of a set of modular learning modules, that the learner can select and combine according to its upskilling needs, making an individualized learning path. Each learning module was designed according to the identified upskilling needs, addressing real problems, a solid hands-on practical experimentation, and considering a blended typology where the presence of instructors ensures the close interaction for faster learning. These learning modules should have a short duration, but not so short as the typical learning nuggets, being a way to complement the learning provided by these nuggets.

This paper describes the proposed learning methodology and the implementation of learning modules focusing on IoT, mobile robotics, and Multi-agent Systems (MAS), using digital resources (e.g., online platforms and simulators) to support the learning activities facing the current pandemic restrictions. The feedback from the participants shows that these short hands-on learning modules strongly contribute to qualifying the workforce and undergraduate students in emergent ICT.

The structure of this paper is as follows: Section II overviews the upskilling and requalification needs in I4.0 and the existing approaches to address this demand. Section III describes the rationale and learning methodology for the designed training plan and Section IV details the practical activities developed during the execution of some learning modules. Section V discusses the feedback obtained from the participants, as well as the impacts provided by the training activities. Finally, Section VI presents the conclusions and points out future work.

II. Upskilling and Requalification in Industry 4.0

The digital transformation, based on the use of emergent paradigms and digital technologies, is re-shaping the world and the way products, processes and people operate, but it is also imposing solid challenges in terms of the qualifications of the workforce. In fact, according to the European Commission (EC), it is expected that by 2030 more than 1 billion young people around the world will not have the required skills or qualifications to become the next generation workforce [7]. Other reports sustain this scenario, e.g., predicting that *"75 to 375 million people around the world may change their professional category by 2030 due to the new job market scenario"* [8] and *"at least 54% of all employees will need reskilling and upskilling by 2022"* [9]. Consequently, millions of people may improve their digital skills to be adapted to the new job market reality, which also requires a need to re-think the current education system curriculum and the existing learning paradigms to support the upcoming skilling and requalification needs of active workers and undergraduate students. This challenge is being tackled by academia, companies, and governmental organizations, e.g., EC.

For example, in the EU FIT4FoF (www.fit4fof.eu), a skill gap analysis was performed in six technological areas, including data analytics, cybersecurity, collaborative robotics, and human-machine integration, allowing to identify more than 100 new job profiles to face this new job market scenario associated with the factories of the future. During this research, the ICoED methodology [5] was established to design learning programs that consider a collaborative environment that integrates three stakeholders, namely companies, educators, and learners. This co-design interaction results in a learning program dedicated to overcoming the learners/companies' upskilling and requalification demands [5]. These resulting learning activities, focusing on soft and hard skills, must be designed for the short-term activities, aligned with a pedagogical paradigm that maintains the learner's interest and concentration, enhancing the activity objective centered on solving the learner's real problems and taking in-situ. Additionally, the learning actions need to comprise solid hands-on practical experimentation.

Another significant trend in this field, pushed by several education projects promoted by EC and particularly by EIT Manufacturing, considers micro-credentials and short-duration learning actions based on the concept of learning nuggets. The nuggets are modularized in short learning pieces, with a small duration, around 3 - 4 minutes, representing standalone learning activities addressing specific skills. According to their job profiles, the learners can combine these learning nuggets to allow individualized upskilling and requalification journeys [10].

Complementary, emergent practices can be explored for upskilling, such as virtual laboratories and blended learning. First, virtual laboratories can be defined as simulation environments that can interconnect humans and the real laboratory equipment through virtual models based on immersive technologies, such as virtual reality or augmented reality [11]. These labs allow the users to learn/acquire the necessary skills to perform a job in a controlled and virtual environment, as shown in the EU project ManuSkills. On the other hand, blended learning integrates e-Learning and traditional classes. The e-Learning part is mostly used for providing the essential knowledge and skills, followed by in-depth seminars with more advanced concepts and practical exercises [12]. An example of blended learning was created by the Erasmus+ DA.RE (Data Science Pathways to Re-Imagine Education) project (dare-project.de), where a pilot course for the training of data scientists was launched.

Despite these advances, there is still a long path to achieve appropriate learning paradigms to address the current upskilling and requalification challenges, considering the particularities of different emergent technologies and learners' needs in terms of their background and specific expected learning outcomes and conditions to perform the learning actions. In particular, it is crucial to focus on the design of individualized learning actions that can be based on learning nuggets but complemented with other learning instruments that consider practical experimentation and the involvement of instructors, if possible, addressing real daily problems of learners and take place in-situ. Note that the 4th industrial revolution does not exclusively impact engineering but reaches a broad spectrum of other professions, such as medicine and administration, which should be considered in the learning activities [13].

III. Learning Methodology for the Training Plan

Within the scope of the DISRUPTIVE project, an upskilling and requalification training plan was designed and implemented to cope with the identified demands for digitization of the regional industries and, consequently, their competitiveness in the global market. This plan aims to promote the adoption of disruptive technologies and particularly support the upskilling and requalification of active professionals and undergraduate students. Based on the approaches identified in the literature review, this plan is based on a set of short and hands-on learning modules, as illustrated in Fig. 1, that the learners can select and combine to pursue a customized learning path according to their upskilling needs.

The typology of these learning modules is mainly based on short and specialized actions that address the requirements previously identified during a co-design process that involved learners, companies, and educators, as suggested

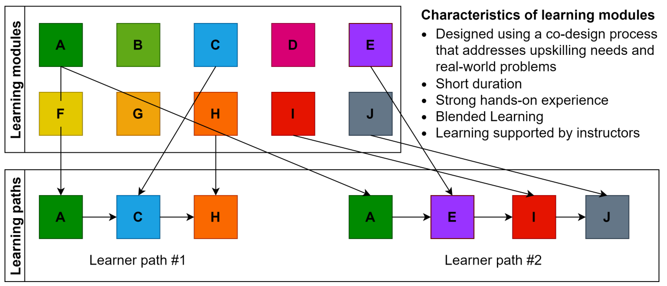

Fig. 1. Training plan based on a set of modular hands-on learning modules.

by the FIT4FoF project [5]. The methodology follows the blended learning paradigm, considering the e-learning training followed by presential learning activities led by instructors and focusing on practical experimentation that considers real problem-solving.

The e-learning component uses a proper e-learning platform, namely the IPB.Virtual, that provides access to the learning materials, available in Portuguese and English languages, as well as "Forum" and "Messages" functionalities to support the interaction between instructors and learners, e.g., to clarify doubts. Due to the sanitary limitations imposed by the Covid-19 pandemic in 2021, these educational activities were adapted to be carried out online by using digital video-conference platforms, namely ZOOM-Colibri, for the online lecturing sessions, and exploring the use of simulation software packages to support the practical experimentation.

All the learning modules include hands-on activities as a form of evaluation of the covered content, where the learners must use the learnt content to develop solutions to solve real problems, with the instructors acting as facilitators in the demonstration of examples and answering questions.

Fig. 2 illustrates the general structure of the designed training plan, including the learning methodology and examples of learning modules. The diversity of learning modules includes online modules and hackathons related to IoT, MAS, and Mobile Robotics, which are emergent I4.0 technologies, and were selected following a co-design process described in [5], which involved learners, educators, and companies. The presence of hackathons provides a more challenging environment to consolidate the learnt skills.

The mobile robotics topic was addressed with two learning modules. The first aims to introduce the learners to the basic concepts related to mobile robots and their implementation using the ROS (Robotic Operating System) framework. Since ROS has a learning curve that is not very friendly to new users [14], the second module is a hackathon that complements the previous learning module, allowing the participants to consolidate the acquired knowledge by developing applications to solve the established challenges in a competitive but also collaborative environment, and supervised by instructors with experience in the ROS framework.

The Introduction to IoT learning module aims to provide skills for developing IoT applications based on the Node-RED platform and the MQTT (Message Queuing Telemetry Transport) communication protocol. The topics referring to MAS were divided into two learning modules, with the first providing the fundamentals and industrial applications of MAS. The second module complemented the previous one, focusing on the developing of MAS applications through the use of the JADE framework, mainly for applications involving CPS and IoT.

IV. Learning Modules

As previously referred, the training activities included a set of learning modules focusing on different technologies. In this section, three learning modules will be further detailed.

A. *Introduction to Mobile Robotics using ROS*

This learning module aims to introduce the main concepts for the use of the ROS framework [15] in the development of mobile robotics applications, which includes a mixed theoretical exposition and hands-on practice. The learning outcomes expected at the end of this module were mainly:

- Understand the fundamentals related to mobile robotics.
- Know the basic concepts and structure of ROS.
- Ability to develop basic algorithms for mobile robotics using the ROS framework.

To achieve these learning outcomes, the structure of the learning module comprises the following contents:

- Theoretical background on mobile robotics: definition, typologies, principles and contextualization in I4.0.
- Introduction to the ROS framework: concepts and purposes, main versions, structure, basic commands, and contextualization about nodes, topics, and messages.
- Practical work on ROS: installation of ROS in a virtual machine, development of applications to control the movement of a mobile robot in a simulation environment.

This module is divided into two online sections of 4 hours each. The first section was dedicated to the theoretical contextualization of the main concepts related to mobile robotics and the ROS framework. In the second section, a hands-on approach took place, where practical work was developed by the participants with the supervision of the instructors, using the ROS framework and the 2D simulation environment STAGE (with the pre-developed simulation environments being provided to the participants). The participants developed control algorithms for their mobile robots, codified in Python and using the Kinetic Kane version of ROS.

As an example, Fig. 3 illustrates one of the practical activities developed in the learning module, where the attendees should navigate a mobile robot (represented by the red square) along with distinct points of a virtual building, performing speed control by sending messages through a ROS topic, and avoiding collisions with walls and obstacles according to the readings received from a LiDAR sensor (with the range being represented with the green color).

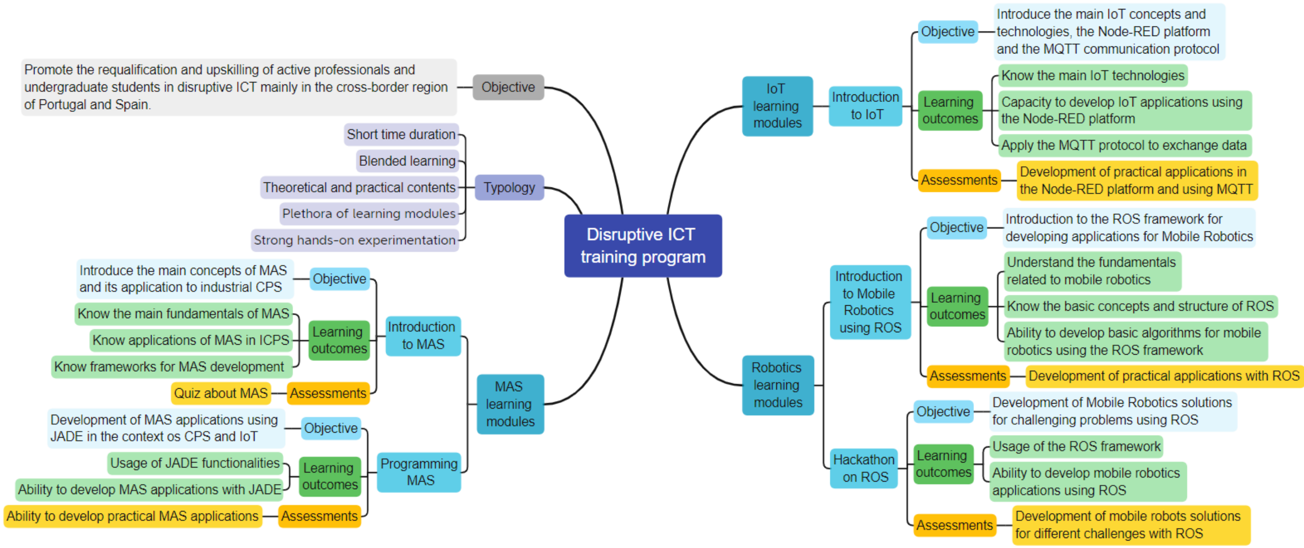

Fig. 2. Overview of the Disruptive ICT training plan.

B. Hackathon on ROS

This learning module was designed to allow the attendees to further develop their skills regarding the ROS framework by developing solutions to different mobile robotics problems, taking advantage of a hackathon methodology, where the attendees could work in teams, realizing knowledge exchanges and brainstorms to solve the problems. The main learning outcomes from the hackathon were:

- Usage of the ROS framework.
- Ability to develop mobile robotics applications using ROS.

The hackathon comprises three challenges to be solved by the attendees during a week, where the first two challenges act as a way to prepare the attendees skills for the third and final challenge. The schedule of activities is the following:

- First challenge: develop a control algorithm for a mobile robot that allows to pass through different points of an environment developed in STAGE.
- Second challenge: develop an algorithm that allows a mobile robot to navigate avoiding the collision with obstacles distributed in distinct scenarios, considering the readings of a LiDAR sensor.
- Final challenge: develop an algorithm to navigate a mobile robot that should avoid the collision with obstacles and searching for the source of a gas leak in the simulation scenario. For this purpose, the robot needs to perform readings on a concentration topic with a white noise that was varying the actual gas concentration at the robot's position by about 1.5%. The winning team was the one that the robot got closest to the gas source.

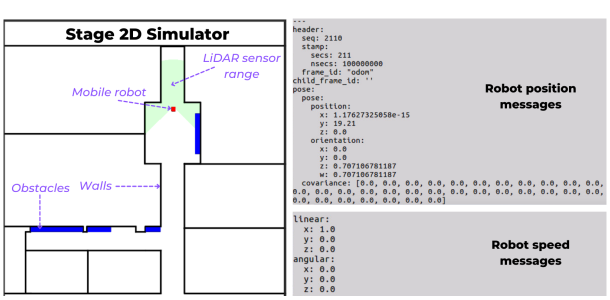

Fig. 3. Controlling the mobile robot using the ROS framework, displaying the STAGE simulator and the mobile robot's speed and position messages.

Fig. 4 illustrates the simulation environment for the final hackathon challenge, as well as a representation of the gas distribution through the environment.

C. Introduction to IoT

The main objective of this learning module is to introduce the basic concepts and technologies of the IoT with an emphasis on the development of practical applications using the Node-RED development platform and the MQTT communication protocol.

The expected learning outcomes were mainly:

- Know the main IoT technologies.
- Capability to develop IoT applications using the Node-RED platform.
- Apply the MQTT protocol to exchange data.

To achieve these learning outcomes, the structure of the learning module comprises the following contents:

- Introduction to the IoT main concepts, technologies and protocols, and particularly MQTT to exchange messages between IoT nodes and applications.
- Introduction to the Node-RED platform for the development of IoT applications.
- Development of practical exercises using Node-RED.

This learning module also has a duration of 8 hours spread over two 4-hour online sections. As an example, Fig. 5 illus-

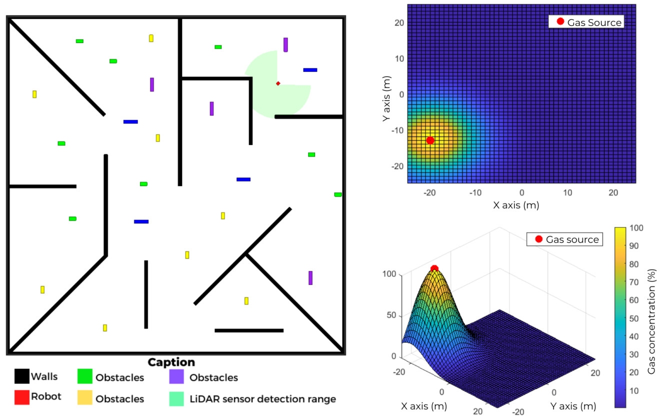

Fig. 4. Simulation scenario of the final hackathon challenge and 2D and 3D representation of the gas distribution in the environment.

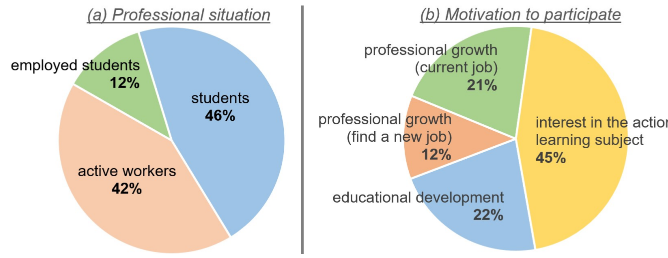

Fig. 6. Professional situation of learners and motivation to participate.

trates one of the activities performed by the module's learners, where an IoT application is developed in the Node-RED platform to store the information received from a BME280 sensor (humidity and pressure) in a database. This module is connected to an ESP32 microcontroller, creating an IoT node that retrieves the sensor data and use the MQTT to publish them to a public MQTT broker. The application developed in the Node-RED subscribes to the message topic of this IoT node to receive the data.

V. Discussion

The implementation of the training plan was performed during the March-June 2021 period, with the participation of active workers and undergraduate students. The training actions were mainly disseminated through the DISRUPTIVE project's partners and their social media channels (responsible for 26% of the registrations) and contacts with students from educational institutions (38%).

The attendees enrolled in the learning activities come from 8 academic institutions (students, professors, and researchers) and 14 different companies, mainly focused on technology and manufacturing sectors. Fig. 6 (a) illustrates the current professional status of the participants, with 42% being active workers (32 participants), 12% workers that are also involved in academic studies (9 participants), and 46% students (35 participants). The presence of several active workers from different companies clearly shows the contribution of these learning actions to support their continuous lifelong learning. Moreover, the significant attendance of students shows their interest in improving their skills for the labor market.

Fig. 6 (b) presents the main factors that motivated the attendees to participate in the training activities, being possible to notice that 45% of the attendees participated because they were interested in the addressed subjects, 21% trying to learn about the concepts to apply them in their current job, 22% as a form of academic qualification, 12% as a way to get qualifications to enter or change their position in the job market. This analysis clearly shows that a significant percentage (55%) is enrolled in the learning activities to upskilling and requalification targeting new job positions.

Fig. 7 presents an overview of the feedback given by the participants after the training actions. It assesses different topics using a Likert scale to indicate the percentage level of agreement based on the scale: not at all, not very, fairly, very, and very much.

About 66.2% of the attendees reported having fairly or no previous background in the topics covered in the learning modules. After their participation, 90.8% reported having achieved significant learning outcomes, and about 78.5% said to have been able to follow all the developed activities without major difficulties, while 86.2% had found the field of the ICT technologies covered very interesting. Around 93.8% of the attendees considered the lecturing presented by the instructors to be very satisfactory, with 81.5% approving the hands-on experiences and 95.4% considering the quality of the support materials outstanding. The expectations for the learning modules met about 90.8% of the attendees, where

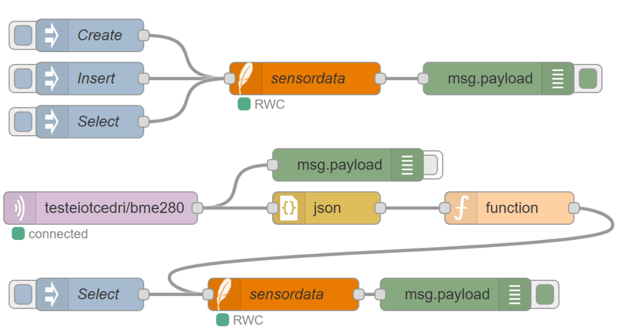

Fig. 5. Example of a Node-RED program developed during the training.

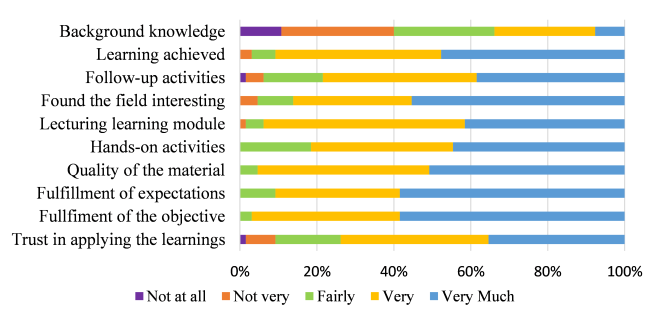

Fig. 7. Feedback from the participants.

96.9% reported that the proposed objectives were achieved, and 73.8% were confident in being able to apply what they have learned.

This means that the impact of the training modules on the attendees was very positive, with the hands-on activities being highly praised for enabling practical learning about ICT and addressing real problems. The use of simulated environments and software platforms, and the digital nature of the learning actions covered by the initial modules also contributed to these aspects. The e-learning approach implemented given the Covid-19 constraints allowed the learning actions to have a broader geographic reach, as the participants were not entirely concentrated in the Portugal-Spain cross-border region as expected, but e.g., reaching significant participation from Brazil. However, some participants felt that the hands-on experiences would have been more worthwhile if held face-to-face.

The learning paths strategy also proved to be positive since many attendees had achieved excellent performance while developing solutions to the challenges proposed at the ROS hackathon. This was possible due to their previous participation in the "Introduction to Mobile Robotics using ROS" module or by watching this lecture module's recordings that were available to the learners through the Youtube platform. In the same perspective of learning paths, 81.5% of the attendees reported being interested in participating in more advanced or specialized modules, and 15.4% might want to participate. A common agreement among the attendees is that the learning modules could have a longer total duration (more than 8 hours) to calmly approach some of the concepts and hands-on activities, which can be achieved by considering shorter learning modules.

VI. Conclusions

This paper discussed the shortcomings of implementing learning strategies for upskilling and requalification of the workforce and undergraduate students in disruptive digital technologies. A training plan based on short and hands-on learning modules and hackathons was implemented, focusing on IoT, mobile robotics and MAS. The described training program is included in a strategy of specialization for the cross-board territory in disruptive ICT that accelerates the acquisition of this knowledge, allowing the hands-on learning and qualification of the active workforce, researchers, and undergraduate students. The qualification of these assets allows for increasing the competitiveness of SMEs established in low population and economic density regions, particularly in cross-border regions, generating new business opportunities by adopting disruptive ICT.

The adaptation of ICT-related topics to short hands-on e-learning modules focused on real industrial problems, shown to be a promising alternative to the ongoing learning methods of technological diffusion, approaching the emerging needs of the Education 4.0 and overcoming the adversities set by the Covid-19 pandemic. Future work will be devoted to developing other disruptive ICT learning modules, besides improving the already developed modules, focusing on face-to-face training components that highlight the practical experimentation approach to solve real industrial problems. The improvements in the learning performance using blended learning, learning nuggets, or hands-on in-situ learning will also be analyzed.

Acknowledgments

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