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Accessible Maker-based Approaches to Educational Robotics in Online Learning

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ABSTRACT Educational Robotics holds the potential to promote the development of important 21st century skills, such as creativity and problem-solving skills in addition to digital literacy. However, the emergence of the Covid-19 pandemic has posed particular obstacles that had to be overcome in order to allow Educational Robotics activities to be conducted in distance learning. In the first place, the obligation to work from home limited the access to required equipment for many students. Secondly, many teachers had to face the novel challenge of creating pedagogically meaningful activities in online learning formats. Aiming to address these challenges, this work explored maker-based approaches as a way to implement Educational Robotics activities in online learning. The devised tools and activities were evaluated in two case studies performed with (i) high school students participating in a mobile robotics summer school and (ii) in- service teachers attending a professional development course on Educational Robotics. The teachers' and students' perception of the proposed activities was analyzed using online surveys and video interviews. The findings showed that the combination of the devised tools and activities allowed teachers and students to explore the basics of mobile robotics while helping them develop a maker mindset. The use of ubiquitous construction materials and affordable electronic components promotes accessibility of the approach. The proposed tools and activities may therefore provide an exemplary framework for more general applications of Educational Robotics in online learning that go beyond the context of emergency remote teaching.

INDEX TERMS Educational Robotics, Maker Movement, Online Learning, Project-based Learning, Teacher Professional Development

I. INTRODUCTION

THE recent technological advances and their impact on modern societies have given rise to the importance of teaching 21st century skills, such as creativity and problem-solving skills in addition to digital literacy [7, 26, 55]. In this context, Educational Robotics (ER) activities have been considered a promising approach to promote the development of such competencies [1, 8, 34, 40]. ER activities provide interesting and motivating learning environments, allowing students to develop solutions for real-world problems, following project-based and goal-oriented learning approaches [27].

Nevertheless, for more students to benefit from ER, some challenges must still be addressed. Previous research has illustrated that ER learning systems usually involve extensive infrastructure such as robots, programming interfaces and playgrounds [16, 34]. However, the high costs associated with these systems still represent a barrier to their adoption in formal education [18, 29], hence limiting the accessibility of ER activities mostly to teachers and students of well-resourced schools. Making the equipment more affordable and accessible is therefore crucial to further democratize the ideas underlying ER. According to Yang et al. [70], another major obstacle to the use of ER in classrooms is the lack of effective pedagogical practices (i.e., instructional processes, strategies and activities). Indeed, previous work has argued that many teachers are not yet prepared to integrate ER into their teaching, despite being aware of the benefits [62]. It is therefore important to develop pedagogically relevant ER activities and allow teachers to experience them firsthand. This may help them in understanding how such activities can be integrated into their teaching practices.

The accessibility of tools as well as the lack of effective pedagogical practices thus represent two main challenges for the implementation of ER activities in formal education and both aspects gained even more importance with the onset of the Covid-19 pandemic. With restrictions imposed on individual mobility, schools and universities worldwide were forced to abruptly move to emergency remote teaching [38] requiring teachers and students to work from home. This situation further complicated access to ER tools for many students, who would normally benefit from their school's infrastructure. Furthermore, many teachers had to adapt their lessons to online formats, facing additional difficulties such as poor online infrastructure or lack of experience with online learning [13]. These aspects were further amplified by the fact that the benefits of ER in online learning are still rather unexplored [6]. The combination of these circumstances complicated the design of pedagogically meaningful ER activities in online formats.

While the challenges pertaining to the accessibility of tools and the design of online activities were difficult obstacles for the implementation of ER activities during the pandemic, they also represented an opportunity to explore new approaches. In an attempt to overcome these challenges, this paper presents a set of maker-based activities designed with accessible materials as a way to implement ER in online learning. Indeed, the emergence of the maker movement has yielded many expressive tools allowing individuals to turn powerful ideas into reality [10]. However, while certain components, such as electronic building kits, have become quite affordable over the years, more sophisticated tools, such as 3D printers and laser-cutters, are still not accessible to everyone. To be independent from advanced construction tools, the ER activities presented in this work leveraged cardboard as the main construction material. Together with low-cost electronic components, openly accessible programming interfaces and simplistic designs for the ER playgrounds, it provided the foundation for the activities presented in this work. To address the lack of effective pedagogical practices, a particular emphasis was laid on the design of the activities and the tools proposed. Previous research has highlighted that the quality of design of a distance learning course is more important than the characteristics of the media used [3, 9, 20, 52]. Based on this idea, existing design frameworks specific to ER were leveraged [32], in order to align the design of the activities and tools with the affordances of the media and tools used for the instruction.

By integrating accessible maker-based ER activities into the context of online learning, the present work aims to lay out an exemplary framework for the preparation and implementation of ER activities in online learning. The next section will present previous work on ER activities in online learning (Section II-A) as well as research on ER in the context of the maker movement (Section II-B). Section III will then outline how both ideas have been combined in this work to create pedagogically meaningful ER activities in online learning. Afterwards, the results of the two case studies evaluating these activities are presented (Section IV), one performed with high school students participating in a mobile robotics summer school and the other with teachers attending a professional development course on ER. The work will conclude with a discussion on the obtained results (Section V) and a final conclusion (Section VI).

II. BACKGROUND

A. EDUCATIONAL ROBOTICS IN ONLINE LEARNING

Online learning has emerged as the most recent manifestation of distance learning [56]. While the aim of online learning is not to replace classroom-based instruction, it may provide new opportunities for students and teachers to communicate and interact with each other. Online learning provides remarkable flexibility helping to surpass barriers of distance and time [59], as well as high accessibility in terms of both convenience and cost [66]. Several studies have shown that learners indeed appreciated these aspects of online learning [44, 51, 63, 71]. In the context of ER, most existing online learning approaches can be either classified as asynchronous, such as massive open online courses (MOOCs), or synchronous, such as remote robotics laboratories.

Asynchronous online learning with ER mainly takes the form of MOOCs, which hold the potential to offer high-quality education to massive audiences at comparatively low-cost [65]. Taking advantage of the internet, MOOCs on ER deliver instruction mostly using video lectures, slides and other digital resources [12]. For instance, De La Croix and Egerstedt [21] used a MOOC on the control of mobile robots as part of a flipped classroom approach for a robotics class. Although the authors assessed the MOOC experience as generally positive, they particularly emphasized the difficulty to integrate hands-on activities using physical tools. Similarly, Mester [49] presented a MOOC as an introductory robotics course. In a series of twelve weekly released online lectures, students can learn about kinematics, dynamics and control of robots. However, to participate in the hands-on activities of the course, students need the Lego Mindstorms robotics kit - a condition that strongly limits the accessibility of the proposed approach. Besides this difficulty of implementing hands-on activities, online learning through MOOCs also complicates the direct interaction of learners with their teachers and peers. Previous work has argued that many ER activities build on the theory of socio-constructivism [33], with learners constructing knowledge through direct exchanges with their peers and teacher. While the asynchrony of MOOCs allows learners to be more flexible in planning their learning activities, it also hampers socio-constructivist learning.

Synchronous approaches to ER in online learning were mostly implemented as remote robotics laboratories. Such environments leverage the increasing capabilities of the internet, allowing learners to control robotic equipment from afar. Video streams provide feedback to the learners and at the same time, enable a direct interaction between teachers and students, hence facilitating socio-constructivist learning. Already in the late nineties, Després and George [22] developed a multi-agent architecture to implement an online learning environment for ER. Secondary school students elaborated the theory using electronic course books and then remotely programmed micro-robots while receiving support from a teacher at distance. In the following years, several works have adopted similar approaches to implement remote robotics laboratories for topics such as control and path planning [23, 30, 42, 48] or to introduce students to programming [5, 24]. While most of the studies targeted the education of students, only few explored remote robotics laboratories as a means for teacher training. Alimisis and Plessas [3] explored in-service teacher training with Lego Mindstorms robots through synchronous audio conferencing. In a series of different activities, the teachers participated in discussions using online whiteboards and received instruction through slide presentations by the trainer. Subsequently, they used simulation tools to virtually design a robot, before being provided with the possibility to send their programs to a remote robot and observe the actions through a video feed. While this work represents an interesting approach to ER in online learning modalities, it could be argued that the physical separation of learners and the main learning artifact (i.e., the robot) may create a hindrance in constructionist learning. Introduced by Papert [54], the theory of constructionism is considered one of the main learning theories underlying ER activities. It constitutes the idea that students construct and reconstruct knowledge by creating artifacts that they can share with their environment. Since most remote robotics laboratories do not involve the manipulation of physical robots, they may not be able to take advantage of one of the most powerful concepts underlying ER.

From the presented approaches it can be seen that designing and implementing ER activities for online learning is not trivial. Synchronous and asynchronous approaches have different benefits and drawbacks that need to be considered when designing the activities. Different choices will for instance influence how teachers and students interact with each other and how support is provided. Decisions with regard to these points will ultimately affect the final learning outcomes and should hence be carefully elaborated. One way to address this issue is to adopt a hybrid approach (i.e. combining asynchronous and synchronous elements) to capitalize on the benefits of both. Indeed, in their work published during the Covid-19 pandemic, Rapanta et al. [57] suggested that online learning activities should comprise a mix of different designs (such as online/offline and synchronous/asynchronous). As a result, such designs could help to shift the focus to the learner as the responsible for their learning, while the teacher assumes the role of a facilitator. The potential of such hybrid approaches has previously been reported by Spradling et al. [65], who prepared a MOOC to train K-12 teachers in basic computer science concepts. In a final survey, they asked the participants which MOOC component they evaluated as the most favorable. Besides instructional projects and video material, participants identified synchronous virtual meetings as the most beneficial to complement the MOOC.

Another major challenge that emerges from the existing approaches (both asynchronous and synchronous), is to provide possibilities for hands-on activities supporting the constructionist learning approaches inherent to ER. In this regard, introducing maker-based approaches with accessible materials, that allows learners to locally build and manipulate their own robot, could provide a remedy to overcome this hurdle.

B. ER IN THE CONTEXT OF THE MAKER MOVEMENT

The potential of ER to implement learner-centered activities has given rise to many commercial robotics platforms dedicated to K-12 education. However, these commercial platforms are often expensive for schools to acquire [18]. Moreover, they often treat learners as consumers, not allowing them to explore the underlying hardware and software features [4]. They are thus likely to be perceived as "black boxes" and consequently, as passive tools for learning [50]. This may prevent the learner from building a profound understanding of the robot's functioning and at the same time undermine the learner's creativity [1].

Alternatively, following a maker approach to ER activities could empower learners to actively engage in the construction and reconstruction of knowledge [28], while providing them with powerful tools to express their ideas [10]. Described as the "pioneer of the maker movement" [28], ER provides many possibilities to incorporate the nine core ideas of making described by Hatch [36] in the maker movement manifesto: make, share, give, learn, tool up, play, participate, support and change. Similar to ER, making is considered to have its foundations in the learning theory of constructionism [46], hence providing a favorable framework for the implementation of ER activities. By acting as inventors, students learn to inquire and innovate [35], overcoming the "black box" consumer technology [58] and building deep structural understanding through hands-on activities. As illustrated in a recent small-scale study conducted by Fortunati et al. [31], building a robot from scratch increased the pupils' knowledge and manual skills in comparison to building it with pre-structured components (such as the ones provided by the Lego Mindstorms robotics kits).

Yet previous research has also highlighted the importance of rendering maker-based learning opportunities accessible to all students in order to bring more equity to education [10, 35, 46]. Approaches to maker-based ER activities that have been explored before [14, 15, 43, 68] often relied on advanced infrastructure such as 3D printers and laser cutters - tools that are still not available in many schools. However, as emphasized by Eguchi [28], rendering the tools and materials accessible is a crucial step to bring maker-based ER activities to formal classroom education, so that more students can benefit from them. In this regard, Eguchi [28] has suggested lowering the entrance barriers by offering "technologically enhanced maker activities that use everyday materials such as crafts materials". Giving students the power to innovate and invent their own robots with easily available construction materials in maker-based classroom activities holds the potential to transform the educational landscape [28].

In addition to making the tools and materials accessible, another critical step for the successful integration of maker activities in formal education is to introduce teachers to the maker mindset [39]. The role of teachers in maker education is largely unexplored with little effective research [45]. However, it is important to introduce teachers to the maker mindset (i.e. values such as creativity, problem-solving and digital literacy) and allow them to experience them firsthand, since planning and teaching in the maker context are different from conventional instructive teaching practices. In this context, it has been suggested that conducting maker activities with teachers can further help them gain expertise in these approaches [37, 39, 61, 67].

C. STUDY OBJECTIVES

The main objective of this work is to explore new approaches with respect to the implementation of ER activities in distance learning. To address the challenges of accessibility and effective pedagogical practices, a maker-based approach with low-cost materials was taken. The idea behind this choice was to allow learners to engage in hands-on activities and capitalize on constructionist learning even in distance education. For the instructional activities, a hybrid online learning approach (i.e., a mix of asynchronous and synchronous activities) was taken, in order to harness the best of both approaches. To ensure educational relevance, the development of the activities and tools was guided by existing design frameworks for ER learning systems [32]. Furthermore, user studies were not only performed with students, but also teachers, to address the lack of research on teacher perspectives on ER in online learning and ER in maker education. The results of this study aim to provide insights with respect to the following research questions:

1) How do high school students perceive maker-based ER activities in online learning as a way of organizing a mobile robotics summer school?
2) How do teachers perceive maker-based ER activities in online learning as a way of introducing them to the maker mindset?

III. METHODOLOGY

Most teaching activities that were performed in online learning during the Covid-19 pandemic can be classified as emergency remote teaching [38]. They represent solutions that were developed (and sometimes even improvised) in order to swiftly respond to the crisis situation. However, with the urgency of rapidly setting up solutions, most advice has focused on the use of technological tools, without pedagogical hints on how, when and why to use them [57]. As emphasized by previous work, the effectiveness of distance education approaches is determined by the pedagogical design rather than the properties of the media used [3, 9, 20, 52]. The activities and tools presented in this work were devised as a response to the restrictions imposed by the pandemic. However, since there was enough time to properly prepare them, a particular emphasis was laid on pedagogically meaningful designs. To consider the peculiarities of ER, the framework for ERLS was leveraged to guide the development [32]. It conceptualizes the alignment of four main elements of ER activities: intended outcomes, instructional activities, assessment and ER artifacts (i.e., robots, interfaces and playgrounds). Indeed, with regard to the implementation of ER activities in online learning, the pandemic required not only a redesign of the instructional and assessment activities but also the ER artifacts used. The ERLS framework, despite being originally devised for the context of classroom teaching, proved also useful in guiding the design process in the context of online learning.

A. DEVELOPMENT OF ER ARTIFACTS

As presented in previous works [16, 34], ER activities usually consist of three types of cognitive artifacts: the playgrounds, the robots and the interaction/programming interfaces. In order to facilitate the implementation in an online learning setting, no specific playgrounds were required to conduct the proposed activities. Instead, the tasks were designed to be performed under any conditions.

As for the robot, CreroBot, a low-cost do-it-yourself educational robot was specifically devised to align with the intended outcome of introducing teachers and students to the basics of mobile robotics and the maker mindset. To render the system easily reproducible, a heavy emphasis was laid on sourcing minimal components that are easily accessible. The BBC micro:bit microcontroller has gained quite some popularity in the domain of physical computing education [60] due to its affordable price tag, compact design and variety of inbuilt sensors (e.g. magnetometer, temperature sensor, light sensor, accelerometer, etc.). Its ease of use as well as its flexibility makes it an ideal platform for the implementation of introductory maker activities and it was hence used as the main board of CreroBot. Other components to build the basic version of the robot include two micro-servo motors, two wheels, a universal wheel, jumper cables and a battery shield (Fig. 1). The use of cardboard for the body of the robot reduced the need for sophisticated infrastructure such as laser cutters or 3D printers. In fact, cardboard represents a material that both teachers and students are familiar with, and that moreover, is available in great masses and at virtually no cost. Previously, a cardboard-based approach was taken to build Smartibot[1], which provided some inspiration to the structural design of CreroBot. To further facilitate the construction procedure, the body of CreroBot was based only on two cardboard pieces that could be cut out and combined using a simple slit system. The basic version was proposed to the teachers and students as an initial simple design to help them get started. However, as the activities progressed, the participants were encouraged to explore different designs, eventually including more components such as distance sensors or using multiple micro:bits for more advanced robot behaviors.

Three openly accessible programming interfaces were proposed for the CreroBot activities:

1) CreroBot PaPL: A tangible programming platform (Fig. 2a) was devised based on development frameworks presented in previous research [47, 53]. Pro-

[1] https://thecraftyrobot.net/

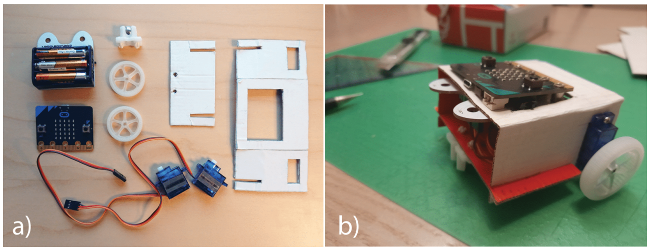

FIGURE 1. Main building components (a) and an example of a CreroBot in the basic version (b).

gramming blocks that can be crafted from cardboard are arranged in a puzzle-like fashion to create sequences of instructions. The use of the cardboard-based PaPL platform represented an opportunity to align the programming interface with the maker-based idea of CreroBot. By taking a photo of the instructions using the PaPL Android application[2] the commands are identified through computer vision algorithms and then sent to the micro:bit via Bluetooth Low Energy (BLE) for execution.

2) Microsoft Makecode for micro:bit: The platform follows a block-based programming paradigm (Fig. 2b) similar to Blockly and Scratch and is implemented as a web-based application that can be run in a web browser.
3) MicroPython for micro:bit: The language follows the Python language framework adapted for the micro:bit micro-controller hardware (Fig. 2c).

CreroBot PaPL and Microsoft Makecode were presented in the activities with the teachers, while the high school students worked with Makecode and MicroPython.

B. FIRST CASE STUDY: ONLINE MOBILE ROBOTICS SUMMER SCHOOL

1) Context

High school students from across Switzerland signed up for a mobile robotics summer school that is annually organized by the Education Outreach Department of the École polytechnique fédérale de Lausanne (EPFL). The workshops are free of charge, and usually take place over the course of a week on EPFL's campus. Due to the pandemic, the summer school was conducted remotely, providing the possibility to study students' perceptions on maker-based ER activities in an online learning setting.

2) Participants and protocol

The participants included 22 students (16-18 years old) from six different public schools. Students connected from their respective schools and all the necessary material was delivered to them beforehand. Participants worked in pairs and followed the course via video lectures and online tutorials.

[2]https://github.com/Antho1426/papl-app/

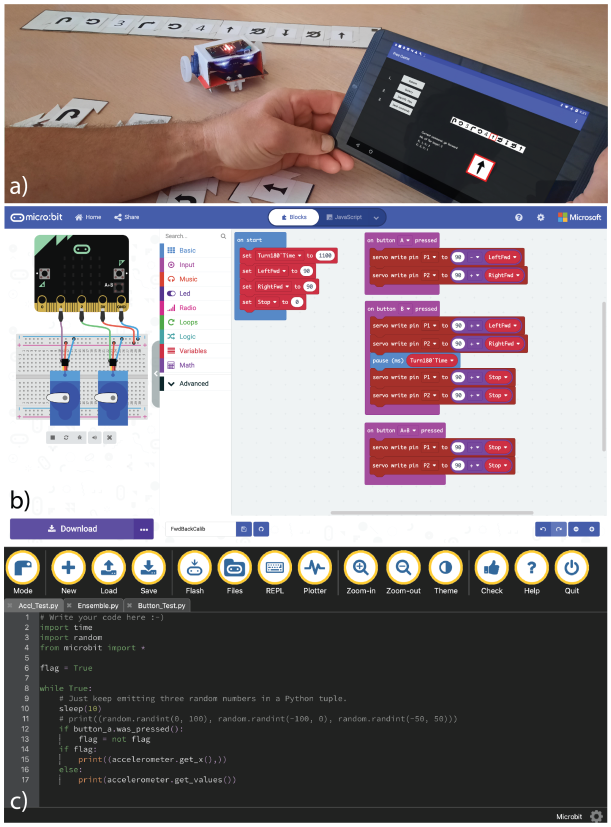

FIGURE 2. The three programming interfaces used for CreroBot: CreroBot PaPL (a); Microsoft Makecode for micro:bit (b); MicroPython for micro:bit (c)

The summer school was structured in a four-day workshop following a project- and maker-based learning approach:

- Day 1: Familiarizing with the micro:bit and interfacing it with different electronic components.
- Day 2: Assembling the Bit:Buggy[3] car and programming it for radio communication with another micro:bit.
- Day 3: Building the CreroBot and using it, followed by an introduction to the computer-aided design (CAD) software Tinkercad[4]. Start of the design challenge for a mobile robot based on the available components.
- Day 4: Continuation of the design challenge followed by the teams' presentations of their solutions and the conclusion of the workshop with the web survey and online focus group.

In the first part of the summer school (before the design challenge), one researcher introduced the topics through short video lecture series followed by students implementing the theory in practical exercises. During the practical work, students worked locally with the material provided and remained connected to the workshop organizers and the other participants through the videoconferencing tool. Individual support was provided to the students whenever necessary.

[3]https://uk.pi-supply.com/products/pi-supply-bit-buggy-car-with-microbit/
[4]https://www.tinkercad.com/

The final design challenge was organized as a mini project that the groups had to complete within two half-days.

3) Measures

Mixed methods were employed to evaluate the students' perception of the online mobile robotics summer school. Firstly, a quantitative analysis was performed on the data collected from a questionnaire administered to all the students in the second half of Day 4 (Table 1). The questions were mostly presented as 5-point Likert scale questions with a few exceptions providing other choices or being open-ended. The questionnaire consisted of measurements pertaining to four dimensions:

1) Student profile (PR): Information about the participants' gender and their previous experience with ER and making.
2) CreroBot (CB): Students' perception of the CreroBot based on the concepts of perceived use and ease of use [19].
3) Online format (OF): Students' perception of the online learning format for the mobile robotics summer school.
4) Overall experience (XP): Students' assessment of the online mobile robotics summer school as a whole.

TABLE 1. Student Survey Questions

Dimension	Label	Question
Student Profile	PR1	Gender (Male/Female)
	PR2	The starting level was adapted to my previous knowledge of programming
	PR3	How often have you used maker systems (3D printing, laser cutting) in your school?
	PR4	How often have you used educational robots (Lego Mindstorms, Thymio, Bluebot, etc.) in your classroom?
	PR5	What kind of robot do you prefer? (Preassembled/Assembly/Maker)
CreroBot	CB1	Did you enjoy the CreroBot activities?
	CB2	Did you find the CreroBot activities easy?
	CB3	Do you think working with the CreroBot allowed fair opportunities for group work?
	CB4	Would you recommend to your peers to build with cardboard to learn about robotics?
Online Format	OF1	The content of the summer school is rich and interesting
	OF2	The online format for this summer school suited well
	OF3	The course is well balanced between theory, examples and applications in practice
	OF4	The coaching of the practical work was good (organization, availability, advice, skills)
	OF5	For the next edition, would you prefer an online format or a format on the EPFL's campus or both?
Summer School	XP1	Did you have fun?
	XP2	Did you learn as much as you wanted?
	XP3	Did the program inspire you for future activities related to robotics?

The results were then triangulated with the qualitative data acquired from a focus group organized after the end of the summer school. In the 30-minute focus group, students were presented six statements one after the other (Table 2). After presenting each statement, the students were asked to discuss with their peers whether they agreed or disagreed with the statement. The discussions were moderated by one researcher, while another researcher was taking notes for later analysis.

TABLE 2. Statements presented in the focus groups

Label	Statement
FG1	The CreroBot activity is a good stepping stone before using laser cutting or 3D Printing.
FG2	Making a cardboard-based robot can be beneficial to introduce the idea of making to beginners.
FG3	Making the CreroBot was easy and intuitive with the materials involved.
FG4	The materials used to make the CreroBot are easily accessible.
FG5	Making the CreroBot helped me plan the design challenge better.
FG6	Making a cardboard-based robot is flexible and can be used for prototyping before implementing more complex designs.

C. SECOND CASE STUDY: ONLINE ROBOTICS COURSE FOR TEACHERS

1) Context

This case study describes an optional professional development course proposed to in-service teachers at the University of Applied Sciences and Arts of Southern Switzerland. Teachers follow this program to obtain a certificate of advanced studies (CAS) in ER. In the course, the teachers learn about the theory and practice of using ER for classroom teaching. The program is organized in three different modules and usually lasts around a year and a half. At the time of the study, the participating teachers had completed almost half of the second training module. Usually the classes take place on campus, but due to the pandemic the course was continued remotely. Hence it provided the possibility to study teachers' perception on maker-based ER activities in an online learning setting and the potential of the activities to help the teachers develop a maker mindset.

2) Participants and protocol

The participants were five in-service teachers that were acquainted with some educational robots such as Thymio, Lego Mindstorms and BlueBot before the study. The participants had experience teaching students in primary and secondary schools. The teachers had two weeks to conduct an individual online learning activity that followed a project-based learning approach. A kit with all the necessary material including the electronic components, cardboard material, printouts with the CreroBot PaPL block icons, and an Android device was delivered to the participants beforehand. A series of video lectures and video tutorials (Fig. 3) were prepared to guide the participants through the following sequence of activities:

1) Making the CreroBot and the PaPL programming blocks (1 h): Preparing the physical elements with cardboard by cutting and assembling the materials.
2) Familiarizing with micro:bit and Makecode (45 min): Performing simple tasks with the micro:bit, including

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using the onboard LED matrix, compass, and programming the robot to move in different directions on pressing the buttons.

3) Calibrating the motors (20 min): Here the participants had to calibrate the motors to move synchronously as a preparation for the subsequent activity.
4) CreroBot as a directional robot (30 min): Programming the CreroBot using the PaPL application to move it in a grid pattern.
5) Bonus task (30 min): Motivated participants could pursue a navigation challenge to program the CreroBot to follow a predefined cardinal direction while autonomously correcting deviations using readings from the integrated compass.

In the case of technical issues, the participants were offered the possibility to contact the researchers for a virtual meeting to obtain assistance.

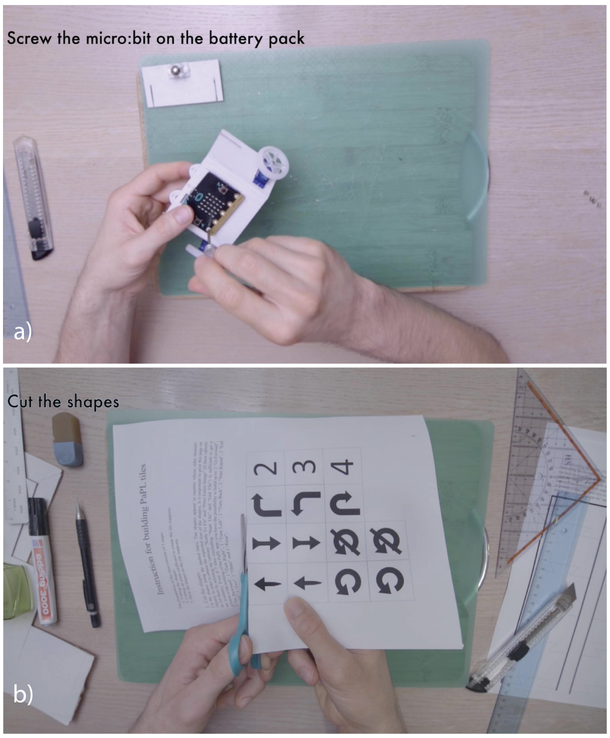

FIGURE 3. Screen captures of the tutorial videos for the construction of the CreroBot (a) and the CreroBot PaPL tiles (b).

3) Measures

The teachers completed a pre–posttest questionnaire (Table 3) followed by individual interviews. The questionnaire addressed three dimensions with questions on a 4-point Likert scale: teaching interest in ER, self-efficacy with ER and self-efficacy with making. Moreover, it included open-ended questions around the teachers' experience with CreroBot. The participants were profiled according to their responses to the questionnaire which directed the semi-structured interviews. Based on their responses interview questions were crafted to allow the interviewees the freedom to express their views within a predetermined theme or context. The themes (and consequently the questions) eventually converged toward specific aspects of making CreroBot and its usability. The interviews were conducted virtually by a researcher with each participant in their native language. All the interviews were recorded after permission was obtained from the interviewees and later transcribed. The teacher interviews lasted between 25-40 minutes. These interviews were then translated to English and all data was processed in accordance with the appropriate research and ethics standards [11].

TABLE 3. Teacher survey questions

Dimension	Question Tag	Question
Teaching Robotics Interest	TRI1	Robotics is interesting for me to teach.
	TRI2	Teaching a Robotics course is more interesting to me in comparison to other courses.
Robotics Self-Efficacy	RSE1	I am confident I can learn Robotics.
	RSE2	It takes me a long time to learn new things in Robotics.
	RSE3	I don't think I have good skills and strategies to learn Robotics.
	RSE4	I am sure I can handle technical tasks (e.g. wiring, calibrating motors, using sensors).
Making Self-Efficacy	MSE	I am good at making/building things with my hands.
CreroBot	C1	Do you think the materials required for this activity are easily accessible?
	C2	Did you find programming CreroBot easy?
	C3	Would you recommend CreroBot as a tool to your peers?
	C4	What did you like in particular?

IV. RESULTS

A. ONLINE MOBILE ROBOTICS SUMMER SCHOOL

The results of the survey (Fig. 4) showed that two-thirds of the participants were male, and one-third female (PR1). Prior knowledge with respect to educational robots was varied (PR4), however, the majority of the participants acknowledged that the level of the summer school was well adapted to their previous knowledge in programming (PR2). Among all participants, only two had prior experience with maker systems such as 3D printers and laser-cutters (PR3).

With regard to their preferred robot type (PR5), half of the participants indicated an assembly robot (such as the Lego Mindstorm series), while the other half indicated a maker robot (such as CreroBot). None of the participants preferred a pre-manufactured robot.

Overall, the students had a very positive perception of the online mobile robotics summer school. With only one exception, all participants agreed or strongly agreed that they would recommend the summer school to their peers (XP4). Moreover, all participants reported that they had fun being part of this summer school (XP1). The majority of participants also acknowledged that the summer school was inspiring (XP3) and helped them learn as much as they wanted (XP2).

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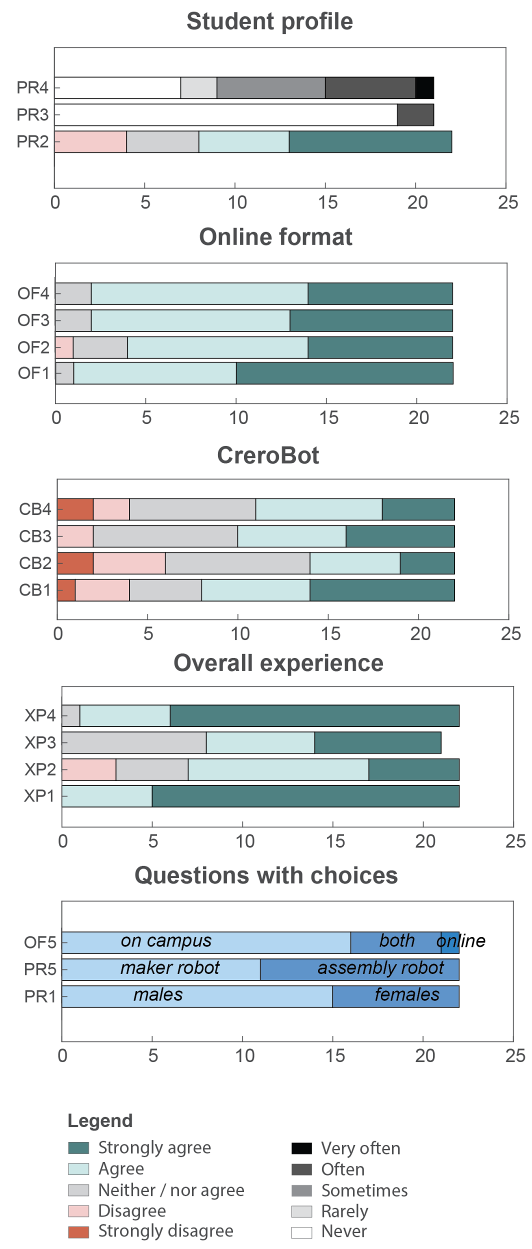

FIGURE 4. Responses of summer school participants to the online survey.

With respect to the online format of the summer school, the majority of participants acknowledged that it was well suited (OF2). Students also agreed that the content of the summer school was interesting (OF1) and well balanced between theory, examples, and practicals (OF3). Similarly, participants were satisfied with the coaching provided during the practical work (OF4). While the online format appeared to be suitable to organize the summer school under the circumstances of the pandemic, it was still not perceived as a replacement for the edition on campus. When asked, the majority still preferred an on-campus format for future editions of the summer school (OF5).

When asked about their experiences with the CreroBot activities, the students' answers appeared to be more ambivalent. While two-thirds of the students acknowledged that they enjoyed the activities (CB1), still one third was entirely not convinced. This proportion was even higher when asked about the ease to build the robot (CB2). Two-thirds did not find the activities easy. Around half of the students believed that CreroBot promotes collaboration (CB3) and also a half would recommend the use of cardboard as a mean to learn about robotics to their peers (CB4). The ambivalent perception on CreroBot was further discussed in the online focus group conducted at the end of the summer school.

In the student focus group, all participants agreed that CreroBot is a good method for conceptualization and helps with spatial representation while prototyping. For the design presentation on Day 4, one group decided to improve their CreroBot for the final design rather than designing one on the CAD software, as observed from their contemporaries. They assessed that the process of physically making with cardboard can be repetitive and time-consuming. However, as the materials and the process used were quite intuitive, they were compelled to spend more time improving the tangible prototype. They suggested that starting with something physical can help since they had trouble starting with the CAD software. Yet more advanced participants pointed out that the activities with CreroBot focused too much on prototyping, while they preferred to directly use the CAD software. These participants saw more value in quickly assembling pre-cut parts and spending more time on using the CAD software and programming. This finding indicates that introductory maker-based robots such as CreroBot, are better suited for novices than for more advanced participants. Indeed, the focus group allowed to identify that the students with less prior experience had a more positive perception of the CreroBot activities, in contrast to the more advanced students.

Furthermore, the participants didn't perceive any long-term use of CreroBot since cardboard is not a rigid material and their prototypes turned out "a little wonky". On the other hand, they faced weight distribution issues and tried to optimize these in their final designs. Participants also took the liberty of taking their robots home after the session on Day 3 and used other materials (straws and tape) to fix some of the issues, while to some extent, displaying a maker mindset. They agreed that they could easily build the robot at home if provided the electronic components. Nonetheless, the participants emphasized the need for an intermediate variant of CreroBot allowing for an adequate progression going from cardboard to more advanced maker activities such as laser cutting. Complex assembly mechanisms such as snapping and locking cannot be implemented with cardboard and thus, more sophisticated designs may not turn out very practical if implemented with it. However, all participants acknowledged that working with the CreroBot can be a good stepping stone to more advanced maker activities.

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B. ROBOTICS COURSE FOR TEACHERS

When analyzing the quantitative data from the pre-post surveys, no significant changes were observed for the three dimensions (Table 4). One possible explanation is that the intervention was too short to observe significant differences. Moreover, all participants seem to have shown high values for each of the dimensions to begin with, thus possibly creating a ceiling effect. This could be justified by the fact that the teachers actively sought participation in the CAS course for ER and they moreover, were already on the final stretch of their training. However, their perception of the CreroBot varied with respect to perceived use and ease of use.

TABLE 4. Teacher response (on a 4-point Likert scale)

Dimension	Pre-Test		Post-Test	
	Mean	SD	Mean	SD
Teaching Robotics Interest	3.3/4	0.64	3.3/4	0.64
Robotics Self-Efficacy	3.4/4	0.66	3.4/4	0.58
Making Self-Efficacy	3.2/4	0.4	3.2/4	0.4
CreroBot	n/a	n/a	n/a	n/a

Once the transcripts for the interviews were prepared, the qualitative data was analyzed using an inductive method based on a semantic approach. A reflective exegesis on what can be understood from the interviews was conducted. Knowledge of key themes in ER and making in the literature were drawn from. The predominant codes that emerged from similarities and associations in the data set guided the derivation of themes [11]. Table 5 demonstrates the themes and codes derived from the interviews. The topics explored with each individual are marked, '+' indicating a positive, 'O' a neutral, and '-' a negative perception.

TABLE 5. Themes derived from the semi-structured interviews; Positive perception (+), Neutral perception (O), Negative perception (-) of the five participating teachers (T1-T5)

Themes	Codes	T1	T2	T3	T4	T5
Impact on teachers' mindsets	Interest & enthusiasm	+	+	+	+	+
	Displaying facets of maker mindset		+		+	+
	Would perform activities with CreroBot	+	+	+	O	+
Classroom activities with CreroBot	Potential for breadth and depth on concepts	+	+			+
	Curricular application	+	+		+	+
	Personalization		+	+		+
Practical Issues	Technical Issues	-	-	-	-	+
	Safety		O		-	O
	Time		O	O		

1) Impact of the activity on teachers' mindsets

Participants identified multiple aspects of the activity that personally benefited them — chiefly the course content, flexibility, and the possibility to explore new tools. The teachers appreciated the opportunity to be introduced to a maker-based approach to ER and to continue their course through online learning. They affirmed that the materials and video lectures made available to them were clear and sufficient to conduct the activities. All teachers mentioned that they enjoyed the activities proposed, which included building the CreroBot, programming the micro:bit as well as crafting the tangible programming blocks and using them to command the movements. One teacher mentioned that they appreciated that they could easily build a robot with very few components.

> "I found it simple enough to assemble [...] It made me curious [...] I liked when it worked [...] I speak for myself, for elementary school students, it is very important to do something manual [...] It is also important for [the students] to do a little decorative work." (T2)

During the activities, the same teacher developed their own design ideas and suggested adding a pen to the CreroBot for math related activities. Two others also displayed facets of the maker mindset, developing their own iterations of the design with additional household materials (e.g. toothpicks), to make their robots more robust.

> "These small 'imperfections', I guess typical of the maker approach, have stimulated me to look for different solutions. For example, the search for a more suitable material for the construction." (T4)

Another teacher affirmed that the CreroBot activity in the online learning context gave them perspective into how new maker activities could be conducted.

> "The lesson has concretely served me to understand that there are easily structured maker activities even without great experience in assembling the components." (T5)

Since a main objective of the activities was to introduce the teachers to the maker mindset, so that they can introduce maker activities in their classrooms, the participants were asked if they would be willing to adopt the activities with CreroBot in their teaching. Four out of the five teachers agreed to do so and one agreed under the condition of some variations of the activities (adapting them to the younger age group of their students).

2) Classroom activities with CreroBot

The application of the CreroBot system in classroom activities was discussed with the teachers to understand where they see it fit in the school curriculum. Three teachers attributed importance to having the students developing a profound understanding of the robot's functioning. With this system, the teachers agreed that their students could build advanced depth in programming (to a level suitable for them) and breadth on complementary concepts.

> "At the elementary school level, it is interesting from the point of view of, say, the construction to thoroughly understanding how [the CreroBot] is built, how it works [...] In any case, it is important not only to press the buttons but also understand what is there underneath it. That is how you learn first. [...] Therefore, they get a better understanding

> of not only the logical but the mechanical aspect as well." (T2)

The interviews also discussed specific subject areas where the teachers thought the CreroBot could be used. Four teachers suggested an interdisciplinary approach mentioning math, arts and geography.

> "It depends on the objectives. It could fall in plastic arts, there is manual work in geography, we work with physical aspects of spatial orientation and whatnot. I think, if I had to just point out specific areas, I would say math and geography." (T4)

> "You could also collaborate with colleagues who do the part of artwork with recycled materials. It would be putting together two things that attract us to a working robot." (T5)

Teachers pointed out that the maker-based system offers an aspect of customization for both, students and teachers. The students are enabled to express their creativity while building the robot and the teachers can change its attributes according to the goal of the activity.

> "Once I've constructed the robot, maybe next time I can customize the CreroBot with another shape that facilitates to explain a certain concept." (T2)

3) Practical Issues

While the teachers evaluated the online learning experience as generally positive, they also raised some practical issues. First of all, due to the fact that the CreroBot and the PaPL Android app were newly developed for the course, there were still some technical issues. Out of the five teachers only one did not encounter any technical issues. However, for all the issues that emerged, it was possible to resolve them with a researcher via virtual meeting.

Furthermore, some teachers discussed the practical issues that would arise if the CreroBot activities were performed in classrooms. Most teachers agreed that students in middle school would be capable of using the tools required for building the CreroBot. However, some expressed their concerns about the use of a cutter knife which was needed for the current design of the CreroBot and that it requires supervision when being used by young children. As an alternative, three teachers suggested cutting pieces themselves when preparing the activity for younger students, also depending on the objectives.

> "If I use the computer in the classroom, there too, I still have to prepare the preparation worksheet in any case, so I don't see this as a great difficulty for the activity." (T2)

Another teacher highlighted how this constraint, could also emerge as a possibility to perform collaborative activities bringing together students of different grades.

> "The construction can be done with the help of senior students who work with junior students [...] So we have the advantage that they can work with very small groups." (T5)

Another issue raised by two of the participants was the time investment required in the making process, in comparison with the time spent on the programming activities presented to them. However, the teachers acknowledged that it would be justified if the CreroBot is used in other activities as a programmable educational robot later on.

V. DISCUSSION

This work sought to introduce maker-based activities as a way to implement ER activities for online learning formats. To this end, two case studies served to investigate the perceptions of students and teachers with respect to such approaches. This section discusses the obtained results and puts them in perspective with pertinent existing literature.

The first case study, an online mobile robotics summer school, helped to explore students' perception of the online learning format. Similar to findings reported in previous work [44, 51, 71], the students assessed the online format as generally positive. The students displayed high engagement and interest to complete the proposed tasks and many of them showcased behaviors that are typical of the maker mindset [25], displayed by a can-do attitude and allowing them to continuously iterate over their project to improve it. The students appreciated the high accessibility of the approach in terms of learning medium as well as used materials. As argued by previous research [10, 28], making ER approaches more accessible is a key factor to provide equal opportunities to students. In this context, the proposed activities involving low-cost components and ubiquitous crafting materials may represent a way to democratize the main ideas underlying maker and ER activities. However, increasing the accessibility of the materials through the use of cardboard also resulted in the drawback of limited complexity of the designs. Approaches such as the CreroBot activities may therefore be especially beneficial to introduce novices to maker activities. Yet intermediate solutions are needed to allow more advanced students make a progression before transitioning towards sophisticated maker tools, such as 3D printers and laser cutters. Indeed, the focus groups showed that it was mainly proficient students that did not enjoy the CreroBot activities as much. While the emphasis of this mobile robotics summer school was of introductory nature, future work could study whether intermediate solutions can be devised for activities with more advanced students. Nevertheless, the students generally enjoyed participating in the summer school and acknowledged that the online format was a good approach under the circumstances of the pandemic. However, a great majority reported that they would still prefer an on-campus version. This finding illustrates that the proposed activities may not be suitable to fully replace in-presence learning, especially in the context of summer schools, where the social component plays a major role. Online alternatives could nonetheless represent a complementary solution addressing learners who otherwise would not have access to such educational opportunities, for instance underprivileged students, or those living in remote areas.

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As highlighted by Kolb [41], teaching is a process, a cycle of learning grounded in experience. Teachers' realization that they can learn alongside their students is central to conceptualizing how they model their students' learning process. This is even more pertinent in the context of making, since previous work has emphasized that teacher professional development for maker-centered activities should address the maker mindset[17]. As a matter of fact, an authentic making experience can provide insights for teachers to model their own maker activities to engage their students [37, 39, 61, 67]. In the present work, five in-service teachers following a continuous professional development course participated in a maker-based ER activity conducted in an online learning format. The findings showed that the proposed activities were feasible and helped to attain the intended outcomes, i.e., to introduce the teachers to the idea of making. Similar to the students, many teachers displayed facets of the maker mindset during the activities, illustrating the effectiveness of the online learning activities. Moreover, the interviews with the teachers illustrated that they were able to imagine specific classroom scenarios using the proposed tools and activities. The teachers agreed that the proposed activities could be aligned with project-based learning in the formal curriculum as suggested in previous work [64, 69]. These findings illustrate that the proposed online learning activities were effective in conveying the main ideas of making to the teachers, and even inspiring some of them to already think about the in-class applications.

VI. CONCLUSION

Previous work has highlighted the importance of the pedagogical design in distance learning [3, 9, 20, 52]. This work therefore laid particular emphasis on a pedagogically meaningful design for the proposed activities. To this end, the ERLS framework [32] was leveraged to guide the development of the activities as well as the tools. As a matter of fact, developing ER activities for an online distance learning format not only requires a redesign of the instructional activities, but also of the learning artifacts involved. Based on the ERLS framework, video lectures and online tutorials were devised as well as the CreroBot with its different programming interfaces. The experiences with the teachers and students illustrated that the devised tools and instructional methods appeared to be well aligned with the intended outcome, i.e., to introduce them to the basics of mobile robotics and the maker mindset. Furthermore, following hands-on approaches in both studies, allowed to preserve the constructionist nature of ER activities [2], even in online learning. The approaches presented in this work may thus represent examples for how ER activities can be designed and implemented in online learning. The implications may go beyond the context of emergency remote teaching and could inform more general approaches to online education. However, it should also be acknowledged that the small sample sizes of this research represent an important limitation. Yet the results of the present work may prove useful to guide future work in this field of research.

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