Inclusive Robotics for a better Society

Final report on Interactive Robotics' education programs and learning activities

Version 1.0

31/03/2021

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 780073.

INBOTS

Inclusive Robotics for a better Society

www.inbots.eu

DOCUMENT HISTORY

HISTORY OF CHANGES			
Version	**Date**	**Change**	**Contributors**
1.0	31.03.2021	Initial version	Rene Alimisi Dimitris Alimisis Monica Malvezzi Chrissa Papasarantou Maria Pozzi Theodosios Sapounidis

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

1 Executive summary

This document reports the results obtained in INBOTS project related to the promotion of highly-accessible and multidisciplinary education programs. The specific objective of the project that is discussed in this document is: "Develop highly-accessible and multidisciplinary education programs" and the obtained results consist in "guidelines and recommendations to develop highly-accessible and multidisciplinary education programs that span from pre-school to postgraduate levels".

This document provides an organised collection of accessible resources for teachers, lecturers, students, workers, professionals and more in general for any person who needs or desire to learn about robotics in general or specific aspects related to robotic issues. Beyond students and professionals in schools and academia, this report can provide additional insights also to policy makers and decision makers to make them aware of the needs, trends and available resources towards new required paradigms in education.

The document is integrated with a series of external links (tables, documents, videos, webpages), detailing and integrating the resources introduced and discussed in the text. The resources specifically described in this document are relative to the current the state-of-the-art. However, the panorama of robotics educational, learning, and training tools is highly dynamic and is rapidly evolving. For this reason, the external tables linked to this document will be continuously updated beyond document release and project ending.

The availability of highly accessible and multidisciplinary education tools for inclusive robotics has become particularly evident in the last year, when COVID-19 pandemic disrupted most of our habits. In particular, on the one side, the pandemic boosted the development of robotic solutions in several environments and new scenarios and increased the need of workers and professionals able to develop, interact, and operate with robots. On the other side, it challenged the educational system forcing most of the students to stay at home, greatly limiting the possibility to access to laboratories and hands-on activities that are very important in robotics learning process.

The document is organised as follows:

- Section 2 presents a summary of the main contents reported in the first deliverable D3.1.
- Section 3 fucuses on pre-academic education: it reports the results conducted on the analytic review of the available educational robotic curricula and proposes a methodology for designing new curricula.
- Section 4 reviews and analyses highly accessible online resources, including both resources specific for the academic education (e.g. MOOCs, lecture series) and resources suitable for learners that are not necessarily students (e.g. teachers, professionals, people interested in general in robotics related topics). The detailed tables are reported as an Appendix to the document in Section 8.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

- Section 5 focuses on a specific typology of technological resources and presents a review on the applications of VR/AR tools in the learning processes in general and specifically as a tool for educating in robotics.
- Section 6, reports an overview on the impact of COVID-19 pandemic on the educational system in general and specifically on robotic teaching both in the pre-academic and in the academic level and how the work conducted in INBOTS project could contribute to mitigate some issues related to it.
- Section 7 presents some conclusive remarks.
- As an annex to the document, Section 9 summarizes the initiatives promoted during INBOTS project for building a community of learners, educators, researchers, experts and robotic companies fostering the discussion on educational robotics and Section 10 reports the papers related to INBOTS WP3 published in the second part of the project.

Regarding the role of educational robotics in schools, it is worth to underline that the INBOTS interventions detailed in Section 3 have introduced a paradigm shift inspired by sound pedagogies and emerging educational trends, to make robotics education inclusive for all the children. The suggested paradigm might be summarized with the motto "make your own robots" with the focus on creativity and the other 21st century skills: problem solving, critical thinking, and teamwork. It is important to underline also that the realization of a new paradigm must be supported by appropriate curricula and technologies at both hardware and software level.

Beyond the school, in this document and in the previous one (Deliverable D3.1) we reviewed, analysed, and proposed a classification of the accessible educational resources for learning and teaching robotics. While in deliverable D3.1 we reviewed and classified robotic academic curricula, thematic courses, summer and winter schools, in this document we focused in particular on accessible online resources and on the applications of new technologies as VR/AR tools for learning and teaching robotics at different levels of basic skills and for different potential interests. The importance of such new tools for education, learning and training has become particularly significant since the last year, when the pandemic spreading deeply modified all our habits and significantly impacted on the whole educational system.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

2 Summary of D3.1: Preliminary report on Interactive Robotics education programs and learning activities

Robotics is a very interdisciplinary subject with several connections among traditionally different domains: the engineering domain (e.g., mechanics, electronics, computer science, etc.), the human physical domain (e.g., physiology, ergonomics, anatomy), the human non-physical domain (e.g., psychology, ethics, economy). Finding a language for connecting them is paramount to get an aware and safe robotic evolution and diffusion, but the definition of this common language presents challenges. The availability of accessible learning resources could foster the knowledge diffusion, and also the discussion and the collaboration between such manifold realities. The preliminary version of this document, released at the end of June 2019, was devoted to providing a classification of the available educational tools and needs for learning and teaching robotics according to the target learner.

A lot of educational tools and resources for teaching robotics are currently available, and they can be classified and organised following different criteria. A first classification can be made considering the environment in which such resources are used:

- Resources integrated within the educational system, i.e. primary/secondary school, academia.
- Resources external to the educational system and available for the general public or for specific categories.

Resources can be classified according to their type:

- Courses;
- Books;
- Public initiatives: challenges, demonstrations, workshops;
- Software packages, toolboxes;
- Educational robots;
- DIY (Do It Yourself) projects, assembly kits, etc.

In the first part of INBOTS project, we conducted an analysis of the state of the art and in the first deliverable we summarized a preliminary organization and classification of the main resources that we identified. The study was carried out by means of both desk research and questionnaires that were distributed to potential contributors through mailing lists, project website and during project related initiatives (e.g., INBOTS Conference, European Robotic Forum, etc.).

Based on the information collected in the first part of the project, the preliminary report objectives were:

- Identify, for different education levels, which are the available educational resources and tools that are more suitable for each level, so to build a shared and highly accessible education platform and identify the missing elements and the specific training needs.
- Investigate on analogies and differences between different countries and institutions in terms of course length, load, and contents. The identified analogies will result in exchange programs.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

- Investigate on the learning needs specific for people that must interact with robots but not necessarily have a suitable technical background, identification of the tools that are more suitable for a rapid and focused application.

The intermediate conclusions from the first phase of the project were:

School

- **Status**. From the analysis of the state of the art and by means of specific questionnaires we could identify different educational tools, activities and resources in Europe and beyond. In the document we proposed classification criteria of such material.
- **Gaps and needs**. Even if the diffusion of educational activities in schools is increasing, it is not yet structured: teaching programs are different among different countries and schools. In high schools, often robotic activities are limited to technological or scientific curricula. Training of teachers is an important aspect that needs to be considered.
- **Contribution**. Monitoring and review of available resources, to get a more complete picture. The main results of the analysis, as well as links to the more relevant initiatives, will be available through the project website.

Universities

- **Status**. Different courses, curricula, training resources and tools are available. We focused on highly accessible on-line resources, and on summer and winter schools.
- **Gaps and needs**. The role of on-line resources is becoming increasingly important for undergraduate students, and for graduates and PhD students that need to integrate their knowledge. Their dissemination could be improved and optimized through dedicated websites and repositories.
- **Contribution**. Monitoring and review of available resources and to make them available through the project website.

Companies

- **Available resources**. Due to robots becoming more commonplace in companies, employers need to be trained and updated. There are different tools that companies can adopt to train their employers in robotics, using both internal and external resources.
- **Gaps and needs**. Training of employers is often an additional cost that limits the adoption of robotic systems, especially in SMEs. There is a gap between the skills provided by schools and universities and the ones required by companies.
- **Contribution**. Further analysis of the state of the art and the available tools.

Non-roboticists, general public

- **Available resources**. In the first document we collected and analysed training resources available for people that have not a specific technological background but need or want to learn robotics fundamentals or specific applications.

Resources collected in this phase are quite various and heterogeneous, due to the wide spectrum of attendees' backgrounds.

- **Gaps and needs**. Robots are becoming more and more important in the everyday life of a lot of people, initiatives aimed at explaining and debating on robotics should be even more encouraged.
- **Contribution**. Monitoring the main resources updated with the most relevant initiatives. Contribution to such initiatives by attending and organising seminars, conferences, and workshops.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

3 Educational curricula in educational robotics in pre-academic education

3.1 Summary: Method of work and the main results reported

In deliverable D3.1 we have reported a literature review in educational robotics for pre-school to secondary school education including a review on technologies currently used in educational robotics. This work is now published in:

- Sapounidis, T., & Alimisis, D. (2020). Educational Robotics for STEM: A Review of Technologies and Some Educational Considerations. In L. Leite, E. Oldham, A. Afonso, V. Floriano, L. Dourado, & M. H. Martinho (Eds.), Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward (pp. 167–190). Nova science publishers.

We have also provided a list of resources available for teachers and educators followed by a qualitative analysis of the resources.

This work is expanded in D3.2 with a review of the curricula in educational robotics and recommendations for curriculum developers (section 3.2) published in:

- Sapounidis T., Alimisis D. (2021). Educational robotics curricula: current trends and shortcomings, EDUROBOTICS 2020 conference proceedings, Springer (accepted for publication).

Based on these reviews, a proposal for a paradigm shift in educational robotics is introduced (section 3.3) incorporating the emerging trend of the maker movement in education and aimed to promote an inclusive robotics education. The proposed paradigm and a review of technologies that can serve the proposed paradigm are published in the following papers derived from our work in the INBOTS project:

- Alimisis, D. (2020) Emerging Pedagogies in Robotics Education: Towards a Paradigm Shift. In: Pons J. (eds) Inclusive Robotics for a Better Society. INBOTS 2018. Biosystems & Biorobotics, vol 25. Springer, Cham
- Alimisis, D. (2021) Technologies for an inclusive robotics education. Open Research Europe (conditionally accepted for publication).

Then, the proposed paradigm is exemplified (section 3.4) with a set of exemplary curricula we developed to reflect upon the needs of pre-school, primary and secondary school education with a focus on the development of the 21st century skills (i.e., creativity, critical thinking, problem solving, social competences). Three different teacher personas, one for each level of education, were devised and used during the development of the exemplary curricula. Indicative open educational resources were designed to support the curricula and are accessible through links in the end of the sessions included in each curriculum. The curricula and resources are intended_for teachers and educators to help them implement the proposed paradigm in their classes and labs and hopefully to inspire them to create their own curricula and resources.

To keep the size of the deliverable easy-to-manage, specific links are inserted in the text leading to curricula for each education level. Then, links inserted in each session of the

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

curriculum lead to corresponding resources. Our aim is to provide the curricula and resources online and this flexible structure helps to this end.

The curricula and resources were piloted with teachers and children in courses held in Athens, Autumn-Winter 2019; a short video from those pilots is available on YouTube.

Moreover, the paradigm shift was presented by the EDUMOTIVA team to teachers across EU through a live webinar on July 20, 2020 that attracted attention from 66 registered teachers. The webinar was recorded and is available online allowing more teachers to attend on demand. During the webinar the teachers were invited to "discover a new paradigm in educational robotics inspired by the maker movement: make your own robots!" The webinar was oriented towards lab activities: through simulations and audiovisual materials, we presented two versions of the "lighthouse project" to exemplify the "old" and "new" paradigm. The attendees were invited to provide their feedback filling in an online questionnaire (link). The analysis of the feedback received has shown a clear support to the new paradigm and will appear soon in a planned publication.

Further steps

The curricula and open educational resources are becoming freely available for teachers and educators through http://inbots.eu/ interlinked with https://edumotiva.eu and they will continue being updated after the end of the INBOTS project. Finally, this work is aimed to serve educational robotics communities as a platform of reference. Actors involved in the field across EU will be contacted to collaborate and support this endeavor: Robotic Teacher Community, EU ROBOTICS/TG Education, SCIENTIX, Association for Teacher Education in Europe ATEE, European Schoolnet and more.

3.2 Review of curricula in educational robotics, recommendations for designing future curricula.

The curriculum is usually the formulation of a teaching proposal and plan. Typical parameters of a curriculum are its objectives, methods, evaluation proposals and the course content. The teaching proposal may refer to the teaching of an entire educational level or class in a particular subject or set of subjects.

Indicative examples of the most representational curricula related to the educational robotics are presented in Table 1.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 1: examples of the most representational curricula related to the educational robotics.

Creator	Technological System	Description	Age Range	Link
BBC Micro:bit Educational Foundation	micro:bit	The curriculum is mostly based on webpages along with videos. The instructions are divided into steps and there are separate materials for students and teachers use. There are also items offered for free in pdfs, word, presentations and source code files. Particularly for teachers, there are notes with extra information, code examples, and possible short extensions. Finally, an instructor may find in the curriculum, the possible learning outcomes along with a time schedule estimation.	8 +	[1]
Lego	WeDo 2	It contains is multilingual Teacher Guides and Preparation Materials for WeDo 2.0. The material was prepared by Lego and is dedicated for teachers and primary school students. There are three project types, (a) getting started projects for novice (b) guided projects, which are related to specific curriculum ideals and contain step-by-step instructions (c) Open Projects, which provide a more open-ended experience. It proposes an indicative time schedule and four phases for the project completion (explore, create, test, and share). It also covers theoretical issues like computational thinking and provides teachers with material like building and programming help along with discussion questions and answers, assessment support, etc. The material is presented in pdfs, videos, webpages and is free of charge.	7 +	[2]
Lego	EV3	The curriculum is developed by Lego education it is contained mostly in pdf files. The content is multilingual and follows a similar philosophy like the WeDo 2 curriculum. It has learning	10 +	[3] [4] [5] [6]

[1] https://microbit.org/en/2017-03-07-javascript-block-resources/#lessons_a
[2] https://education.lego.com/en-au/support/wedo-2/teacher-guides
[3] https://education.lego.com/en-us/downloads/mindstorms-ev3/curriculum
[4] https://le-www-live-s.legocdn.com/downloads/LME-EV3/LME-EV3_MAKER_1.0_en-GB.pdf
[5] https://education.lego.com/en-au/lessons/maker-middleschool
[6] https://education.lego.com/en-au/lessonsfilter?Products=LEGO%C2%AE+MINDSTORMS+Education+EV3+Core+Set&rows=9

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

		goals, optional extra material list that can be used, indicative time schedules, lesson plan, student Worksheet, assessment tools along with building and programming tutorials.		
Carnegie Mellon Robotics Academy	VEX IQ, VEX CORTEX, VEX V5, Lego EV3, Parallax BOT	It is a series of curricula developed by the Carnegie Mellon's Robotics Academy. The curricula cover many robotic platforms and use pdfs, videos and webpages. Parts of the content are free while most of them not. There are tips for preparing the class, optional activities, writing reflection questions, worksheets, rubrics, additional handouts. It also covers some theoretical issues related to educational robotics and programming. The material appears to be self-paced with step by step guided video instruction and built-in-questions with instant feedback. During the sessions there are semi-guided "Try It!" investigation activities to let students uncover additional explorations & experimentations	Adults and children	[7] [8] [9]
Washington State Library	EV3	It covers programming basics for the Lego EV3. It contains pdf and video files (provided in a CD). The content is broken into modules and is accompanied by 22 videos ranging from 1 minute to 18. The exercise videos have no narration though some of them have occasional tips.	16+	[10]
RoboESL	EV3	It contains a series of curricula produced by the ERASMUS+ project ROBOESL. The material is inspired by the project-based and constructivism learning principles and proposes pedagogical approaches for robotics-based learning. The material is based on video - text and also provides validation tools to estimate the impact of the curriculum on the participants.	13 +	[11]

[7] https://www.cmu.edu/roboticsacademy/
[8] https://www.cmu.edu/roboticsacademy/roboticscurriculum/Lego%20Curriculum/index.html
[9] https://www.cmu.edu/roboticsacademy/PDFs/Curriculum/Intro-to-EV3/EV3-teachers-guideWEB.pdf
[10] https://www.sos.wa.gov/_assets/library/libraries/projects/youthservices/legomindstormsev3programmingbasics.pdf
[11] http://roboesl.eu/?page_id=591

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

		The material is multilingual and can be used by teachers and students.		
VEX Robotics	VEX IQ	The material is for middle and elementary school students. There are 12 units that can be used in sequence or stand-alone lessons. The curriculum is in pdfs and also contains videos. The units also contain content material, building instructions, rubrics, written exercises, optional activities, and teacher supplements and guides. Some of the above are free for downloading while other parts are only printed. For the development of some resources, VEX has partnered with Robomatter and PLTW, which are educational curriculum providers.	10 +	[12] [13] [14]
Parallax	ActivityBot, cyber:bot, Boe-Bot, Scribbler 3, FLiP Try-It Kit, Badge WX, Shield-Bot, ELEV-8, Arlo	The material covers minimum two age groups and facilitates a wide range of programming languages and robotic platforms ranging from Arduino, micro:bit, ELEV-8 v3 Quadcopter and many other. The content is separated by platform and programming language and follows an approximately 45-60 minute lesson-based structure. The tutorials for the robotic kits are usually divided in three sections (Prerequisites, Main Lesson, Projects). The robotic platforms strongly promote the DIY movement offering additional accessories. The instructions and step by step guides are based mostly on webpages, and video animations. For the registered educators it is offered a series of assessment material, extra guides and code examples.	5-8, 9+	[15] [16] [17] [18] [19]
Robotics WPS, Microbric	Edison	The curriculum is aligned with the technologies learning area requirements of the Australian	7+	[20]

[12] https://www.vexrobotics.com/vexiq/education/educational-tools
[13] https://content.vexrobotics.com/vexiq/curriculum/228-3319-VEX-IQ-Robotics-Education-Guide-20160511.pdf
[14] https://content.vexrobotics.com/vexiq/pdf/228-3428-750-Clawbot-IQ-Build-Instructions-Rev10-20150901.pdf
[15] https://www.parallax.com/education/teach/learn/educator-resources
[16] http://learn.parallax.com/
[17] http://blockly.parallax.com/blockly/
[18] http://learn.parallax.com/tutorials?field_language_tid=All&tid=All
[19] http://learn.parallax.com/tutorials/series/activitybot-blocklyprop-tutorial-series
[20] https://meetedison.com/robotics-lesson-plans/

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

		Curriculum (v8.3). The content is free downloadable pdfs and released under Creative Commons licences thus anybody may, use, share, translate or use it as a base to develop other lessons. The material is separated for teachers and students. It contains teacher's guides and lesson plans while for the students there are tutorials, activities, extension projects and worksheets. The content is also separated by the programming language used. Most of the offered lessons might be completed within 90 minutes depending on student's age and experience.		[21]
STEAM Studio	Arduino	This curriculum is an accumulation of heterogeneous material from many different sources. It is mainly videos, pdfs and websites created by individuals or companies and presented in a single form. This approach does not require the creation of new material by the creator of the curriculum but the discovery and utilization of already available material from different sources and creators.	12+	[22] [23]
Sparkfun	Arduino micro:bit Raspberry Pi Paper Circuits	Material for many platforms and programming languages developed by Sparkfun which is an online retailer, active in open source tech. The material is presented in many forms (pdfs, videos, webpages, ppts etc.) and follows a dissimilar philosophy for the different technologies. There are, learning objectives, time schedules and calendars, activities, open projects and examples for the project expansion along with assessments. Usually the material can be separated for students and teachers and in some cases, there are extra lecturing slides for the teacher.	11+	[24] [25]

[21] https://meetedison.com/robotics-lesson-plans/10-robotics-lesson-plans/
[22] http://steamcurriculum.weebly.com/arduino-based-robotics.html
[23] http://steamcurriculum.weebly.com/arduino-microcontrollers.html
[24] https://www.sparkfuneducation.com/curriculum.html
[25] https://learn.sparkfun.com/resources/39?_ga=1.93270749.1176615929.1473301234

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Individuals - instructables	Usually open technologies (Arduino, raspberry pi etc.)	The material is published in "Instructables", a platform which has a community of innovators, hobbyists and individuals with different skills who share what they are making. The material is usually webpages, with videos and external links for additional information. Usually the material is not separated for teachers and students and does not contain material like extensive assessments, tests, timetables etc. The "intractable" community strongly promotes the DIY movement with step-by-step guides using any kind of materials. As expected, there is great differentiation between the qualities of the material presented. This approach ensures new projects in regular bases if the creators of the material are too many and deal with domains such as educational robotics.	Adults and children	[26] [27] [28] [29] [30] [31] [32] [33]

26 https://www.instructables.com/class/Robots-Class/
27 https://www.instructables.com/id/How-to-Build-the-ProtoBot-a-100-Open-Source-Super-/
28 https://www.instructables.com/id/Simple-Bots-Wobbler/
29 https://www.instructables.com/class/Arduino-Class/
30 https://www.instructables.com/id/Line-following-Robot-with-Arduino/#discuss
31 https://www.instructables.com/id/St-Patricks-Day-Pinch-Detector-With-Circuit-Playgr/
32 https://www.instructables.com/id/Robot-Maze-Solver/
33 https://www.instructables.com/id/Build-your-own-Max-95-Mobile-Robot/

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

3.2.1 Conclusions from the review:

1. The existing curricula are developed in

- Webpages
- Pdfs
- Videos
- Printed material with the product

2. The developers are usually

- The company which develops the robotic system (e.g Lego, makeblock)
- Private or public educational organization (eg. Universities like Carnegie Mellon Robotics Academy [1], Catlin Gabel School [2])
- Research project (eg. RoboESL project [3])
- Hobbyists, individuals (eg. [4],[5])

3. Their aim is to

- Promote of relevant products (eg. Lego, [6])
- Sell the curricula
- Develop a community about robotics (eg. [7])
- To help others (i.e., teachers, parents, etc., eg. [4], [6])

4. The material is created for:

- Children
- Children and adults (there are too many cases where the children need help from an adult to follow the instructions)
- For educators (in this case the material is mostly for the training of educators)
- For educational organizations who need to buy the curricula

5. The curricula contain

- User instructions for the development of simple robots or mechanism
- User instruction for basic programming
- Connection of the session with real-world problems
- While is rarely contained
- Course objectives
- Separate role of the teacher and the student
- Possible extensions and task variants eg. [3]
- Evaluation tools

3.2.2 Recommendations for curriculum developers

3.2.2.1 COLLABORATION SCRIPTS IN ROBOTICS PROJECTS

One of the ER benefits appears to be the opportunities offered for collaborative learning and social interaction. Collaborative learning is based on the assumption that knowledge is created between the members of the group who actively share experiences and roles. Simultaneously, group members can monitor one another's work while at the same time

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

gain access to the knowledge, ideas, and skills of other team members. Although the importance of students' collaborative learning has been highlighted by many researchers mainly for cognitive, social and metacognitive reasons, recent studies have revealed that if students left without teachers' support might fail to engage in fruitful collaboration affecting their performance and learning outcome [8]. To better support group members during interaction teachers and scientists have proposed the use of collaboration scripts [9]. Collaboration scripts are didactic scenarios which considered as scaffolds intending to improve collaboration by structuring and specifying the way the group members interact with one another [10,11]. In other words, the collaboration script is a guide that describes how two or more learners should collaborate and solve interaction problems. Studies have shown that by scripting the collaboration process group members might improve peer tutoring and review along with argumentation skills [9, 11]. In view of the above, we argue that systematic introduction of collaboration scripts at the domain of ER might have a significant impact on student's active participation, collaboration skills, engagement, and probably learning (eg. [12]).

3.2.2.2 GUIDANCE IN LEARNING

Failure is an important part of the learning process. Through trial-and-error efforts are welcome in the constructivist approach, and some frustration is inevitable when learners are engaged in robotics projects. Concurrently, novices coming into a robotics lab need a considerable amount of support and facilitation before they can start making their projects [13]. Learners, especially the novices, should be carefully introduced to the lab activities and not to be exposed to excessive levels of frustration [13] in order to avoid disappointment and discouragement. Besides, this is important for the development of students' self-confidence and self-esteem, sense of self and sense of belonging in a team.

The role of guidance in the learning process has attracted the interest of the research community a long time ago. Many studies point out that learning should be monitored and guided through various strategies, to maximize learning outcomes (eg. [14,15,16]. Simultaneously, other researchers believe that the constructivism model which facilitates knowledge construction through discovery and exploration of real word challenging problems is fully compatible with the idea of guided learning [16]. The main disagreement between researchers appears to be the level of guidance, as well as the impact of the different forms of guidance on students' skills and learning [17, 18].

In detail, researchers believe that the minimal (or even none) guidance approach may seem appealing but is less efficient than strong guidance, especially for novice students [19]. This claim is based on the fact that human working memory capacity is limited and thus the minimal or even worse, no guidance overloads the pupils' work memory and limits learning abilities and speed. For this reason, it is believed that strong guidance at each step of the educational process with direct corrective feedback is an efficient approach [20]. On the other hand, other researchers believe that strong guidance can cause workload on both students and teachers [21] and possibly may be totally unnecessary when students acquire a specific level of knowledge about the taught field [22, 23]. By combining these two trends we can assume that in order to design successful guidance we should be aware of human cognitive architecture in order not to increase the cognitive load of students. Simultaneously, the guidance must take into

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

account the level of the students (novice or experienced) as well as the difficulty of the new knowledge to be taught. Finally, special care should be made to "fade out" the guidance when the trainees begin to acquire the required knowledge and skills [24,25]. Considering the above, we argue that the efficient adaptation of guidance on ER exercises and tasks is necessary to help students to better acquire knowledge and skills in the domain.

3.2.2.3 RELIEVING THE ANXIETY OF LEARNERS WITH ICEBREAKERS

Many teachers and instructors have faced situations where one or more hesitant learner refuses to leave his or her protective shell and participate in a class. These learners need help in order to feel more open, to relieve inhibitions, to begin conversations and get acquainted with the other group peers [26]. To promote the needed safe environment, teachers make simple activities (Icebreakers) to assist learners simply learn students' names, cultivate curiosity, a positive attitude for a subject, bring humor into the course and so build the appropriate atmosphere in class [27]. Ice-breaking activities are introductory events or actions which are used in group processes and are intended to help participants, to better know one another, to feel comfortable and have the first contact with the subject of the activity. In general, Icebreaking activities, are believed to contribute at the beginning of a course, to arouse student's attention and curiosity about a subject, to assist team bonding and help participants feel comfortable [27]. These activities are usually short and may involve, writing (e.g., personal information), talking, singing, or have physical action (dancing, jumping). They intend to bridge the beginning of an event and let many teachers/instructors connect and better understand students' needs and backgrounds and so build students' positive attitude for the learning subject [26]. These kinds of activities have been applied to a variety of group settings, formal and informal learning, different age groups, and many domains (e.g., learning, meetings, etc.).

Although, there is a lack of systematic work that provides empirical evidences on the advantages of using ice-breaking activities at the beginning of a class some preliminary studies exist [28]. In detail, studies have shown that icebreakers may increase student's attention and help instructors to easier link students to the class processes [27]. Other, studies have shown that audiovisual materials as ice-breaking activities may have positive effects on motivation and participation [29] and might prepare the students for deeper collaborative learning [30]. Simultaneously the combination of icebreakers and re-energizers in class may help to improve student participation and so enhance learning [26]. Unfortunately, at the domain of educational robotics, there is not adequate integration of icebreakers. Thus, we argue that the systematic adaptation of icebreakers in educational robotics curricula might be beneficial for both students and educators.

3.2.2.4 A GENERIC MODEL FOR CURRICULA DEVELOPMENT

By reviewing the educational curricula for scientific topics, we noted that there are some general educational robotics curricula for teaching physics or math for early and middle-high school students (e.g., [31,32]). However, these approaches are constructed for certain educational robotic platforms and so have limited applicability on other platforms. Consequently, the lack of specific rules and models for the creation of curricula has led to a chaotic landscape where curricula rarely share common elements and principles. It

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

is noteworthy that even among the curricula made by the same manufacturer there are different deficiencies and disparities. We, therefore, propose the development of a generic and as comprehensive as possible model that could lead curriculum makers to develop complete and more structured curricula for educational robotics.

3.2.2.5 MULTILINGUAL CONTENT

Regarding the educational material and their languages, many researchers have found that the failure to utilize pupils' language and culture might have a negative impact on their motivation and achievement [33]. In contrast, addressing cultural and linguistic students' diversity as a resource rather than as a discrepancy, by adopting multilingual practices, can promote performance and communicative competence [34]. Although the need but also the value of multilingualism in curricula has been emphasized (e.g. [35]), in the field of educational robotics multilingual curricula are rather rare. It is characteristic that there are cases where educational material for children has been developed in a language that children most probably do not know if they are not native speakers. Therefore, we propose to exclusively develop multilingual curricula that can be used more effectively by the international audience (teachers and students) interested to engage in educational robotics.

3.2.3 Conclusions

The use of open technologies (hardware / software) is making a real breakthrough at the ER curricula as teachers can adopt a low-cost one-to-one approach for their students so each student may have his / her robot to play with [36,37]. Undoubtedly the spread of open technologies is not accompanied by the corresponding development of the related curricula, which makes, even difficult for users to follow user instructions for the development of simple robots or mechanisms [38]. Particular for open-source educational robotic constructions is quite hard to find well-organized user instructions and corresponding curricula.

At the same time, regardless of the technologies used (open source or not), icebreaker activities are not integrated with the curricula thus teachers must develop their own icebreaking activities to facilitate their lesson. Moreover, it is extremely difficult to find collaborative scripts for each session to help teachers to separate students into effective groups and thus accomplish the best learning outcome. Similarly, curricula are lacking sections with detailed information on how teachers may guide students to the difficult points of a session (scaffolding) to enable learners to learn faster without losing their interest.

A model for the procedure of curriculum development might include four distinctive stages. The first stage identifies the need for material creation and clarifies the purpose it will serve, the cognitive skills or attitudes it cultivates. The profiles of the users of the material are then defined (students - Teachers) to better serve their needs and expectations. Finally, at this stage, an idea/scenario is formulated that could serve the specific need, promote the desired skills of the selected target group (both students and teachers).

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

The second stage involves the planning of the sessions based on the prerequisites. This stage consists of two different processes, one involves the material to be developed for the teachers and the other the material to be used by the learners.

The procedure for teachers includes the preparation of sessions based on the available equipment - time and the training methodology to be followed. Then is needed to identify the areas where students are likely to encounter problems in order to develop additional supportive material. The students' procedure involves the breaking of the sessions into smaller pieces to develop autonomous sub-tasks while identifying potential alternatives that lead to the same result.

The third stage involves the development of the resources for teachers and students. Teacher's processes include the development of step-by-step guides for the session, collaborative scenarios that support the chosen methodology, and Instructional tips for the difficult points identified earlier. Students are provided with a rather free and flexible worksheets as well as resources.

The fourth and final stage includes the trials and pilots of the curricula. In the first stages of the trials (most probably implemented by the teacher alone) we usually return to the third stage to make changes and optimizations while after real-time implementation we can return to the second stage in order to develop alternative or completely different activities that serve better the same needs.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

3.3 A paradigm shift to make robotics education inclusive for all the children.

In the last two decades curricula and open educational resources (OERs) are very often developed in robotics education according to a narrow perception that robotics should address only talented youth or science- and technology-oriented students. Current societal developments call for moving away from this elitism to the recognition that fluency with robotic technologies is no longer just a vocational skill, but it is knowledge and skills valuable for every citizen.

The robotics kits available in the market come often with inherent lock-in mechanisms, closed hardware and/or software, instructions to assemble pre-defined models and teaching/learning materials that dictate step-by-step guided approaches for learners. This way the commercial kits define in a rather authoritarian way what is best for teachers and learners handling them just as consumers who have simply to follow step-by-step recipes to construct and program pre-defined robots. Not surprisingly this situation results often in poor learning that doesn't go beyond superficial and trivial knowledge acquisition instead of deep learning and skills development that can support the development of future generations of empowered citizens [39].

On the other hand, lately, the educational community proposes a change in educational methodologies and curricula in order to adopt the maker movement [40,41,42]. The maker movement appears to provide broad access to learning opportunities in formal and informal settings, for everyone, emphasizing mostly on the relationship between learning and making through exploration [40], [39]. The idea behind the adaptation of maker's and Do-It-Yourself (DIY) movement has its origins in the constructivism theory that proposes the generation of knowledge from the interaction between ideation and experience [43] arguing that learning is more effective when students have to deal with meaningful real word objects [44]. The adaptation of DIY and maker culture in educational robotics suggests a paradigm shift and a radical change in robotics curricula.

Contrary to the conventional educational robotic practices, the new paradigm encourages students to develop their own robots and robotic mechanisms using 3D printed, open-source and low-cost tools instead of using pre-fabricated and ready-made robots. Although the incorporation of the maker movement is very attractive and has deep theoretical roots in Papert's constructionism ideas [44], it is hardly identified in the existing STEAM and robotics curricula in the European schools [39].

To make robotics education inclusive for all the children, the INBOTS interventions have introduced a paradigm shift inspired by sound pedagogies (Papert's constructionism [45]) and emerging educational trends (maker movement in education [18]). The suggested paradigm might be summarized with the motto "make your own robots" with the focus on creativity and the other 21st century skills: problem solving, critical thinking, and teamwork. We are aware that the realization of a new paradigm must be supported by appropriate curricula and technologies at both hardware and software level.

The new paradigm needs support from relevant curricula and proper technologies. To this end, in addition to a collection of available resources, a set of specific exemplar curricula and open educational resources for school education was developed in INBOTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

to exemplify the new paradigm. The INBOTS curricula and resources have been piloted with teachers and children in courses held in Athens (Autumn-Winter 2019); a short video from pilots is available on YouTube. The curricula and resources are presented in the next sections and intended for teachers and educators to help them implement the proposed paradigm in their classes and labs and hopefully to inspire them to create their own curricula and resources.

Moreover, the new paradigm - and the INBOTS curricula - needs support from appropriate technological tools. We have already provided a systematic review of the most prominent available educational robotics technologies that appear in the literature [46].

The proposed paradigm and a review of technologies that can serve the proposed paradigm are reported in the already cited publications derived from our work in the INBOTS project [39, 47].

The paradigm shift was presented by the EDUMOTIVA team to teachers across EU through a live webinar on July 20, 2020 that attracted attention from 66 registered teachers. The webinar was recorded and is available here allowing more teachers to attend on demand. During the webinar the teachers were invited to "discover a new paradigm in educational robotics inspired by the maker movement: make your own robots!" The webinar was oriented towards lab activities: through simulations and audiovisual materials, presented two versions of the "lighthouse project" to exemplify the "old" and "new" paradigm. The attendees were invited to provide their feedback filling in an online questionnaire (link). The analysis of the feedback received has shown a clear support to the new paradigm.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

3.4 Exemplifying the new paradigm with curricula and Open Educational Resources for early elementary school, primary school, and secondary school education.

In the context of the INBOTS European project, exemplary curricula on robotics are developed to reflect upon the needs of pre-school, primary and secondary school education as far as STEM and the acquisition of 21st century skills (i.e., creativity, critical thinking, problem solving, social competences) are concerned. Their aim is to propose several learning activities, revolving around the DIY culture and the constructivist methodology, and thus addressing specific content such as electronic circuits, programming structures and engineering concepts. The ultimate goal is a pedagogical shift where students become active learners and makers, with high need of exploring, discussing and sharing experiences and ideas, while teachers are facilitating them as their coaches, helping and encouraging them to explore and construct their own knowledge. This section aims to present the theoretical background and the methodology upon which the aforementioned curricula were based and structured.

Using teacher personas

The first step towards the realization of the curricula, was the exploration of the existing needs on robotics for each educational grade. For this purpose, it was initially decided the introduction and development of a persona. As a persona is defined a fictional character, representing a rather real-life teacher and her/his immanent needs concerning teaching. In this sense, three different personas (one for each level of education) were developed: one for kindergarten and early elementary education; one for primary education and one for secondary education. Each of them has a background story regarding her/his teaching methods, the motivation behind her/his decision to get involved with educational robotics, as well as the ways s/he envisions introducing robotics to her/his class. Another issue that is stressed through each persona is the diversities that can be met in a school class. This is done through the description of the group of students that each of them is working with. Through this lens a number of parameters/qualities such as the educational level, the number and the age of students, as well as their background on robotics, are reflected.

The development of a persona and her/his needs led also to another emerging issue regarding the available equipment for supporting a curriculum in robotics education. Therefore, and again from the perspective of each persona, a number of different technologies and tools that can be found in a school or can be easily accessible (by buying or borrowing them), were recorded, leading to the formation of three different lists (one for each educational grade). These lists, combined with the aforementioned qualities that were stressed out, shaped the guidelines for unfolding the sessions of the INBOTS curricula. The description of the 3 personas is available here.

Apart from the aforementioned key considerations, our work draws upon fundamental principles and ideas inherent in the Maker Movement in Education trend as well as additional constructionist educational practices. Teamwork, expression of creativity, hands-on practice, playful explorations, embracement of DIY culture and spirit, problem solving, embodied interactions, as well as storytelling are infused in the sessions towards

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

robotic artefact constructions, adapted to the needs of each target group, namely early elementary (5-6 years old), primary (7-12 years old), and secondary (13+ years old).

In the next sections, a number of methods and practices emerging from pedagogical theories are highlighted and analysed. The ultimate goal is the creation of a solid pedagogical infrastructure upon which the curricula will be developed.

3.4.1 Pedagogical framework and key considerations

The INBOTS curricula invite learners to playfully explore robotic artefacts and meaningfully engage in robotic artefact constructions. Towards this end, the design of the curricula draws heavily upon the learning theory of "constructionism" introduced by Papert and his group at the Media Lab [48]. Constructionism, constitutes an expansion of Jean Piaget's constructivism [48] according to which:

"learning is not the result of a transmission of knowledge, but an active process of knowledge construction, based on the experiences gained from the real world and linked to personal unique pre-knowledge" [49].

The learning experience is stronger when the children construct artefacts and knowledge by playing with and exploring concrete materials [45]. The social context of these explorations is also crucial, and teachers can provide scaffolding by creating a learning environment that supports children's collaborative explorations and experimentation.

The aforementioned social aspect is reflected in the Resnick's creative spiralling cycle of *Imagine, Create, Play, Share, Reflect*, and back to *Imagine* – and is used to describe a process where children "imagine what they want to do, create a project based on their ideas, play with their creations, share their ideas and creations with others, reflect on their experiences – all of which leads them to imagine new ideas and new projects" ([50], p.18).

This spiralling cycle has a place in the INBOTS curricula, and it is used as the backbone of proposed sessions, activities and projects (adapted to the needs of each target group). This spiralling cycle is identified in several activities in kindergarten and based on Resnick, it is worth keeping it live to additional upper educational levels.

In addition, the INBOTS curricula draw inspiration from the Maker Movement in education, a global trend that encourages young students to create and develop new things (digital or non-digital) using new technologies and tools [42,40,39]. Since the INBOTS curricula are intended for classroom deployment, we aspire to bring making practices in the classroom and sow the seeds for a more creative school that values and embraces the DIY spirit and the making culture.

Going through the three curricula one can identify several additional considerations and pedagogical ideas that derive to a great extent from the aforementioned pedagogical theories and trends. The focus is placed on how these ideas have been integrated in the INBOTS curricula.

Building further on the ideas of constructionism

The INBOTS curricula are based on the implementation of projects towards robotic artefact exploration and construction. An idea that is highly embraced is related to the

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

provision of projects that have *"Low floor, high ceiling, wide walls".* The robotic projects, designed under this principle, offer an easy entry for novices (low floor) while enabling more experienced learners to work on increasingly more complicated projects (high ceiling); noteworthy, they have also "wide walls" as they can support a wide range of different explorations [51].

The projects and the activities that are described in the INBOTS curricula are student-centered and bring into focus the concept of *"hard fun"*. The emphasis on "hard fun" refers to the way according to which students become active participants in the learning process through activities that support playful learning and are challenging but not straightforward [45,52].

Interdisciplinary approach to learning

The projects integrated in the INBOTS curricula are also interdisciplinary in nature. Interdisciplinarity/multidisciplinarity is mainly related to the creative combination of more than one subject area. In example, the construction of the robotic DIY automobile, a key session in the INBOTS curriculum for secondary education, invites students to explore concepts from different subject disciplines namely maths, engineering, technology, science, and environmental education. Under this approach, the infusion of arts is also promoted through the INBOTS curricula. Art subjects can impact positively on the development of essential skills like collaboration, communication, problem-solving, and critical thinking encouraging deeper levels of expressing themselves, creating artefacts and responding to challenges.

A note on collaboration and sharing

The National Education Association's guide (2010) [53] on the 4C's puts emphasis on the value of creating collaborative learning experiences in the classroom:

"Not only does a collaborative effort create more holistic results than individual efforts, but it also creates knowledge for a greater number of people. As a result of students working collaboratively, the group can generate more knowledge, making collaboration a key ingredient to student success in today's global society".

It is important to offer students opportunities to practice collaboration and understand that they can build upon the experiences and results of others and others can learn from their own experiences and outcomes. Sharing can be crucial for developing social skills, as well as for enhancing student's self-esteem. The making process itself offers ideal opportunities for teamwork: tinkering and artefact construction support collaborative, iterative design methodology, where student-centered projects prepare students for real-world challenges where group discussion, ideas and knowledge exchange have a place.

The INBOTS curricula deploy a number of strategies towards boosting collaboration and sharing:

Promotion of discussion and brainstorming: The INBOTS curricula invite students to discuss in groups 1) topics related to robots 2) plans for solving robotic challenges 3) plans for communicating and demonstrating the work or the current status of the work.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Provision of feedback: The INBOTS curricula encourage students to exchange ideas and to support one another. Provision and eliciting of feedback is highly encouraged on a regular basis.

Making the learning process and results visible: The INBOTS curricula call often the group of students to present the current status of work or the final artefact in the plenary, to elaborate on their designs and communicate their future plans and ways of dealing with emerging problems.

Design of activities and projects that encourage collaboration: The projects and the activities integrated in the INBOTS curricula are indented for teamwork. Role interchange among the teams is also foreseen.

Fostering embodiment and embodied skills

Embodiment is a rather complex and multifaceted notion. A short research will reveal an extended number of definitions coming from interrelated, but also different, scientific fields, such as philosophy, phenomenology, psychology, cognitive science etc. In summary, the notion of embodiment denotes the physical (and organic) existence of an embodied entity, namely of an organism who perceives, communicates, and interacts with her/his environment (spatial and social) through her/his body and mind [54, 55, 56, 57, etc.]. Therefore, through her/his embodied skills (senses, memories, behaviours, movements, gestures, feelings etc.) a person is able to feel, perceive and shape her/his lived experience over the world [58, 59, 60, 61, 62, etc.]. In this sense, the notion of embodiment is also closely related to the learning ability and process (especially in tasks that are implicitly or explicitly related to spatiality).

The notion of embodiment can be considered as one of the main key words on the development of STEAM related educational activities in two ways:

The first one concerns methods and activities that are mostly addressed – and in the context of INBOTS suggested – to preschool or/and primary school curriculum. Since embodiment is inextricably related to a person's sense of self-awareness for her/his presence in a specific place, it is considered as the most proper notion to describe activities concerning the familiarization of students with new technologies through their own body. Terms such as, self-awareness, spatial awareness, social awareness, and sensory perception can be considered suitable for generating questions regarding students' embodied experience. Moreover, sensory perception reflects all the embodied skills that are included and applied during kinaesthetic learning (i.e., performing physical activities, making sense of the world through their body, reflecting this knowledge to another person through oral commands or recreating this somatic experience by using a robot etc.).

The second one concerns methods and activities that are mostly applied to the Secondary School curriculum. In this age group, the suggested activities are more advanced as far as concept and interactivity are concerned, while hands-on activity has a principal role. Thus, the sense of embodiment is considered as an already obtained skill and is mainly approached through the lens of embodied interaction, a parameter that reveals the embodied skills that should be taken into consideration in the process

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

of designing an interactive object or environment [63, 64, 65, etc.]. In this sense, students should be encouraged to include bodily skills as a main parameter to the design process of an interactive artefact, so as to determine easier the nature of input and output components (sensors, switches, motors etc.). If, for example, their intention is to create an artefact that is buzzing an alarm when some kind of movement is detected, then they should determine what kind of movements want to trigger their system so as to search for the proper electrical components. This information can also determine the scale and the form of their construction. Students should be also encouraged to get familiar with experiences that are related with feelings such as success or failure, and reflect their thought upon these experiences, since it is argued that these behaviors can be related to methods of obtaining knowledge, through recalling previous gained learning experiences [62].

Seeing learners as explorers and designers of games

Gaming is also an intricate and multidimensional notion, which can be perceived not only as a playful act of escaping from reality, but as an engaging activity associated with social life (Leach in [66], p.328). A game can be considered as "a problem-solving activity approached with a playful attitude" ([67], p.37), and as a spatial situation that combines a number of rules (inspired by real life) with fiction ([68], p.163), while being characterized -among others - by interactivity ([67], p.34) and decision-making processes towards a meaningful outcome [69]. There are four basic elements that constitute a game and these are: mechanics (namely the procedures and rules of the game), story (sequence of events that unfold in the game), aesthetics (elements concerning the general experience denoted by a game), and technology (any medium that activates and shares the aforementioned three elements, making the game feasible) ([67], pp.41-42).

Games are "per se motivating" [70] and are inextricably related to the act of playing [67, 69]. In this sense, they should be also linked to the process of learning ([71], p.3). Games, such as video games and particularly those belonging to the field of "serious games", are "information-rich" interactive environments and therefore are considered as valuable tools for STE(A)M related learning activities since they are enhancing the acquisition of knowledge, while supporting behaviors of exploration, problem solving and team-building ([72], p.80; [70]). In addition, they are having a positive impact on skills such as "communication, adaptability and resourcefulness" ([73], p.96). All these assets are not only related to the act of playing, but also to the act and process of designing. After all, as Bogost argues (in [66], p.307), a reason that we are playing games is to make sense of the possibilities lying behind them and think of their implications in our daily life.

According to [70], p.5, designing and using games (and particularly serious games) are highly interrelated to constructivist learning theories about the creation of knowledge through the experience of "exploring the world and performing activities". Thinking of ways that new technologies could be implemented for integrating play, design and learning – and based on Kafai's documentation on elementary school students who became more creative thinkers through designing their own games – [71], p.4 argues that a possible way could be through providing children "the opportunity to design their own games". As a result, he and his research group in MIT, in collaboration with Kafai,

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

developed Scratch, the block-based programming environment (*proposed here together with additional block-based programming environments as a tool in primary school educational curricula*) that enables novices to apply programming concept for instructing different elements, thus designing interactive digital models (games included) through a rather playful and pedagogically meaningful process.

Several programming environments and robotic kits promoting constructivist learning theories and strategies of gamification have been developed since then. Makey-Makey for example (which is also introduced in primary school educational curriculum*)* can enable learners to extend virtual games to the physical environment, adding the parameter of embodiment to the design process. Towards this direction and through the implementation of such technologies, the proposed curricula introduce the notion of game in two ways:

through the lens of playing in early and primary education and by introducing strategies and practices of role playing, storytelling as well as collaboration, while fostering learning activities that encourage students to progressively create their own artefacts, shifting the entire process from playing to designing.

through the lens of designing and resourcefulness in secondary education by adopting strategies of gamification (exploring real scenarios, solving problems, communicating and sharing the content) and implementing them through the creation of (interactive) robotic artefacts.

Putting forward "storytelling" practices

"We are educated and motivated by Story, and a good story telling can change our perspective, give us new insights, shape our dreams and desires" (Bigbeacon site: [http://bigbeacon.org/2013/12/twitter-chat-2013-12-11-8-pmstorytelling-in-stem-education/)](http://bigbeacon.org/2013/12/twitter-chat-2013-12-11-8-pmstorytelling-in-stem-education/).

Stories are inextricably related to the nature of human communication [74]. Over time, it is through stories and storytelling that people share their ideas, their culture and their values [74]. In a sense people are defined through and by their stories [75].

Studies report that narration (and consequently storytelling) has a major impact on learners through building a sense of connection among them and consequently motivating them to engage in cooperative behaviors [76, 74]. It is also argued that learners can become easier engaged in activities when information is presented in a form of story (and not as a list of bullets, a short text etc.), since they are able to easily remember and grasp the content and the context of the task. Moreover, if storytelling revolves around characters and role adaptation methods, learners feel that they are related to the entire process in a more mediate way.

Storytelling coupled with STEM methodologies/practices, can address the integration of interdisciplinarity across the curriculum (since it assists students to "think more critically about the interconnectedness between the many branches of science and the world as a whole"), which leads to reaching the learning needs of the majority of the students, and especially the female students (who tend to perceive STEM activities as more creative and artistic when storytelling is included) [77,78,79]. For example, there are teachers who implement texts from novels as the vehicles for carrying the concept of a lesson (i.e. Maths, Physics etc.) [78, 79].

Therefore, the INBOTS activities and projects (included in several sessions of the present curricula) aim to familiarize students with several robotic challenges that are engineered through a story/narration/plot. In a more advanced stage, the learners are encouraged to collaboratively create their own stories and/or narrations that act as vehicles of robotic challenges practicing further their creative and critical thinking as well as their problem solving skills.

Pushing against tool-oriented approaches

Last, the INBOTS curricula invite teachers and educators to explore a variety of affordable constructive technologies and tools towards robotic artefact construction. In other words, the curricula are not tool-oriented. Indicative tools that can be used are mentioned and alternative solutions are also presented. Noteworthy, at a great extent an attempt is made to propose the use of open-source, low-cost technologies and tools that can be used by the learners to move from passive receivers of knowledge to explorers and makers or robotic artefacts.

With inspiration from the aforementioned educational constructionist pathways and modern pedagogical approaches, the INBOTS curricula propose a flexible educational scheme that aims at encouraging students to explore, create, re-create, assembly and extend robotic artefacts by using low-cost technologies, tools and everyday materials. The success of classroom learning is dependent on how students relate to one another, what the classroom environment is, how effectively the students' collaboration and communication is and the roles that the teachers and the students play. Below the roles of teachers/educators and the learners within the classroom where the INBOTS curriculum is applied are described:

Teacher role: the teachers are not the sages on the stage, and they are not supposed to have all the answers to the questions that may emerge. They rather help and encourage the students to explore and construct their own knowledge, to organise their thoughts and ideas, to work effectively in teams. They encourage teamwork, experimentation, hands-on activity, challenge seeking and the sharing of knowledge. As Seymour Papert (1993) [45] advocated, "the role of the teacher is to create conditions for invention rather than to provide ready-made knowledge". Through questions and observations, the teacher engages students in articulating and extending their own observations, through processes, and explorations. The teacher may not directly answer students' questions but rather show them how to find it themselves. This kind of exploration fosters an environment in which what we often see as "failure" is actually a natural step of the learning process, a signal to ask questions and explore further. A shift from teacher control and decision making over students' learning can support students to develop self-regulation and become independent and effective learners The INBOTS curriculum embraces this approach and encourages teachers to take several roles (the roles of the mentor, trainer, facilitator of the learning process, self-esteem booster, co-maker, co-learner, evaluator) and adapt their support and guidance based on the needs along the way.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Role of learners: In going through this process, school students develop and refine their abilities as creative thinkers. They learn to develop their own ideas, try them out, test the boundaries, experiment with alternatives, get input from others – and, perhaps most significantly, generate new ideas based on their experiences (extending the given project scenarios). They also learn to develop concept-generated ideas through the implementation of storytelling-oriented activities (this is mostly applicable to primary school students).

3.4.2 Learning Objectives

Making in education with an emphasis on robotic artefact construction, may address specific learning content, for example electronic circuits, programming structures, engineering concepts, debugging procedures and more. Besides STEM and technology interest, knowledge and competencies, this includes creativity, innovation skills development, artistic expression and problem solving. Maker students are active learners, with a high need to explore, to discuss and to share experiences and ideas. Also, social and personal competences are to be included in our potential learning goals. In general, the skills of creating and innovating can have a broad impact on students' lifelong learning and ultimately for education and society [41].

In pre-school education (Table 2), the curricula focus on the familiarization with robotic artefacts. Through age-appropriate tools (i.e., tangible robots, tile-based visual coding etc.) and embodied tasks, kindergarten children are encouraged to identify a robotic artefact and implement simple programming commands. In primary school education (Table 3), the students will also become familiar with hands-on practices (i.e., crafting, electrical circuit making), while being acquainted with certain techniques of programming, turning the entire process of coding from something abstract and ambiguous to a more concrete and meaningful procedure. Multimodality is also promoted through the introduction of additional methods for supporting learning experiences such as storytelling, use of role-playing games and more. Finally, in secondary education (Table 4) through the introduction of open-source technology and the engagement in DIY projects students learn how to put the already gained knowledge to a context, and progressively support their own ideas towards robotic artefact construction.

Through the proposed curricula, attitudes such as expressing self-confidence in solving robotic tasks, as well as positivity regarding working together with other people are foreseen. Boosting students' self-confidence on forming new ideas and making recommendations as well as exploring their own abilities and skills through the adaptation of different roles are also encouraged.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 2: learning objectives for 5-6 years old students.

5-6 years old **Learning objectives**
Knowledge
- to explain what robot is - to explain what a robot does - to identify robots in their daily life - to explain in simple words what an electrical circuit is - to name materials and items that can be used for making circuits - to identify and explain how symbols and icons are used to communicate a message/address a behaviour - to describe the various ways that robots can move
Skills
- to put directional commands in a sequence - to make lines and figures using floor robots - to create stories/plots for the floor robot - to test different sequences of icons/commands - to solve robotic challenges collaboratively - to create electrical circuits using simple materials
Attitudes
- to express self-confidence in solving robotic challenges - to participate meaningfully in classroom activities -to express positive attitudes regarding team work -to direct an effort to achieve a desired result - to propose ideas and make suggestions for overcoming problems - to formulate questions related to the behaviour of the robot - to creatively express themselves

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 3: learning objectives for 7-12 years old students.

7- 12 years old **Learning objectives**
Knowledge
- to describe what a robot is and what it can do - to name robots that are used in daily life - to describe what a command is - to explain what a sequence of commands does - to recognize everyday symbols for addressing directional commands - to distinguish between conductive and non conductive materials - to name basic electrical components - to explain with simple words how an electrical circuit works - to demonstrate a scenario with robots - to explain basic programming constructs/concepts
Skills
- to program a robot using icons and/or block-based commands - to trace visual code - to assembly electrical components - to use conductive items - to experiment with alternative ways or more optimal ones for controlling the robot - to give directional commands - to make measurements in order to instruct the robot reach a goal - to make figures and shapes using mathematics and geometry - to direct others with oral guidelines (orientation skills) - to interact with others in order to find solutions - to create their own games/stories/plots - to organise and plan their work towards robotic artefact constructions

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Attitudes
- to express self-confidence in solving robotic tasks -to express positive attitudes regarding working together with other people -to direct an effort to achieve a desired result - to form new ideas - to make recommendations regarding optimal solutions - to appraise scientific work in the area of robotics - to formulate questions related to the behaviour of the robot - to value artwork - to creatively express themselves

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 4: learning objectives for 13+ years old students.

13+ years old **Learning objectives**
Knowledge
- to explain what the field of robotics is -to define what a robot is - to identify and explain how block-based commands and constructs are used to communicate a message/address a behaviour - to explain what sensors are and how they work - to discuss on how robots facilitate real-life situations - to explain what a script does - to explain what conductivity is - to identify electrical components - to explain how an electrical circuit works - to explain basic programming constructs/concepts
Skills
- to construct a robotic artefact using simple materials - to re-use materials towards creating something new - to create electrical circuits as part of a robotic construction - to use programming commands to address a specific behaviour to the robotic artefact - to experiment with alternative solutions regarding programming and modelling - to program a robot so that to interact with the environment (using sensors and actuators) - to build or construct a robotic artefact following a design process - to exchange ideas and views in groups regarding emerging robotic challenges
Attitudes
- to express self-confidence in creating robotic artefacts - to set a plan for overcoming problems/challenges

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

-to express positive attitudes regarding working together with other people -to direct an effort to achieve a desired result - to form new ideas and make recommendations - to creatively express themselves -to appraise scientific work in the field of robotics - to express positive attitudes towards scientific careers - to value experts' opinions and build upon them

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

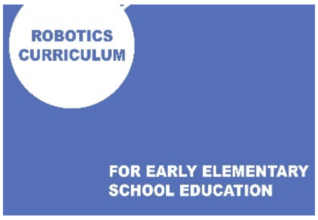
3.4.3 Presenting the INBOTS curricula

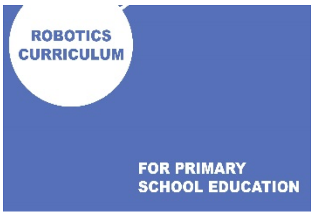
The INBOTS curricula include several proposed activities in the form of sessions. The sessions are gradually introducing and involving students to the Do It Yourself (DIY) culture and making practices, taking into account the diversities that can be met in a school class as far as the background on new technologies are concerned. The variety of ages included in each educational group constitutes another critical parameter. There are no compulsory sessions. However, the links between the sessions are mentioned. Therefore, it is up to teachers/coaches to choose among those that fit better to their class needs and dynamics. Additional educational practices such as storytelling, role-playing in the class, connections with experts/scientific community, and engagement in information searching online on specific topics are also introduced through the INBOTS curricula.

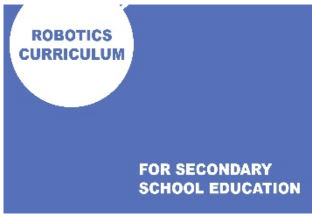
Each session follows a basic structure, and for each educational group there are some common stages, such as introduction to the activity (mainly through warm-up activities or collaborative challenges), brainstorming and planning, work in groups, sharing and free exploration of new ideas.

Each session (in the curriculum) is accompanied by a short description, the outline of the session, the activities that students will perform, the learning objectives, as well as the resources that can be used (including resources that have been specifically designed for the INBOTS curriculum and others that are freely available online and can be reused in the context of the proposed activities), a list of indicative technologies that can be used and the knowledge that is pre-required. The time per session may vary and can be extended or shortened given students' needs and group dynamic.

The pictures below are linked to the curricula. The open educational resources are accessible through links in the end of the sessions included in each curriculum.







3.4.4 Technologies and tools (mentioned in the three curricula)

Educational robots

Kubo: https://kubo.education/

Blue-bot: https://www.terrapinlogo.com/products/robots/blue/blue-bot-family.html

Bee-bot: https://www.terrapinlogo.com/products/robots/bee/bee-bot-family.html

Pro-Bot: https://www.terrapinlogo.com/products/robots/pro/probot.html

Botley: https://www.learningresources.com/shop/collections/botley

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Roamer: https://www.roamer-educational-robot.com/

Colby mouse: https://blog.generationrobots.com/en/tutorial-robot-mouse-colby/

Cubelets: https://www.modrobotics.com/

Thymio: https://www.thymio.org/

Dash: https://www.makewonder.com/robots/dash/

Dot: https://www.makewonder.com/robots/dot-creativity-kit/

Edison: https://meetedison.com/

Platforms

Little Bits: https://sphero.com/collections/all/family_littlebits

Chibitronics: https://chibitronics.com/

Makey-Makey: https://makeymakey.com/

SnapIno: https://shop.elenco.com/consumers/snapino.html

Arduino: https://www.arduino.cc/

Software and apps

Wonder Workshop INC:
https://play.google.com/store/apps/developer?id=WONDER+WORKSHOP,+INC.

Edscratch: https://meetedison.com/robot-programming-software/edscratch/

Scratch: https://scratch.mit.edu/

Microsoft Makecode Editor: https://makecode.chibitronics.com/

mBlock: https://mblock.makeblock.com/en-us/

Snap4Arduino: http://snap4arduino.rocks/

Open Roberta Lab: https://lab.open-roberta.org/

TinkerCad: https://www.tinkercad.com/learn/circuits

App Inventor: https://appinventor.mit.edu/

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

4 Accessible Educational Resources for Teaching and Learning Robotics

In this section, we revise online available educational material, including videos, podcasts, and coding tools, aimed at facilitating the learning of robotics related topics at different education levels including universities, schools (students and teachers), professionals, and general public. The potential of e-learning for robotics is still under-exploited, and here we provide an updated list of resources that could help instructors and students to better navigate the large amount of information available online. This research has been published in the paper

- Pozzi, M.; Prattichizzo, D.; Malvezzi, M. Accessible Educational Resources for Teaching and Learning Robotics. *Robotics* **2021**, *10*, 38. https://doi.org/10.3390/robotics10010038
  The paper is open-access and can be accessed from the following link: https://www.mdpi.com/2218-6581/10/1/38 and it appears in the This article belongs to the Special Issue Advances and Challenges in Educational Robotics

All the resources mentioned in this section are summarized in the Appendix and reported in file available online (link) that will be updated also after document release.

Robotics has considerably improved industrial processes and is expected to become soon an important part of our daily life, since it has started to face more human-centered problems [80].

Important technological innovations (e.g., the miniaturization of mechatronic components, the development of resistant but compliant materials that can be processed by additive manufacturing technologies, etc.), as well as relevant advancements in control and learning methods for robots, led to the construction of lightweight robot arms able to effectively co-work with humans [81, 82, 83], humanoid robots that can physically and cognitively interface with their surroundings in a human-like fashion [84, 85], intrinsically soft robots capable of safely interacting with the environment [86], and wearable robots that can significantly improve the quality of life of impaired people [87] . In other words, robots are starting to be ready to work alongside humans, not anymore confined in industrial environments or research laboratories [88]. Are we, humans, ready for collaborating with robots?

The rise of Human-Centered Robotics not only poses questions about the socio-economical, legal, and ethical impact of robotics on the society, but also challenges educational systems to promote and create highly accessible learning and training material on robotics related topics.

Robotics is an interdisciplinary subject whose possible applications involve traditionally separated domains: the engineering domain (e.g., mechanics, electronics, computer science), the human physical domain (e.g., physiology, ergonomics, anatomy), and the human non-physical domain (e.g., psychology, ethics, economy). Even though each discipline addresses robotics from a different point of view and with a different level of detail, establishing a common ground of knowledge (terminology, basic notions, expectations, etc.) could encourage a fruitful discussion and collaboration between such manifold realities. The availability of accessible learning resources of different types and with different target audiences is fundamental to reach this aim.

Depending on the individual background and objectives, one can choose to approach the study of robotics in various ways. In this paper, we collect and analyze accessible educational resources that

i) explain basic and advanced robotics concepts through structured on-line courses (Section 4.2),
ii) inspire audience through brief talks, tutorials or podcasts on specific robotics related topics (Section **Error! Reference source not found.**),
iii) allow to learn robotics from practical experience (Section 4.4).

A preliminary version of the review on accessible resources for learning and teaching robotics was presented in the preliminary version of this document, and summarized in [89], listing only online courses and toolboxes. In this document not only we expanded and updated the list of online courses, but we also included other types of educational material, and conducted a more detailed analysis of the selected resources in terms of treated topics and target audience. Recently, the main advances in educational robotics, which is an active research area studying devices and methods to teach robotics and with robots, were summarized by Evripidou et al. [90]. In [91], Esposito analyzed the main tools and methods that are used to teach robotics at a university level, including textbooks and software environments, and underlined that only few instructors rely on online material. In this paper, we focus on online available resources, as we believe that an updated overview of the available educational material on robotics can be beneficial, especially in view of the increased demand of e-learning tools due to the COVID-19 pandemic [92] [93].

4.1 Methods

4.1.1 Classification criteria

The objective of this study is to provide a possible *map* for orienting a learner interested in robotics among the heterogeneous amount of material available online. This section illustrates how we selected and classified the resources. As a first step, we divided the analyzed resources into three main sets:

- Resources requiring a sequential access, i.e., in which a predefined order has to be followed to fully understand the contents.
- Randomly accessible resources.
- Resources for hands-on learning.

The first set of resources is intended to provide the contents typically covered in a course (e.g., in a Master Degree course). Among these resources we identified two eminent subsets: Massive Open Online Courses (MOOCs) and Lecture Series.

MOOCs are designed and organized as on-line resources: besides video contents other material is often provided (e.g., text and slides containing additional notions, tests for self-assessment, etc.) and offer the possibility to get an official certificate.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Lecture Series are typically the recordings of lectures held in academic courses, which were originally intended as support and integration material for the course attendees, but thanks to their accessibility became a useful resource also for students from other universities, or even for the general public.

The second set includes all the resources that can be easily accessed without following a predefined order. They provide small, focused video and/or audio contents, that typically can be understood without a prior specific knowledge. In this second set we included YouTube thematic channels, thematic talks from TED and TEDx conferences, and podcasts.

In the last part of the study we collected a set of tools and activities that are useful to learn by doing robotics. In this set we reviewed in particular tools that are highly accessible also for distance learning, namely software simulation tools and guidelines and manuals for building robots. We also reviewed the most relevant robotic competitions and challenges.

4.1.2 Selection and inclusion criteria

For each type of resource, we adopted different selection and inclusion criteria, as detailed in the following.

4.1.2.1 RESOURCES REQUIRING SEQUENTIAL ACCESS

MOOCs. The research on available MOOCs on robotics started on the Class Central website [94], a well-known search engine for MOOCs, and then was refined by scanning the webpages of the most diffused MOOC providers (e.g., Coursera, edX, FutureLearn, etc.).

For each identified course, we reviewed

- the contents and organization,
- the accessibility and costs
- contents,
- potential users,
- required prior knowledge.

During the research we identified also courses where robots do not represent the subject, but are the object of the course. For instance, in the course on *3D Model Creation with Autodesk Fusion 360* [95] provided by Coursera the attendee is guided in the design of an Unmanned Aerial Vehicle (UAV), but the focus of the course is the design process, rather than the designed robot. Courses where robots are not the main subject have not been considered in this review for the sake of brevity.

In general, we privileged resources in English, as they can be understood by a vast audience. However, in the list of courses targeting school students and teachers, we also included MOOCs in other languages, because, in this case, having material in the native language can better support the learning process.

Lecture Series. Concerning Lecture Series, we selected the resources from eminent scientists active in robotics. The courses were selected on the basis of their coherence

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

and completeness. Some of these courses are available on YouTube platform, other ones have a dedicated web page where additional material can be downloaded.

4.1.2.2 RESOURCES ACCESSIBLE IN AN ARBITRARY ORDER

Thematic channels on YouTube. YouTube offers collections of videos that are not intended as courses but provide insightful contents that can be used as teaching and learning material. In this paper, we presented some resources that were selected based on prior knowledge, integrated with a specific research on YouTube including the words "robotics", "thematic", "channels". For each identified resource we evaluated: the coherence of the treated themes, the quality and originality of the proposed contents, the number of views and subscribers, whether the resource was still active and updated.

Podcasts. Podcasts represent another informative channel that is spreading and getting interest as an integration of learning tools. In this paper, we provide a review of the currently available thematic podcasts regarding robotics. The resources, that have been identified based on prior knowledge and an internet research, have been selected according to the coherence of the contents and the update frequency.

TED talks. Other interesting resources providing insightful perspectives on robotics are TED conferences. The contents of TED talks can be accessed either as videos or as podcasts. In this paper, we reviewed and identified some relevant TED talks that tackle robotics from very different points of view, ranging from technology to psychology, art and history. The search was carried out on the TED webpage [96], and our selection privileged talks with a multidisciplinary perspective.

4.1.2.3 RESOURCES FOR HANDS-ON LEARNING

Programming and building robots

A comprehensive review of educational robotics technological resources for STEM subjects in schools has been recently published in [97]. In this paper we focused in particular on resources easily accessible also in distance-learning conditions and we selected a set of software frameworks specific for the academic level and a set of online platforms guiding in the realization of simple robotic systems. The resources were included on the basis of prior knowledge integrated with a specific online research.

Competitions

Competitions and challenges represent an interesting but heterogeneous set of activities, whose purposes are different and range from the application of the most advanced research results by scientists and engineers, to learn-by-doing robots with simple and accessible toolkits realized by primary school students. In this review we collected the most widely known international competitions, selected on the basis of prior knowledge and integrated with a specific research, with the aim of highlighting different types of application and participants.

4.1.2.4 PRELIMINARY COMPARISON

A preliminary overview and comparison between the resources analyzed in this section is presented in Table 5, in particular we highlighted the required access criteria (sequential or random), the type of provided contents, if it's possible to get credits or

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

certifications for attending a specific initiative, the average level of specialization, if they are free of require a fee payment. Challenges have not been considered in this first comparison.

Table 5: Preliminary comparison between the analysed resources.

Resource	**Access order**	**Type of content**	**Credits/ certification**	**General/ specialistic**	**Free/ paid access**
MOOCs	Sequential	videos, reading material, tests for self-assessment	Yes	Specialistic	Typically free access for learning material, they often require a fee for getting the certification
Lecture series	Sequential	videos, reading material	No	Specialistic	Free
Youtube thematic channels	Random	video	No	General	Free
Podcasts	Random	audio	No	General	Free
TED talks	Random	video and audio	No	General	Free
Tools for programming and building robots	Sequential	software, videos, reading material	No	Specialistic	Free/ paid access

4.2 Resources requiring sequential access

In this section we present currently available on-line courses in the form of Massive Open Online Courses (MOOCs) and video lecture series. Similarly to books and standard school and university courses, these resources require to be studied in a sequential order to gradually enter into the subject and acquire knowledge step by step, and are taught by worldwide recognized experts in the field. The lists of resources that we found are reported into tables in the Appendix reported in Section 0.

4.2.1 Massive Open On-line Courses (MOOCs)

Massive Open Online Courses (MOOCs) are the most relevant available resources for digital autonomous learning [98]. Since their introduction, the trend of MOOC diffusion has been steadily increasing [99]. In 2020, there has been a relevant boost in the number of enrolled students in 147 MOOCs [100], mostly as a consequence of the

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

COVID-19 pandemic which forced nearly 1.6 billion 148 students worldwide to remain at home [101].

Most of the MOOCs are delivered on global platforms. Those having the highest numbers of registered users are, in order, Coursera (founded by Andrew Ng and Daphne Koller, Artificial Intelligence Lab, Stanford University), edX (MIT and Harvard), Udacity (a byproduct of Sebastian Thrun's free computer science classes by Stanford University), and FutureLearn (Open University).

MOOC platforms not only provide students with educational material, but also allow them to track 154 their progress and to benefit of other services (possibly through the payment of a fee), such as institutional credits, certificates, human tutoring or assignment marking, and proctored examinations.

Almost the 30% of MOOCs available in 2020 teach Technology, Engineering, or Mathematics 157 related topics. We analyzed MOOCs dealing with different aspects of Robotics and classified them according to the intended target audience and the treated topic.

Courses developed for university students include single courses as well as Specializations including more than one MOOC (see Table A1 and Table A2 in the Appendix). Most of the times these courses require basic knowledge of calculus and physics and are developed through the collaboration between an online platform and a University.

It is also possible to find MOOCs addressing school students and teachers (see Table A3 in the Appendix). These courses are sometimes delivered in languages different from English (e.g., Spanish, French) and allow learners to familiarize with robotics related concepts or to build and use specific educational platforms.

Educational Robotics has become and important research area and several robotic kits have been released in the last years [102]. In schools, robots can either be the subject of study, or the tool through which other subjects are taught [103].

Robotics has already and will continue to have a profound impact on society. Therefore, it is important to create and distribute educational contents related to the ethical, social and economical implications of the introduction of robots in human contexts. Several MOOCs address this topic (see Table A4 in the Appendix), targeting a wide and interdisciplinary public.

Notwithstanding the tools and resources available at different education levels, from the analysis of the state of the art, we realized that only a few online resources are dedicated to the training of professionals and workers. Table A5 in the Appendix includes two MOOCs that go in this direction and target two different applications of robots. The first is an introduction to the state of the art and challenges of medical robotics. The second tackles safety standards in collaborative robotics. Both MOOCs address a specific application domain but are still far from providing specific training to operators (e.g., healthcare professionals, surgeons, workmen, etc.) that need to use a certain robotic system to carry out their work. Usually companies, as well as healthcare facilities, organize their own internal courses or collaborate with external public or private institutions to provide workers with the required knowledge to use specific technologies.

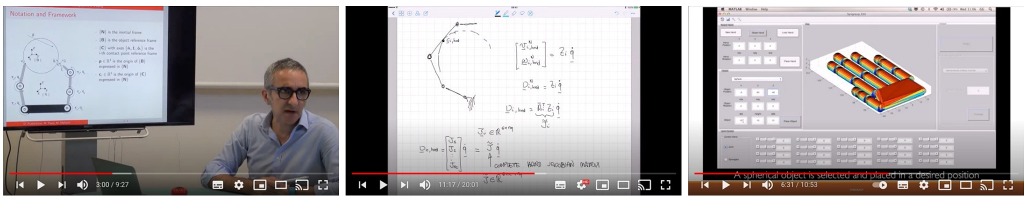
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

As a conclusion of this overview, it's worth to highlight an ongoing initiative promoted by Prof. Siciliano, entitled "Robotics goes MOOC" [104], that will be released in 2021. The initiative includes the organization of a MOOC – offered through Federica Web Learning – and the publication of a book, that is part of the Springer MOOC & BOOK project, based on the online course, with the aim of combining the quality of a scientific text with the communicative power of an online educational product. The contents of the book and online course cover the state-of-the-art overview of various aspects of the rapidly developing field of robotics.

4.2.2 Lecture Series

In addition to MOOCs, there are other online resources that can help students learning robotics in a "sequential" way, i.e. lecture series on YouTube or other platforms (see Table A6 in the Appendix). These series usually consist of playlists of videos shot during in person lectures and are offered for free, without the additional services typical of MOOC platforms.

One of the most famous lecture series on robotics is the "Introduction to Robotics" by Prof. Khatib, that is online since 2008 and is hosted on the Stanford Engineering Everywhere (SEE) website. Also the lessons by Prof. Anarnath are online since 2008. Prof. De Luca recorded and shared both his courses on robotics and Proff. Lynch and Park complemented their book entitled "Modern Robotics" [105] with almost 100 video lectures. Courses on more specific topics include "The Art of Grasping and Manipulation in Robotics" by Prof. Prattichizzo et al. (Figure 1), "Programming for robotics (ROS)" by Prof. Fankhauser et al., and "Evolutionary Robotics" by Prof. Bongard.



a) b) c)

Figure 1. Three screen shots from the "The Art of Grasping and Manipulation in Robotics" by Prof. Prattichizzo et al.; a) basic definitions, b) robotic grasp modelling, c) simulating robotic grasps with Syngrasp toolbox [106].

4.2.3 Main Topics of MOOCs and Lecture series

We identified four main categories of online courses based on the treated topic: Robotics Foundations,

- Advanced Robotics,
- Robot building and programming,
- Societal impact of Robotics.

The first one includes lectures that deal with the very foundations of robotics either at a beginner (e.g., "Robotics Specialization" on Coursera), intermediate (e.g., "Modern Robotics Specialization" on Coursera) or advanced level (e.g., "Robotics" on edX). The second accounts for courses which focus on specific types of robots or advanced

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

algorithms for robotics. The other two categories include MOOCs and lectures about more practical aspects of robotics and about the challenges that need to be faced for facilitating the social uptake of Robotics. As shown in Figure 2, the majority of available MOOCs and Lecture series deal with Robotics Foundations.

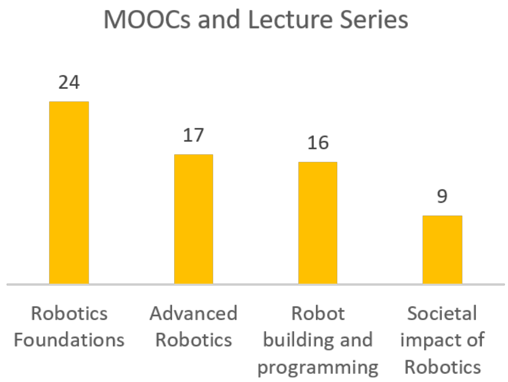


Figure 2. Treated topics of MOOCs and Lecture Series on Robotics. Note that we counted each one of the MOOCs included in Specializations as a separate item.

4.2.4 Preparing a Lecture series or a MOOC: design choices and lessons learned

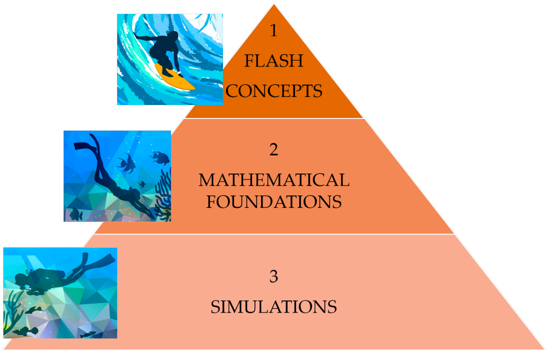
The main challenge for an educator that creates an online course (a MOOC or a lecture series) is to avoid that students get "lost in information". The learning flow must be clearly stated from the beginning, and video lectures must explain one, or maximum two, important concepts at a time. For example, in the context of robotic grasping and manipulation, the well-known book written by Murray et al. in 1994 [107] is a complete and fundamental reference textbook for the study of robotic manipulation. However, it can be very complex to understand for students without a strong background in robotics or mechanical engineering.

In the design of the lecture series "The Art of Grasping and Manipulation in Robotics" [108] we adopted a pyramidal course structure with three main levels of learning (Fig. 3) to encourage self-learning and create educational resources suitable for a diverse public We called them "Surfing", "Snorkeling", and "Scuba Diving" to transmit the idea that level by level, students will get a deeper and deeper understanding of the subject. People who have never studied robotic grasping will start by scratching the surface of the topic through very concise lectures explaining basic concepts (Level 1: "Surfing"). These concepts will be then examined in depth by looking at the underlying math, with equations and rigorous proofs in Level 2: "Snorkeling". Level 3: "Scuba Diving" will allow students to apply the knowledge acquired in previous levels to code simulations with the SynGrasp MATLAB Toolbox [106].

The MOOC on The Art of Grasping and Manipulation in Robotics was recorded during real lectures and is structured in 4 units: the first belongs to Level 1, the second and the third to Level 2, and the last to Level 3 (see Fig. 3). Unit 1 explains basic notions for understanding robotic grasping, including the difference between power and precision grasps, the friction cone, and the Grasp Matrix. Units 2 and 3 explain the mathematical

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

model of a grasp and how it can be used to design proper control strategies for grasping tasks. Unit 4 introduces the features of SynGrasp Toolbox and proposes some simulation exercises to the students. Instead of relying on a specific MOOC platform, we published the MOOC in YouTube Playlists that can be retrieved from the website of the course. This choice has the main drawback that students cannot get a certificate after the course but guarantees a wide spread of it.



Level	Contents
Level 1 ("Surfing")	Unit 1: Basic concepts
Level 2 ("Snorkeling")	Unit 2: Grasp modelling
	Unit 3: Grasp control
Level 3 ("Scuba Diving")	Unit 4: SynGrasp

Figure 3. Levels of learning and how they were implemented in the "The Art of Grasping and Manipulation in Robotics".

4.3 Resources accessible in an arbitrary order

In this section, we review the main resources on robotic education that can be easily accessed and that do not need to be followed with a fixed sequential order. Internet has made available and highly accessible a huge amount of informative and educational material in all the knowledge sectors, including videos, articles in magazines and journals, newsletters, podcasts, webinars, etc. These resources provide several opportunities:

- educators can include them in their lectures to clarify concepts that are difficult to be understood with traditional means;
- students can integrate their knowledge by themselves;
- people in general can access them to be informed and updated on the topics they are interested in.

4.3.1 Thematic channels on YouTube

The use of YouTube videos by STEM instructors is common [109]. Many of them show videos during their lectures to explain concepts that are difficult to be understood by static images [110].

Although there are some studies analyzing the impact of online videos resources on education, especially in STEM courses, only a small amount of data are available about students' voluntary use of YouTube videos to learn topics taught in their courses. The problem could be tackled from another point of view, by analyzing the performance in terms of views and interactions of YouTube videos and channels dealing with science and technology communication. In [111], an analysis of the factors influencing YouTube videos about science communication was performed. The study highlighted the role of the authors (professional-generated contents vs user-generated contents) and the impact of having a consistent science communication or not. Rosethal also analyzed, by means of an online survey, the amount of internet users that watch science videos on YouTube for learning and information purposes [112].

Besides the opportunities, the availability of highly accessible partially controlled dissemination videos as the ones available on YouTube could have an impact on how the people perceive robots from the psychological and moral point of view [113].

In this study, we analyzed a set of thematic YouTube channels about robots and robotics. The channels that were considered in the analysis have been identified as the first ones resulting from a standard web research on the Google search engine and are summarized in Table A7 in the Appendix, ordered according to their popularity (in terms of number of subscribers). It is interesting to notice that 8 out of 13 channels are the official communication channels of relevant companies in the robotics community (e.g. Boston Dynamics, Kuka, ABB, etc.), whereas the other ones are user-generated contents. It is also worth mentioning that user-generated channels have the highest popularity ranks: 4 out of 5 are within the 5 channels with the highest number of subscribers (see Fig. 4). In addition, 4 out of 5 user-generated channels have a clear orientation on providing contents for education and training.

Although the analysis is only partial, since the number of available resources is high and continuously changing, it is evident that this type of highly accessible resources represents a concrete opportunity for learning about robotics even outside a structured educational framework.

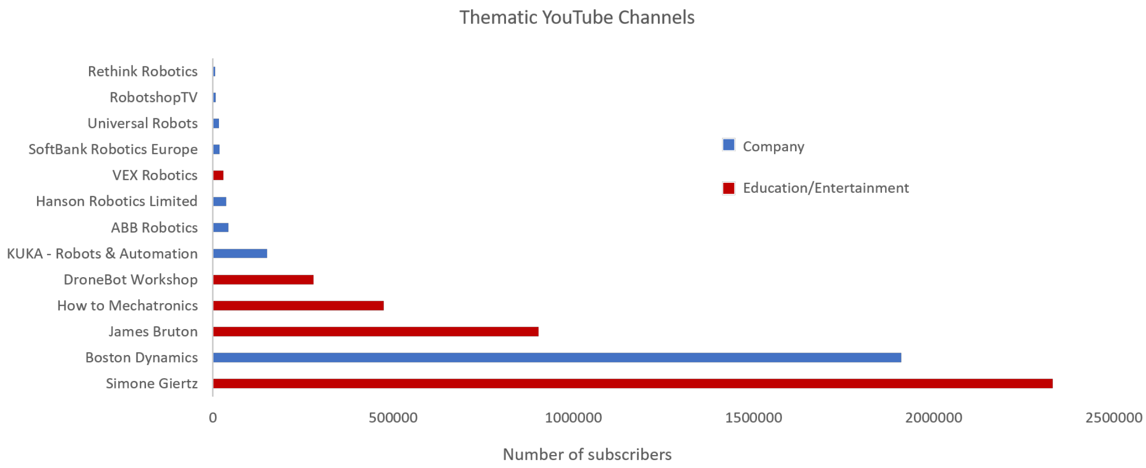


Figure 4. Number of subscribers of the main YouTube channels on Robotics (updated in December, 2020).

4.3.2 Podcasts

Podcasts allow people "to listen to what they want, when they want, where they want, and how they want" [114]. This sentence well summarizes the advantages of podcasts and the reasons why they are becoming increasingly popular. Podcasting also represents

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

an emerging educational tool and studies on the educational potential of podcasts have been conducted at different levels [115,116].

Podcasting offers the opportunity for lecturers, educators and experts to easily broadcast engaging audio content, which students and learners can then freely listen to at any time and wherever they are. While reading a text or watching a video requires the learner's full attention, podcasts can be listened to during daily activities, including commuting, traveling, driving, taking care of house chores, training in the gym, etc. Podcasts are also useful in cases where a visual impairment makes traditional learning methods difficult, or in case of other difficulties, such as dyslexia. Podcasting is an effective medium for courses where the visual aspect is less important, such as learning a new language. However, it can constitute an additional, auxiliary support element also for scientific and technological courses, including robotics.

In this section, we analyzed a set of podcasts available online and dealing with robotics. Although they are designed to be informative channels rather than educational resources, the contents that they present provide also basic knowledge concepts, illustrate the current developments and trends, and foster the discussion in multidisciplinary domains. We believe that they can represent a useful medium for people that have little or no experience with robotics to understand the foundations of this subject.

There exist both general also more specialized podcasts discussing specific themes, such as soft robotics. The podcasts that we considered were selected according to their accessibility and popularity, only English resources were included in the analysis. We listed the main podcasts that we collected in our survey indicating the treated topics, the time frequency, the year in which they were released for the first time, the last released episode, and their current activity (see Table A8 in the Appendix). Regarding the introduction year, it is interesting to notice how they are spreading in the last years and especially in 2020: out of 23 analyzed podcasts, 11 (almost the 50%) were released in 2020 (Figure 5).

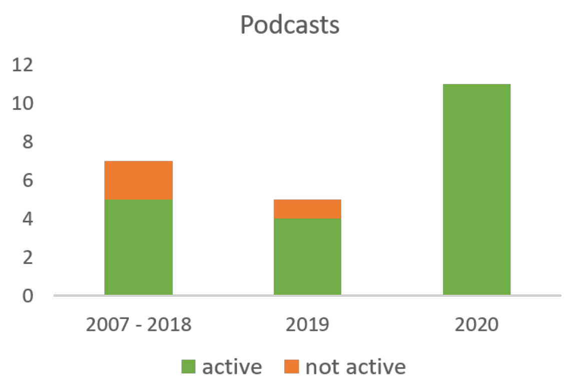


Figure 5. Year of release and status (active/not active) of the main podcasts on robotics.

Figure 6. A screen shot from the talk provided by one of the INBOTS project participants at TEDx Roma in 2014 entitled "Wearable technology for the sense of touch."

4.3.3 TED talks

TED (Technology, Entertainment, Design) goal is spreading ideas, usually in the form of short and engaging talks (typically 18 minutes or less) by eminent people covering almost all topics - from science to business to global issues - in more than 100 languages. TED talks have been acknowledged as effective educational tools in different application fields [117, 118, 119]. Besides TED main conferences, many independent events named TEDx have been organized worldwide to help sharing ideas in communities around the world (Figure 6).

Being robotics a cutting-edge technology able to engage and intrigue a wide range of people, often TED and TEDx conferences include talks by roboticists, scientists, engineers, and experts talking about their latest research achievements. The high quality of the presentations, the important role of the speakers in the robotics community, and the accessible and informative language adopted in the presentations, make these recorded talks useful resources for introducing robotics and inspiring students in learning this subject. In January 2021, the research of the term "robot" on TED web page provided 184 talks, 82 people, 25 playlists, and 167 blog posts covering several and very multidisciplinary aspects, ranging from history, [120] to design, [121] psychology, [122] art, [123] etc.

As a representative and meaningful contribution, it is worth mentioning the talk by Cynthia Breazeal focusing on the complex relationship between humans and robots [124]. Much more talks can be found among the independently organized events, accessible through the dedicated YouTube channel [125].

4.4 Resources for hands-on learning

Learning robotics also means to actually build and program robots. Many of the courses that are listed in Section 4.2 end with an hands-on hardware and/or software project requiring to build and/or program a robot. There are several available kits and resources for students of different levels but here we focus on resources designed for distance and self-learning. These include freely available toolboxes and guides for simulating and building robots.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

An important tool to encourage the real-world testing of robotic systems is the organization of competitions. Recently, the most important ones thought for students were summarized by Evripidou et al. [90]. In this paper, we analyze some of them and other more targeted to research groups, focusing on whether the challenge allows also an online participation or not.

4.4.1 Programming and building robots

Several software frameworks were devised with the objective of teaching robotics, mostly at an academic level. They were recently revised by Cañas et al. [126], who also introduced a new ROS-Based Open Tool for teaching robotics. The use of these platforms usually requires the support of an instructor or need to be coupled with structured courses on the topic, as those we presented in Section 4.4.

ROS is rapidly entering the educational world. In [127], for example, the development of laboratory exercises using MATLAB Robotics Systems Toolbox and ROS-enabled robots was presented. One of the most 30 active companies in the field of robotics education through ROS is The Construct [128], which provides both paid and free contents.

There are several toolboxes and programs for simulating robots available online. A very famous one is the MATLAB Robotics Toolbox by Peter Corke [129]. Other examples are SynGrasp [106] and GraspIt! [130], devoted to the simulation of robotic grasping, and ARTE (A Robotics Toolbox for Education) [131], allowing the study of industrial robotic manipulators. Three of the most complete and versatile open source robot simulators are Webots (Cyberbotics Ltd.) [132], V-REP [133], and Gazebo [134].

These are mostly used for research and education at a university level. Simulators allow students to apply the learned notions in a safe environment, where several analyses can be conducted, before actually programming real robots [135].

With the advent of rapid prototyping techniques, building robotic devices became cheaper and easier, allowing also the development of compliant devices [136]. There are online resources that guide people in the building of robots through illustrated manuals [137] or MOOCs. Despite these tutorials are accessible, most of the times they require learners to have access to the instrumentation and the components needed to build the devices.

4.4.2 Competitions

Several works on educational robotics report challenges and competitions as an additional tool for robotic education, learning and training [138, 139].

In [140], the outcomes of the workshop "Robotics Competitions: What Did We Learn?" are summarized. The workshop was organized at the 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) and the speakers discussed about the role of competitions both in research development, and as a way to engage students in science and technology activities.

Challenges and competitions provide stimuli for robotics research, as they allow to benchmark and compare different solutions, and to accelerate robot technology and innovation. Relevant examples of challenges in which cutting-edge solutions are presented are the DARPA challenge [141], the Cybathlon [142,143], and the Amazon Picking Challenge [144].

Robot competitions are also useful tools to train early career roboticists (e.g., SAUC-e competition on underwater robots [145. 146]), and to encourage younger people to enter STEM fields (e.g., FIRST Lego league [147]). Some of these competitions have a good resonance on media and represent an important tool for promoting robotics to the general public. The YouTube video presenting the funniest fails of robots during the 2015 edition of the DARPA challenge, for instance, has about 2.5M views [148].

Robotic competitions and challenges have been greatly affected by the COVID-19 pandemic, since most of them require the physical presence of participants during the competition. In normal conditions, the event itself is a great opportunity, especially for young students, to meet new teams, exchange ideas and establish fruitful connections and collaborations. Nevertheless, also among the competitions, new strategies have been found to proceed even with pandemic-related restrictions and, where possible, the events have been organized in 2020 in online and/or distance mode. A relevant example on how the competitions have adapted to this new situation is represented by Cybathlon, a competition on compensation and rehabilitation devices for people with disabilities that is usually held in Zurich, and that in 2020 launched the "Global" edition, with the participation from several countries.

A list of the main robotic challenges is reported in Table A9 in the Appendix. Notwithstanding the difficulties related to the pandemic, several challenges offer the possibility of participating online or from distance. Among those that we collected, 6 out of 12 have this option (see Fig. 7).

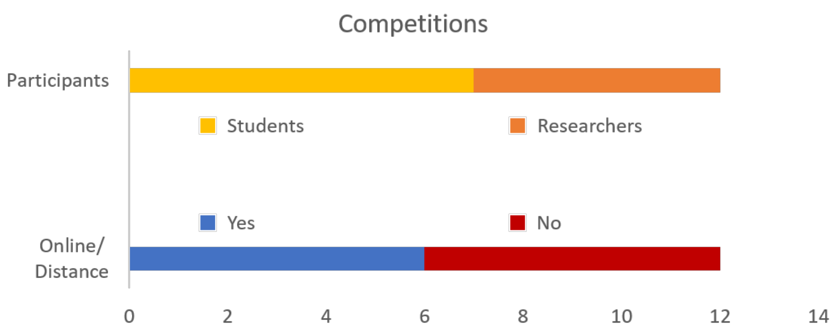


Figure 7. Target participants and participation modes of the main Robotics Challenges.

4.5 Conclusions and perspectives on Accessible Educational Resources for Teaching and Learning Robotics

Internet has made an enormous amount of knowledge accessible and affordable to everyone. However, it is often difficult for learners to orient themselves within all the available resources and to find the ones that are most suitable for their needs, expectations and background.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

In this section, we proposed a review and classification of some of the most eminent resources for learning robotics. This review is intended as a support tool for any person interested in learning robotics for improving and updating their skills. For instance, regarding teachers and educational systems, even if the diffusion of robotics educational activities in schools is increasing, it is not yet completely and homogeneously structured: teaching programs are different among different countries and schools. In high schools, often robotic activities are limited to technological or scientific curricula. The review presented in this section could, for example, suggest training tools for teachers interested in introducing robots in their courses.

The role of on-line resources is becoming increasingly important for undergraduate students, and for graduates and PhD students that need to integrate their knowledge. Their diffusion could be improved and optimized through dedicated websites and repositories. More in general, since robots are becoming increasingly important in the everyday life of a lot of people, initiatives aimed at explaining and debating on robotics should be encouraged and promoted.

The objective of this study was to provide a map for orienting the learner to deal with the heterogeneous amount of material available online. The review presents a classification of such resources in terms of specific subjects, basic skills, and applications and therefore represents a useful resource for selecting the proper learning material for specific learner's needs. By analyzing the available resources, we also identified some best practices and effective "design" criteria that should be adopted when designing an online course.

Besides the communication channels that have been considered in this review (YouTube videos, Podcasts, TED and TEDx conferences), there are other well-known platforms (e.g. Instagram, Facebook, Clubhouse, etc.) in which there are specific profiles and thematic channels talking about technology and robotics. However, according to our experience, the panorama in these platforms is still rather inhomogeneous and difficult to be classified and organized, for this reason we did not considered them in this review. Nonetheless, this is an interesting topic to be considered in robotic education and dissemination and will be considered in future extensions of this work.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

5 Exploiting VR and AR technologies in education and training to Inclusive Robotics

5.1 Introduction

Robots represented a step-change in industrial automation and are now a fundamental pillar of the so-called fourth industrial revolution. [149] Their presence in homes, hospitals, shops, and other service environments, however, is still limited. Several technical barriers still need to be tackled, including sensorization, power supply, safety, and human-robot interfaces, but also non-technical challenges are present, as we already discussed in the preceding sections. To facilitate the social uptake of interactive robots, interdisciplinary questions about the socio-economical, legal, and ethical impact of robotics on society need to be answered, and effective methods and resources to spread the knowledge of robotics-related topics must be developed [150]. As already introduced, robots can play multiple roles in education: they can be the subject of the learning process [151] or they can be used to teach other STEM subjects [152]. Recently, also virtual, mixed and augmented reality technologies have become important tools for training students and workers [153, 154, 155].

The need for innovative training and education tools, allowing distance learning, possibly through the use of virtual environments, has become evident during the recent lockdown period due to the COVID-19 pandemics.

In this section, we present a review on VR and AR resources for educating in robotics or in the use of particular robotic systems. After an overview of the advantages and disadvantages of using VR and AR for training and education (Sec. 5.2), we outline the challenges faced when teaching robotics at different levels (schools, universities, professionals) and describe existing VR and AR tools applied to robotics (Sec. 5.3). In Sec. 5.5, we discuss future perspectives related to the use of innovative tools to teach and learn robotics.

5.2 VR/AR technologies for training and education

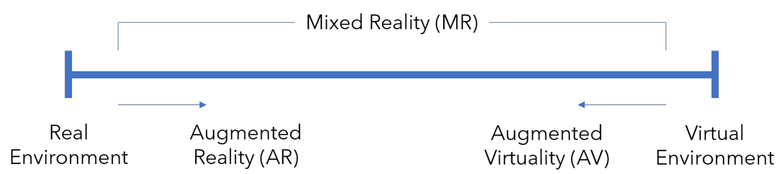


Fig. 8. Reality-Virtuality continuum.

Virtual Reality (VR) has been given a variety of definitions, most of the times dictated by market requirements and technology advancements. Milgram and Kishino [156] laid out the Reality-Virtuality continuum (see Fig. 8), in which the VR is set at the completely opposite side with respect to the Real Environment (RE) since it provides an entirely virtual representation of the information. Between RE and VR, there are a variety of

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

technological solutions aimed at "mixing" the image captured from the real scene with the digital content. Products proposed in the last ten years, including entertainment (e.g., PokemonGo) and communication (e.g., Snapchat) technologies increased the popularity of the term Augmented Reality (AR) to indicate platforms which overlay virtual images on real ones, but usually do not allow the interaction between the user and the virtual information in the scene. Mixed Reality (MR) is frequently referred to as an extension of AR, in which real and virtual elements can interact with one another, and the 3D content reacts to the user in the same way as it would do in the real world.

Both VR and AR became very famous in the past decade thanks to advances in motion tracking, graphics processing power, and display technologies. Solutions became rapidly popular and relatively inexpensive, creating sets of tools including 6DOF-tracked hand controllers and headsets, the latter used as wearable immersive visors, rather than sensor cameras. Device-oriented solutions that mix virtual objects to real scenarios, creating a hybridization of the original terms "virtual" and "real" into mixed reality, have also been proposed, including, e.g., Hololens (Microsoft Inc.).

Given this rich scenario, in which technological advancements found a florid market and fast development, relevant scientific results came to support the investigation of training and education with this technology. In particular, a key feature of VR is the "immersion" defined as the "experience of being immersed in virtual environments". [157] Immersive VR (IVR) systems, in which devices with headsets are able to "isolate" the user from external visual cues, create a highly engaging experience.

Isolation from visual cues and immersion, brought by IVR technology, are desirable features in the training domain [158].

Chittaro and Bottussi proposed an immersive serious game delivered through a head-mounted display for teaching aviation safety procedures and found several advantages with respect to conventional training techniques [159]. Krokos et al. compared IVR with non-immersive desktop VR condition for undergoing memory training and found that subjects showed better recall capabilities when immersive training was applied. [160].

5.3 A review on VR/AR based tools for professional training

Given the promising results and the growing market interest, VR and IVR technologies are becoming more and more popular in industry and healthcare sectors where training environments are particularly challenging for safety, cost, or feasibility. In [161], for example, the authors proposed a solution based on VR to teach bimanual assembly skills to workers in factories. In the healthcare field, most of the previous works aim at teaching operators specific procedures or at preparing them for the interaction with patients. Vaughan et al. [162], for example, created an IVR training system for paramedical operation to improve skills for needle cricothyroidotomy and chest draining, Butt et al. [163]used IVR and serious gaming to teach catheterization skills, whereas Shorey et al. [164] investigated the use of a desktop VR setup to train nurses in interaction with patients (Virtual Counseling Application).

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Recently, a smartphone-based VR-application (OpenJustice) has been applied with promising results to legal education [165].

AR has been found effective for training professionals in different areas. In industrial scenarios, Webel et al. [166] introduced a framework based on the use of AR software and a tablet for teaching assembly and maintenance skills, enhancing the tasks comprehension, while Gavish et al. [167] found better effectiveness of AR with respect to VR in industrial assembly training for maintenance skills. Recently, Catal et al. [168] developed a game-based AR platform to train employees on building evacuation scenarios, whereas Rojas-Muñoz et al. [169] positively evaluated the use of an AR platform for telementorization of practitioners in cricothyroidotomy procedures.

5.4 VR/AR for students' education

It is indeed in the education sector that the cost-effectiveness and the technological advancements of VR technology are reflecting a great interest. Radianti et al. [158], in their survey paper, found that the most used immersive VR technologies in higher education are Head-Mounted Displays (HMDs), such as Oculus Rift (Facebook Technologies, LLC.) or HTC Vive (HTC Corporation).

Simeone et al. [170] explored a training scenario in which IVR was used to train college students and found that the presence of the instructor (in the virtual environment) has beneficial effects for the learning process. In the evaluation of Lifelique Museum, Allcoat and von Mühlenen [171] taught plant cells to college students with two different methods, one based on IVR, and one based on videos and textbooks. Participants who tested the IVR condition reported engagement, connected to a better learning experience, increased positive emotions and memory recall abilities. Many commercial VR headsets embed eye trackers and Rahman et al. [172] proposed to use this feature to record students' eye-gaze during lectures, thus allowing teachers to identify distracted or confused pupils and promptly guide their focus onto the important parts of the lesson.

Augmented reality is largely studied in educational contexts, too. Tobar et al. [173] used an AR game-based learning technique to promote reading comprehension among school students, and compared it to traditional approaches. Results showed increased motivation in learning and better abilities in problem-solving and socialization. ARLIS, an instruction system created by Chen and Tsai [174], supported the investigation on learning performance with respect to traditional textbooks. Erbas and Demirer [175] investigated the use of AR-based activities in a ninth-grade biology course and found that these activities led to increased students' motivation and course success with respect to conventional methods. Sahin and Yilmaz [176] developed an AR booklet representing the Solar System resulting in an improvement of the motivation and learning achievements of students.

5.5 VR/AR technologies for robotics training and education

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 6: Main outcomes of the literature review.

	VR/AR technologies for robotics training and education		
	Training		**Education**
	Industry	**Healthcare**	
who	workers	practitioners (surgeons, nurses, etc.), customers/patients	students
what	use of specialized robotic systems	use of specialized robotic systems, execution of robot-assisted procedures, robot aided rehabilitation exercises	functioning, programming, and control of robots
VR systems	Roldán et al. [177], Pérez et al. [178], Haruna et al. [179]	Peral-Boiza et al. [180], Wang, et al. [181], Knopp et al. [182], Mariani et al. [183], Raison et al. [184], De la Iglesia et al. [185], Grimm et al. [186]	Crespo et al. [187], Theofanidis et al. [188], Román-Ibáñez et al. [189]
AR/MR systems:	Pai et al. [190]	Christensen et al. [191], Chowriappa et al. [192]	Jara et al. [193], Cheli et al. [194], Krajník et al. [195], Quintero et al. [196], Ostanin et al. [197]

The main outcomes of our literature review on robotics training and education through VR and AR technologies are summarized in Table 6 and discussed in the following sections. We decided to classify the selected papers based on the potential users of the described systems. Sec. 5.5.1 describes works addressing the training of professional operators in the use of specific robotic platforms or in the execution of robot-assisted procedures in two different main domains: industry and healthcare. Sec. 5.5.2, instead, analyses systems that are more suitable for training students and beginner robot programmers.

5.5.1 VR/AR-based training in the use of robots

The widely used computer-based training for robotics instruction now comprehends the benefits of extended-reality technologies to enhance the user experience. Current VR/AR solutions are aimed at covering the two fundamental needs of

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

- training in the use of specialized robotic systems, and
- training in robot-assisted procedures, differentiating those intended for professionals or for customers/patients.

These technologies have been applied in industrial scenarios as well as in the training of health professionals.

Technological, industrial examples include virtual environments intended for training system operators, allowing them to program and check whether a certain robotic system will do what is expected. In [178] a VR framework to train operators in the use of an industrial robot is presented. The adoption of VR ensures workers' safety and the immersiveness of the proposed solution improves training effectiveness. Different potential users (robotic engineers, robot operators, and assistant operators) evaluated the system and found it usable and useful. Haruna et al. [179] developed a VR-based system that visualizes haptic information through perceptual images overlaid at the contact points of a remote robotic hand. They showed that such a "visual haptics system" can help the pre-training of operators that need to learn how to control a robotic manipulation system from remote. With the aim of reducing lead time and lowering manufacturing costs, Pai et al.[190] evaluated the design of an augmented reality interface aimed at strengthening user's understanding and at improving interaction with the manufacturing environment. The AR interface guides users from the layout planning phase to the prototyping of the product of a fully automated work cell.

Other interesting approaches are those virtual training platforms that integrate data mining or predictive algorithms able to perform operator functions and support their decision making. Both strategies foster the adaptation process, understanding, coordination and workload of trainees. The study by Roldán et al. [177] focused on the creation of an immersive interface system which enables multi-robot interfaces training while implementing a layer for evaluation/prediction of operators capabilities: workload, situational awareness, stress, and trust.

Virtual simulators are extremely valuable for health professionals who work with multiple robots in different scenarios. Acknowledging that realistic imitation of robotic surgery has allowed safer training for surgeons and patients rather than by caseload practices, surgeons have adopted these technologies to improve their technical proficiency, mostly with wristed instruments used in laparoscopy and endoscopy procedures. Peral-Boiza et al. [180] reported on the suitable use of their virtual reality training platform for robot-assisted flexible ureteroscopy interventions which enables real-time user interactions in a wide range of urolithiasis scenarios. Likewise, Wang et al. [181] concluded in their study that urologists improved their skills for vesicourethral anastomosis and shortened the learning curve when using virtual training for anastomosis. Knopp et al. [182] created a robotic immersive VR surgical training scenario to teach trainees hip replacements and, recently, Mariani et al. [183] showed the effectiveness of VR for robotic surgical adaptive training.

The continuous and growing generation of VR solutions for surgical training forces the industry to settle on a standard. It is worthwhile to obtain specific metrics for all generic sequential tasks across different robotic skills exercises to ensure that competencies in robot-assisted surgery have been achieved. For this reason, several research groups from medical institutions have introduced a benchmark score for virtual robotic simulations in order to determine a competency-based virtual robotic training curriculum [184].

Also, AR-based solutions have been proposed for the training of surgeons, with the intent of facilitating the communication between trainer and trainee in minimally invasive surgery [191] or in specific operations. Chowriappa et al. [192], for example, showed that using an AR environment boosts robot-assisted surgery skills acquisition for urethrovesical anastomosis with minimal cognitive load.

On the other side, solutions based on VR, AR, and customizable games have been proposed to improve the user interface of robotic equipment for patient rehabilitation, aiming at increasing the interest of patients so that they keep performing their exercises [198, 199]. Exoskeletons connected to VR systems may allow a patient to perform personalized exercises with immersion in a motivational environment. The approach by De la Iglesia et al. [185] consisted of a context-aware VR system focused on patient follow-up on elbow rehabilitation. This solution moves towards future telerehabilitation offering a low-cost exoskeleton combined with different medical sensors to capture relevant patient data enabling remote medical monitoring, cloud rehabilitation exercises, and cloud storing data. Taking virtual reality beyond a simple motivational training space, but generating an environment fed by parameters captured by sensors and robotic systems, Grimm et al. [186] proposed an ambitious goal of automating the treatment for recovery of upper limb movements post-stroke. In particular, their approach targeted the improvement of upper limb range of motion based on the adaptation of the virtual environment to the patient's robotic-assistance dependence during unsupervised adaptive training of reach-to-grasp exercises.

5.5.2 Teaching robotics and with robotics through VR/AR

As already introduced in the document, robotics is a learning subject requiring multidisciplinary knowledge and skills: using robots in education activities engages students and improves their technical and non-technical capabilities, including problem-solving, analytical and critical thinking, reflection, and creativity [200, 201]. Robots are also a useful tool for promoting cross-subject projects, supporting, for example, the learning of other STEM disciplines (physics, biology, etc.). Teaching activities involving robots are becoming increasingly common both in schools and universities, where robots are often used in engineering and computer programming courses.

In the previous sections, we have pointed out that VR and AR technologies are becoming popular tools to enhance education and training at different levels. In particular, they can be exploited to teach professionals and end-users how to use a certain robotic system, allowing mitigation of the costs due to the physical building of the system and the possible damages provoked by inexperienced users.

In the context of robotics education, VR can be used to create training interfaces and virtual laboratories [202], while AR technologies can enrich the students' direct experience with the robots. Here we analyze works in which VR/AR/MR are used to teach robotics-related topics or to ease robot programming.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Several previous works proposed the use of VR to teach students and operators how to program robot manipulators [187, 188]. These works usually rely on a simulator of the robot and provide the user with an immersive interface to command it. Crespo et al. 187 showed that VR based training is effective for engineering students. Theofanidis et al. [188] showed that a VR-based solution allows users to control a robot arm in a more efficient way with respect to a less realistic interface. VR, however, is itself outperformed by the kinaesthetic teaching, in which the user physically interacts with the robot.

Román-Ibáñez et al. [189] focused on undergraduate students' education and introduced a low-cost IVR environment to teach how to program robotic manipulators. The use of a virtual laboratory avoids the need for performing experiments in real conditions, which usually costs time, money, and energy. Even though a similar result could be achieved using a simulator (e.g., the Robotics Toolbox [129]) , immersive VR can foster students' engagement.

AR/MR technologies, likewise robots, can be used to make concrete, visible, and even touchable otherwise abstract and intangible concepts. One of the first works combining AR and robotics education describes an AR-based interface allowing students to simulate and teleoperate a robotic arm [193]. AR-based activities can also help students to see what happens behind the scenes, inside the robot, for example reading sensor values or visualizing the code that is currently executing [194], or visualizing the state of the robot [195].Cheli et al. [194] underlined that using AR based interfaces can help students to debug their code and discuss together how to fix problems. However, the authors also recognized that AR systems could have usability issues and need to be properly designed to be successful.

MR can be used to intuitively program manipulators by superimposing a holographic robot over the real one and allowing the visualization and modification of the robot trajectory [196, 197]. Quintero et al. [196] proposed an AR-based system thanks to which the user could interact with a robot arm through speech and gestures. This solution allowed to program the operations of the manipulator more efficiently than using kinaesthetic teaching. The observed differences were mainly due to the fact that the use of the AR interface required less human motions.

While in [187,189,193,194,195] authors aimed at creating educational and training platforms for students of different levels, in [192, 196, 197] authors presented systems that can ease robot programming thanks to the use of VR/AR/MR technology. Results obtained by the latter could inform the development of future educational platforms.

The technologies used in the works described in this section are summarized in Table 7. In most of the cases, HMDs are employed and there is a focus on robot manipulators.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table 7: Technologies employed in the works analyzed in this section.

Paper	AR/VR system	Robot
Crespo et al. [187]	Oculus Rift (Facebook Technologies, LLC.), Razer Hydra Joysticks (Razer Inc.)	Mitsubishi RV-M1 Robot Manipulator
Theofanidis et al. [188]	Oculus Rift (Facebook Technologies, LLC.), Leap Motion (Ultraleap)	4-DOF Barrett Whole Arm Manipulator (WAM) (Barrett Technology)
Román-Ibáñez et al. [189]	Cardboard VR glasses with a smartphone placed inside	Industrial Robot Manipulator
Jara et al. [193]	3D visualization on a screen of real information from the robot, complemented with some virtually generated data.	Scorbot ER-IX Robot Manipulator (Eshed Robotec Inc.)
Cheli et al. [194]	iPad (Apple Inc.) with Thingworx View (PTC)	EV3 Mobile Robot (LEGO® MINDSTORMS® kit)
Krajník et al. [195]	Robot information overlaid on the real video	AR-Drone Quadcopter
Quintero et al. [196]	Hololens (Microsoft Inc.)	7-DOF Barrett WAM (Barrett Technology)
Ostanin et al. [197]	Hololens (Microsoft Inc.)	UR10 (Universal Robots) and LBR iiwa (KUKA AG) Robot Manipulators

Notwithstanding the optimism and enthusiasm arising from the described promising experiences, there are still some remaining challenges to the successful exploitation of VR and AR in robotics teaching, especially in the first levels of education, in which educational robotics is not yet fully structured in educational programs and is not homogeneously distributed over different countries and regions. In addition, teachers often lack the knowledge of robotics in their own schooling or training courses. The introduction of educational robotics and the effective use of AR and VR technologies in this context requires reviewing existing pedagogical approaches for many teachers. Therefore, effective professional development of teachers is a key aspect.

5.5.3 Conclusions and perspectives on VR and AR technologies in education and training to Inclusive Robotics

Technology constitutes an important resource for many aspects of our lives, including training and education. In particular, Virtual and Augmented Reality applications are living a fruitful development phase in terms of accessible devices and resources, and

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

effective applications. At the same time, robots, initially confined in high-tech research centres and in large companies with automated production lines, are nowadays becoming familiar to the whole society.

The need for adequate and accessible tools for learning robotics and training with robots at different education levels and for different purposes is becoming significant.

From the pedagogical point of view, several experiences demonstrated that robots are an effective tool to enable people with different forms and levels of expertise to come together and express their ideas, demonstrate problems, construct shared knowledge and communicate potential solutions to others. In fact, robots can give concreteness to otherwise abstract concepts and issues.

In this paper, we discussed how technologies leveraging virtual reality or different levels of mixed reality can be used in robotics training and education. We reviewed the applications that, to the best of our knowledge, are most relevant, by highlighting the positive effects and the potentialities of such systems.

The use of VR interfaces allows teachers to deliver laboratory lectures without the need for large and expensive infrastructures. At the same time, avoiding the direct interaction with robots ensures a safe learning environment. VR based educational activities cannot completely replace the training with real robots, but they can serve as a preliminary learning step before programming and using real devices.

AR and MR interfaces do not substitute the interaction with the real robot, but rather they enrich it, giving the user intuitive tools to program the robot and monitor its state. Applications in robotics education are still limited as the use of these technologies requires additional training for students, who must learn to manage the interface as well as the robot.

Other drawbacks connected to the use of VR and AR for robotics training and education are mainly related to the accessibility of these resources, in terms of costs and educators' training. It is worth mentioning that as soon as a system gets out of a specific applicative environment, and starts being adopted by the society as a whole, the technological, scientific and engineering aspects become only a part of the problem, as also human-related and non-technical aspects, such as psychology, law and ethics must be considered. Regarding this last aspect, it is worth to recall that in INBOTS project there is a specific Work Package dealing with Ethical, Legal and Socioeconomic aspects related to Inclusive Robotics, the interested reader can find further details on the related deliverable D2.2. We, therefore, believe that an inclusive approach to robotics and a harmonic dialogue between technical and non-technical experts is fundamental for the fruitful exploitation of VR, AR, and robot technologies in education.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

6 Some preliminary considerations on the impact of COVID-19 pandemic on robotic education

As a follow-up of the discussion on "Inclusive robotics in the pandemic times" promoted during EDUROBOTICS Conference organised by INBOTS WP3 partners, this section presents an overview on the consequences of the pandemic spreading in the educational robotics world and some possible solutions that have been adopted in these months to mitigate the drawbacks of distance and discontinuous learning conditions. This overview is necessarily partial, and the presented results are rather preliminary, since the adaptation to this new situation was abrupt, in many cases the educational system at any level was not prepared to manage it, and the pandemic is still ongoing.

Most of our habits in everyday life have been disrupted in the last year with the spreading of COVID-19 pandemic. In these months, it was evident that robotics and artificial intelligence technologies can not only mitigate difficulties caused by the pandemic, but also help in facing the current and future effects of the crisis due to it [203]. Robots can help in the control and management of the pandemic (e.g., robot-controlled surface disinfection through ultraviolet (UV) light, mobile robots for temperature measurement in public areas, etc. [124]), but also in keeping people in contact with their beloved ones [204]. COVID-19 pandemic has created a surge not only in the demand for essential healthcare equipment and medicines, but also in the need of innovative information technologies to solve problems such as contact tracing and detection and diagnosis of COVID-19 and related symptoms [205]. Several new robotic and digital solutions were proposed by the scientific community and, in some cases, they were shared in online platforms like "Tech for Care" (https://techforcare.com/it/).

Even before the pandemic spreading, robotics represented an emergent and rapidly increasing sector: according to an article published on The New York Times at the end of 2019 [206], robotics would create 133 million jobs by 2022, with robot sales estimated at 553,000 units by the end of 2020. These estimations probably have not been attended due to the economic impact of the pandemic, however, it is evident that the integration of robotics into education at any level, from pre-school to academia and in the post education professional training can enhance future career development prospects.

The COVID-19 pandemic significantly impacted on traditional educational methodologies, and the education system needed to rapidly adapt to this abrupt change. The closure of schools and universities in 192 countries has interrupted the education of nearly 1.6 billion students, representing 90% of the world's student population (UNESCO Institute for Statistics data [207]). In Europe, the closure of schools of all types and levels involved approximately 76.2 million students and 6.3 million teachers (Eurostat data [208]).

In [209] a study on the Impact of COVID-19 and "Emergency Remote Teaching" on the UK Computer Science Education Community is presented. The study is based on the analysis of quantitative and qualitative findings from a survey of the educational workforce conducted after the sudden closures of schools in March 2020 and the shift to online delivery. The paper reports that teaching computer science subjects online presented globally less limitations and negative aspects with respect to other disciplines. However, there are also activities which involve hands-on practical projects and laboratory experiences, such as electronics, mechatronics, and robotics. In these cases, the students' experience has been significantly modified by the distance learning transformation. Robots are inherently physical entities, that can be used in the learning process to learn abstract concepts (e.g. mathematics, physics), but require a hands-on aspect that is difficult to replicate with distance learning modalities.

Possible solutions to mitigate these limitations leverage on the use of simulation environments and in general online resources as those described in Section 4 and/or AR and VR resources as the ones that will be described in Section 5. In [210], for instance, the authors report an experience in which two groups of secondary school students from Canada and Turkey successfully studied and developed reinforcement learning models for autonomous vehicles by means of an online simulation environment, despite not having any prior experience in machine learning nor artificial intelligence, and without testing the developed algorithm on a real physical robot. They conclude that, at least for secondary school students, "*physical robotics kits and dedicated robotics spaces are not essential to the teaching of programming and robotics".* Even if these results are relative to a specific set of students (high-school) that already have some experience and background, this conclusion is interesting also beyond the pandemic situation: it represents an opportunity for instance for marginalized communities that do not have the resources to support robotics instruction.

The academic education has also been moved to an online modality in most of the universities. Lectures were provided either in synchronous (lecture streaming) or asynchronous (recorded videos) modalities. In [211] the teaching based on the live classroom system and the live teaching based on the video conference system were compared for a robotic teaching course. It is evident that there are significant differences in the learning environment requirements, learning materials and resource delivery, and learning activity organization between the live teaching based on the live classroom system and the live teaching based on the video conference system, however the results of this study showed that there were no significant differences in factors including lecturer-student interaction, lecturer's question answering and tutoring, learning anxiety, self-evaluation of learning performance. Another study on the impact of distance learning modality in an academic robotics course has been presented in [212]. In this work, the conclusions in terms of students' evaluation results and students' overall learning experience are rather positive. In the context of academia and in some cases also for high school students, the drawbacks of distance-learning transition in robotic learning can be mitigated, also thanks to the availability of a wide amount of online resources as those presented in Section 4.

An experience involving elementary school students is reported in [213], in which Augmented Reality technology was integrated in an e-learning system with educational robots. The study showed that systems leveraging on augmented or mixed reality technology and robots can have positive outcomes, increasing students' motivation and learning performance. One of the main challenges in teaching with robots in an online modality, is the availability of robotic systems that students can build, program, and use at home. In [214], the authors presented a flipped-classroom approach with elements of blended learning and using compact, robust, custom-made educational robotic

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

modules, called EDMOs. In this way, students could achieve the intended learning outcomes that require experimenting with robotic hardware. In general, there are several initiatives and proposed solutions for teaching robots and with robots even in the pandemic context. The resources analysed in Section 3.2 and the provided guidelines represent a useful reference for schoolteachers interested in introducing robotics in their courses, even in this complex situation.

Due to the long-lasting lockdown periods, there has been a common feeling of isolation and suspension among people. While many of us felt as being "put on hold", the world has actually kept evolving, rapidly and permanently. In this scenario, the education system not only had to adapt to the new challenges described above, but it had (and has) to answer the need for support and culture that the young population needs now more than ever. On the one hand, innovative teaching methodologies, like those promoted by educational robotics, turned out to be fundamental to keep students engaged in the learning process, even from a distance. On the other hand, the pervasive use of technology during this pandemic period has shown the importance of spreading knowledge about new digital and robotic devices at different levels in the society. Robotics education and training are key for the development of technology-aware citizens of the future, and the pandemic only made this clearer.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

7 Concluding remarks

The main challenge that INBOTS project wants to overcome is the lack of a clear understanding and communication between all the stakeholders involved in interactive robots, intended as any robot that is interacting in close proximity with humans. It is clear that education plays a fundamental role in building a common language between the multidisciplinary, technical and non-technical subjects.

This document, together with Deliverable D3.1, provides a wide and organised collection of resources for learning interactive robotics at any level, from pre-school to university and also outside the educational system that will be updated also after document release and project ending.

The resources have been organised based on learners' typology and background:

- Resources for pre-academic education
- Resources for academic education
- Resources for workers, professionals, teachers, educators
- Resources for the general public interested in learning about robotics.

Among all the available resources we pointed out especially the highly accessible and online ones.

As an important result of the work conducted inWP3 it is worth mentioning the proposed paradigm shift on educational robotics in school based on the concept "make your own robots", which fosters creativity and the other 21st century skills: problem solving, critical thinking, and teamwork.

In this document and in the previous one (Deliverable D3.1) we reviewed, analysed and proposed a classification of a wide set of the available and accessible educational resources for learning and teaching robotics. We focused in particular on accessible online resources and on the applications of new technologies as VR/AR tools for learning and teaching robotics at different levels of basic skills and for different potential interests. The outcomes of our review and analysis of available online resources are twofold. Firstly, the organised collection of resources represents a resource for orienting people with different base skills and different learning objectives in finding the best tools for their learning needs. Secondly, the research allowed us to extract some best practices and effective design criteria for developing online courses and lecture series. The importance of such new tools for education, learning and training has become particularly significant since the last year, when the pandemic spreading deeply modified all our habits and significantly impacted on the whole educational system.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

8 Appendix

8.1 Resources requiring sequential access

Table A1. Table summarizing the main MOOCs on Robotics for university students with already some basic math and physics knowledge. Here we list single courses.

Title	Instructors	Platform	Link
Robot Development	A. Cangelosi and M. Schlesinger	edX (FedericaX)	accessed: 12-2020
Robotics	M. Ciocarlie	edX	accessed: 12-2020
Autonomous Mobile Robots	R. Siegwart, M. Chli, M. Hutter and D. Scaramuzza	edX	accessed: 12-2020
Hello (Real) World with ROS – Robot Operating System	M. Bharatheesha, G. van der Hoorn, C. Hernandez Corbato, M. Wisse	edX	accessed: 12-2020
Underactuated Robotics	R. Tedrake, R. Deits, T. Koolen	edX (MITx)	accessed: 12-2020
Data Management, Data Security and Robot Operating System as a Common Tool for IoT	A. Kapitonov, S. Distefano, K. Berkolds, A. Nikitenko	edX	accessed: 12-2020
Autonomous Navigation for Flying Robots	J. Sturm, D. Cremers, C. Kerl	edX	accessed: 12-2020
Introduction to Haptics	A. Okamura	edX	accessed: 12-2020
Artificial Intelligence for Robotics	S. Thrun	Udacity	accessed: 12-2020
Robots Are Coming! Build IoT Apps with Watson, Swift, and Node-RED	M. Sadowski, L. Frantzell	cognitiveclass.ai (IBM)	accessed: 12-2020

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table A2. Table summarizing the main MOOCs on Robotics for university students with already some basic math and physics knowledge. Here we list courses that are grouped together either in specializations, or because they are taught by the same professor.

Title	Instructors	Platform	Link
Robotics Specialization: Aerial Robotics,Computational Motion Planning, Mobility, Perception, Estimation and Learning, Capstone	V. Kumar, C. J. Taylor, D. E. Koditschek, K. Daniilidis and J. Shi,D. Lee, S. Deliwala	Coursera	accessed: 12-2020
Modern Robotics: Mechanics, Planning, and Control Specialization: Foundations of Robot Motion, Robot Kinematics, Robot Dynamics, Robot Motion Planning and Control, Robot Manipulation and Wheeled Mobile Robots, Capstone Project - Mobile Manipulation	K. Lynch	Coursera	accessed: 12-2020
Self-Driving Cars Specialization: Introduction, State Estimation and Localization, Visual Perception, Motion Planning	S. Waslander and J. Kelly	Coursera	accessed: 12-2020
Robotics Foundations I - Robot Modeling	B. Siciliano	edX (Federicax)	accessed: 12-2020
Robotics Foundations II - Robot Control	B. Siciliano	edX (Federicax)	accessed: 12-2020
Electricity & electronics: Robotics, learn by building	I. Juby	Udemy	accessed: 12-2020
Digital Electronics: Robotics, learn by building II	I. Juby	Udemy	accessed: 12-2020
Robotic Drives & Physics: Robotics, learn by building III	I. Juby	Udemy	accessed: 12-2020
Introducing Robotics	P. Corke	FutureLearn	accessed: 12-2020
Robotic Vision: Making Robots See	P. Corke	FutureLearn	accessed: 12-2020

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table A3. Table summarizing the main MOOCs on Robotics suitable for school students and/or teachers.

Title	Instructors	Platform	Link	Language
Begin Robotics	R. Miller, W. Harwin	FutureLearn	accessed: 12-2020	English
Introducing Robots: Making Robots Move	P. Corke, E. Pepperel, O. Lam	FutureLearn	accessed: 12-2020	English
Introducing Robotics: Build a Robot Arm	P. Corke, E. Pepperel, O. Lam	FutureLearn	accessed: 12-2020	
Robotics With Raspberry Pi: Build and Program Your First Robot Buggy	A. Parry, N. Szymor	FutureLearn	accessed: 12-2020	English
Building Robots with TJBot	J. Bisson, L. Frantzell	cognitiveclass.ai	accessed: 02-2021	English
Robótica (tr. Robotics)	E. Ruiz Velasco	Coursera	accessed: 12-2020	Spanish
Scratch: Programming for Teachers	F. Hermans	edX	accessed: 12-2020	English
Coding a scuola con software libero (tr. Coding at school with free software)	A. Formiconi	edX	accessed: 12-2020	Italian
Diseña, fabrica y programa tu propio robot (tr. Design, manufacture and program your own robot)	L. Armesto Angel	edX	accessed: 12-2020	Spanish
Le robot Thymio comme outil de découverte des sciences du numérique (tr. The Thymio robot as a tool for the discovery of digital sciences)	F. Mondada, D. Roy, E. Page, M. Chevalier	edX	accessed: 12-2020	French
Die digitale Welt mit dem Thymio Roboter entdecken (tr. Discover the digital world with the Thymio robot)	D. Assaf, J. Dehler Zufferey, M. Garzi, C. Giang	edX	accessed: 02-2021	German
Introducción a la robótica e industria 4.0 (tr.	L. A. Munos Ubando, D. A.	edX	accessed: 12-2020	Spanish

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Introduction to robotics and industry 4.0)	Sansores Peraza, D. A. Sansores Peraza			
Fun with Beginner LEGO MindStorms EV3 Robotics	Y. Lu, Y. Chen	Udemy	accessed: 02-2021	English
Robots y Videojuegos en las aulas: Scratch y Arduino para profesores (tr. Robots and video games in the classroom: Scratch and Arduino for teachers)	M. A. Rodriguez Fernandez	Miríadax_	accessed: 12-2020	Spanish

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table A4. Table summarizing the main MOOCs on the potential impact of Robotics and technologies in general on the society.

Title	Instructors	Platform	Link
Introducing Robotics: Robotics and Society	P. Corke, E. Pepperel, O. Lam	FutureLearn	accessed: 12-2020
Building a Future with Robots	S. Veres	FutureLearn	accessed: 12-2020
Future Robots. Towards a Robotic Science of Human Beings	D. Parisi	edX (FedericaX)	accessed: 12-2020
Communicating with Robots and Bots	E. Sandry, G. Peaty	edX	accessed: 12-2020
Responsible Innovation: Ethics, Safety and Technology	J. van der Hoven	edX	accessed: 12-2020
Mind of the Universe Robots in Society: Blessing or Curse?	V. Dignum, J. Bieger, R. Mercuur	edX	accessed: 12-2020
SDG: Moving Towards Sustainable Work	E. M. Blázquez Agudo, M. G. Quintero Lima, M. T. Alameda Castillo, A. B. Munoz Ruiz	edX	accessed: 12-2020
Designing the Future of Work	S. McIntyre	Coursera	accessed: 12-2020
My Friend is a Robot: Introduction to Social Robotics	N. Zilberman	Coursera	accessed: 12-2020

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table A5. Table summarizing the main MOOCs on Robotics targeting specific robotics applications.

Title	Instructors	Platform	Link
MedTech: AI and Medical Robots	S. Xie	FutureLearn	accessed: 12-2020
Collaborative Robot Safety: Design & Deployment	B. Carlisle, A. Sivadas	Coursera	accessed: 12-2020
Drones for Agriculture: Prepare and Design Your Drone (UAV) Mission	L. Kooistra, J. Valente	edX	accessed: 02-2021

Table A6. Table summarizing the main courses on Robotics for university students available as online lecture series.

Title	Instructors	Online since	Link
Introduction to Robotics (CS223A)	O. Khatib	2008	accessed: 12-2020
Lecture Series on Robotics	C. Amarnath	2008	accessed: 12-2020
Robotics 1	A. De Luca	2014	accessed: 12-2020
Programming for Robotics (ROS)	P. Fankhauser, D. Jud, M. Wermelinger	2017	accessed: 12-2020
Modern Robotics: Mechanics, Planning, and Control	K. Lynch, F. Park	2017	accessed: 12-2020
The Art of Grasping and Manipulation in Robotics	D. Prattichizzo, M. Malvezzi, M. Pozzi	2018	accessed: 12-2020
Robotics 2	A. De Luca	2020	accessed: 12-2020
Evolutionary Robotics	J. Bongard	2020	accessed: 12-2020

8.2 Resources accessible in an arbitrary order

Table A7. Table summarizing the main YouTube channels dealing with robotics

Title	Subscribers (12-2020)	Link	Type
Simone Giertz	2.33 M	accessed: 12-2020	Entertainment
Boston Dynamics	1,91 M	accessed: 12-2020	Robotic company
James Bruton	903k	accessed: 12-2020	Education-entertainment
How to Mechatronics	474k	accessed: 12-2020	Education-DIY
DroneBot Workshop	279k	accessed: 12-2020	Education-DIY
KUKA - Robots & Automation	151k	accessed: 12-2020	Robotic company
Hanson Robotics Limited	37.2k	accessed: 12-2020	Company

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

ABB Robotics	42.2k	accessed: 12-2020	Robotic company
VEX Robotics	29.3k	accessed: 12-2020	Education
SoftBank Robotics Europe	18.6k	accessed: 12-2020	Robotic company
Universal Robots	16.1k	accessed: 12-2020	Robotic company
RobotshopTV	7.1k	accessed: 12-2020	Company
Rethink Robotics	6.3k	accessed: 12-2020	Robotic company

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Table A8. Table summarizing the main Podcasts dealing with robotics

Title	Link	Frquency	Since	Active	Audience
Robohub	accessed: 12-2020	2/month	Jun-08	yes	general
ROS developers podcast	accessed: 12-2020	weekly	Jan-18	yes	technical
Robot report podcast	accessed: 12-2020	weekly	Jun-20	yes	general
RobotPsych	accessed: 12-2020	weekly	Jan-15	yes	psychology, human science
Soft robotics podcast	accessed: 12-2020	weekly	Aug-19	yes	technical
VECNA robotics	accessed: 12-2020	weekly	Jul-20	yes	industrial
Exapte	accessed: 12-2020	daily	Jun-20	yes	general
The Robot State Reports	accessed: 12-2020	monthly	Mar-20	yes	general
RoboZone podcast	accessed: 12-2020	monthly	Sep-16	no	general, students
Littler AI, Robotics and Data	accessed: 12-2020	quarterly	Mar-19	yes	legal, ethics, social aspects
Robotics assemble	accessed: 12-2020	2/month	Aug-20	yes	general, students
Wake up learn	accessed: 12-2020	quarterly	Jun-17	yes	general, students
No fear of the robots	accessed: 12-2020	monthly	Jan-20	yes	general
The Robotics Engineering Experience	accessed: 12-2020	monthly	Jun-20	yes	general, technical
Robot talk	accessed: 12-2020	weekly	Sep-20	yes	general
The Robot Industry Podcast	accessed: 12-2020	weekly	May-20	yes	technical
Orange Intelligenz	accessed: 12-2020	monthly	Apr-20	yes	technical, company

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Inside the hive	accessed: 12-2020	quarterly	Jul-19	yes	general
Learning Machines 101	accessed: 12-2020	quarterly	Apr-14	yes	general
Human Robot Interaction	accessed: 12-2020	quarterly	Mar-19	yes	human sciences
Robot in Depth	accessed: 12-2020	weekly	Sep-19	no	general
Talking Robots	accessed: 12-2020	monthly	Jan-07	no	general
The Cobot Show	accessed: 12-2020	not regular	May-20	yes	technical, company

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

8.3 Robotics competitions

Table A9. Table summarizing the main robotics challenges

Name	Since	Last	Online/ Distance	Organised by	Type of robots	Participants
DARPA Challenge	2004	2018	no	Defense Advanced Research Projects Agency,	Autonomous robots	Research groups
Cybathlon	2013	2020	yes	ETH, Zurich	Rehabilitation and assistive robots	Research groups
MBZ International robotic challenge	2017	2020	no	Kalifa University	UAV	Research groups
competition ACRE	2020	2020	yes	Metric project	Agrifood	Research groups
Amazon Picking Challenge	2016	2019	no	Amazon	Hands and grippers	Research groups
SAUC-E	2006	2019	no	SAUC-e	Underwater robot	Students
SAUVC	2019	2020	no	SAUVC	Underwater robot	Students
Nao challenge	2015	2020	yes	Nao challenge	Humanoid robot	Students
Zero Robotics	2009	2020	yes	MIT	Robot programming	Students
FIRST Lego League	2002	2020	yes	Lego	Lego robots	Students
Robocup	1997	2019	no	Robocup	Mobile robots	Students
VEX Robotics Competition "Make It Real" CAD Engineering Challenge	2017	2020	yes	Autodesk	CAD design	Students

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

9 Building a community of teachers, learners and experts on Educational Robotics

9.1 Thematic conferences on Robotic Education

As robots are spreading in several industrial, service, healthcare domains, also Educational Robotics is becoming a subject of research and discussion. The International Conference on Robotics in Education (RiE) is aimed at presenting and discussing the latest results and methods in the fields of research and development in Educational Robotics. In 2021, the 11th edition of RIE will be hold online. EDUROBOTICS is another thematic conference on educational robotics that was first held in Venice in 2008 in the form of an international workshop in the context of the TERECoP project entitled "Teaching Robotics and Teaching With Robotics-TRTWR". Then it has been repeated every two years. Thematic sessions and workshops are organised within the most important robotics conferences, including the IEEE International Conference on Robotics and Automation (ICRA) and the IEEE International Conference on Intelligent Robots and Systems (IROS). In 2019, two workshops on Educational Robotics were organised in the European Robotics Forum (EURobotics). An issue of IEEE Robotics and Automation Magazine was entirely on Educational Robotics in 2016. Other relevant initiatives for the general public where educational robotics is widely discussed are the Maker Faire in Rome, the Robotics Festival (Festival della Robotica) in Pisa, etc.

9.2 The EDUROBOTICS 2020 experience

The 2020 edition of the **Educational Robotics International Conference (EDUROBOTICS, former TRTWR)** was organised as an initiative related to INBOTS project. The conference was originally planned in November 2020 in Siena, Italy, but due to COVID-19 restrictions it has been transformed in an online event and postponed to February 2021. EDUROBOTICS contributed in building a community of researchers and educators in Educational Robotics at European and international level. It was previously organised in Venice (2008), Darmstadt (2010), Riva del Garda (2012), Padova (2014), Athens (2016), Rome (2018). The chairs for the 2020 editions were Monica Malvezzi (University of Siena, Italy, INBOTS project partner), Dimitris Alimisis (EDUMOTIVA, Greece, INBOTS project partner) and Michele Moro (University of Padova).

Notwithstanding the online modality and the uncertainties related to the particular situation, 30 papers have been submitted to the conference. The geographical distribution of the authors is reported in Figure 8. As it can be seen, even if the majority of the works are from European authors, there are also works coming from extra-European countries. All the papers were reviewed by at least two reviewers and 19 of them were selected for the presentation at the conference.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

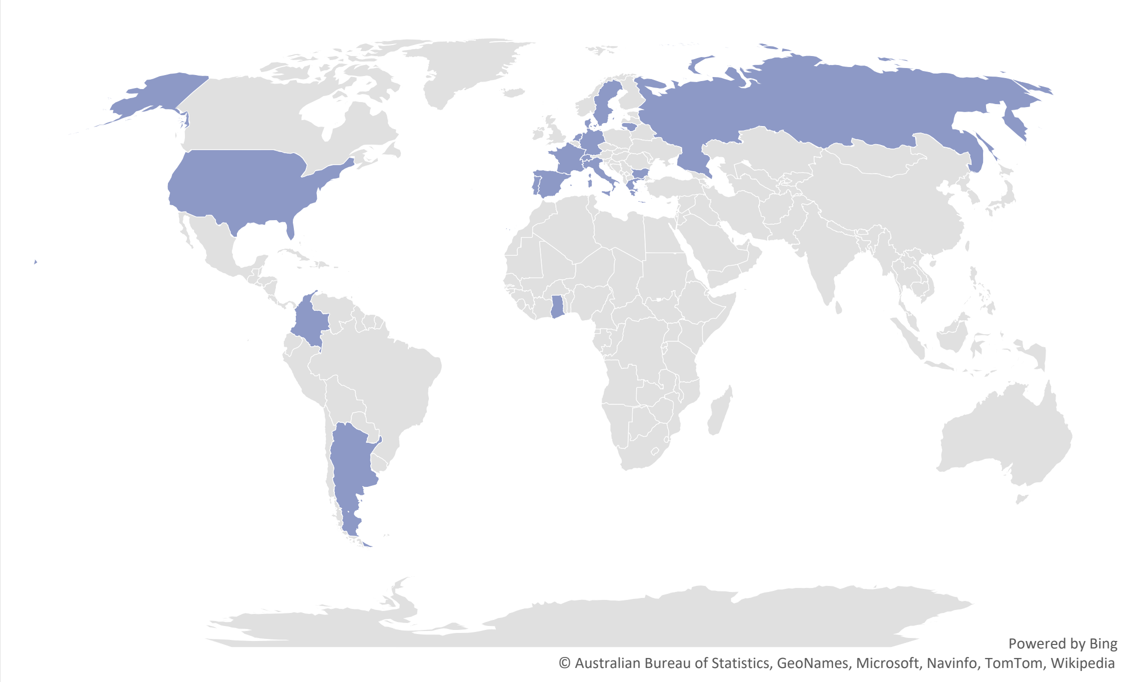


Figure 8. Geographical distribution of the authors who submitted their work at EDUROBOTICS conference.

The conference started with the keynote talk by Paulo Birkstein and Arnan Sipitakiat (Figures 9, 10). They introduced the history of educational robotics, discussed research-based design principles, presented examples of good and bad design, and demonstrated a brand-new lineage of open-source platforms for educational robotics that will help lead the field into the future. Paulo Blikstein [215] is an Associate Professor of Education and an Affiliate Associate Professor of Computer Science at Columbia University, where he directs the Transformative Learning Technologies Lab. His main research focuses on how new technologies can transform the learning of science, engineering and computation, and on how machine learning and AI can be applied in educational research. Arnan (Roger) Sipitakiat directs the Teaching and Learning Innovation Center (TLIC) at Chiang Mai University in Thailand. The center spearheads novel learning approaches, defines and operates competency frameworks, and conducts training for more than two thousand faculty members throughout the university. As a faculty and researcher at the Computer Engineering Department, he also directs the Learning Inventions Laboratory (LIL).

The conference ended with the invited talk by Gary Stager [216] (Figure 11), one of the world's leading experts and advocates for computer programming, robotics and learning-by-doing in classrooms. Dr. Stager presented an expansive view of robotics to serve a diverse population of learners, discussed contexts for using robotics as a vehicle for knowledge construction, and shared models for inspiring teachers to embrace the potential of robotics as an expressive medium and incubator of powerful ideas.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Figure 9. A screen shot from the keynote speech by Paulo Blikstein.

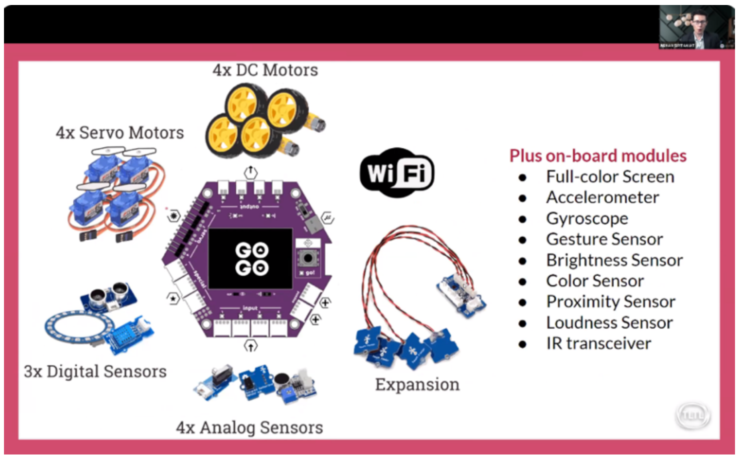


Figure 10. A screen shot from the keynote speech by Arnan Sipitakiat.

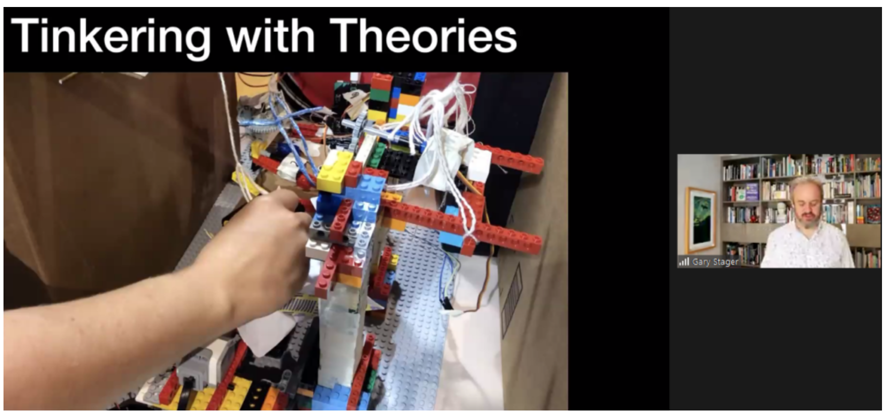


Figure 11. A screen shot from the invited speech by Gary Stager.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

The conference included a session related to INBOTS project in which the following papers were presented:

- *Exploiting VR and AR technologies in education and training to Inclusive Robotics*, by Maria Pozzi, Unnikrishnan Radhakrishnan, Ana Rojo Agustí, Konstantinos Koumaditis, Francesco Chinello, Juan C. Moreno Sastoque and Monica Malvezzi;
- *Educational robotics curricula: current trends and shortcomings*, by Theodosios Sapounidis and Dimitris Alimisis
- *Dance & Robots: Designing a Robotics-enhanced project for dance-based STEAM Education Using ENGINO*, by Sofia Almpani and Dimitris Alimisis
- *Robots entering the care sector: The case of a new curriculum for the education of assistant nurses in Sweden*, by Britt Östlund.

An interactive panel discussing on "Inclusive robotics in the pandemic times" was also organized, in which the panelists and the attendees were invited to present their experiences and discuss on the following questions:

- How does the robotic education survive during the pandemic times?
- What solutions have been adopted?
- How much is inclusiveness impacted by pandemic?
- What are the lessons learnt?

In the discussion some experiences and solutions were shared. Most of the teaching activities previously organized in presence, with hands-on activities, moved to an online, distance-learning modality. The importance of online resources was therefore highlighted and issues on inclusiveness were pointed out. The main lesson that was learnt is that the pandemic required a great effort to reorganize teaching activities and materials, but these efforts leaded to solutions that will be used also after this period.

It's worth to mention the participation of Robotic Teacher Community (ROTECO – link-FR, link-EN, link-IT), a Swiss-based project aimed at building a community of teachers and educators sharing their experiences and initiatives in robotic education. ROTECO actively participated to the conference with a paper and in the panel discussion.

9.3 Webinars for teachers

Within INBOTS project, EDUMOTIVA and the University of Siena planned to organize a summer school in Greece for teachers and high-school students. The summer school was planned in July, to avoid overlaps with school activities. Global pandemic situation forced the organizers to postpone the summer school beyond INBOTS project end. However, to partially compensate the missing activity and to involve teachers in the discussion on educational robotics, a series of webinars were planned.

The first one, already introduced in Section 3.1, was organized on July 20, 2020, and was hold by EDUMOTIVA (Dimitris Alimisis, Chrissa Papasarantou). The title was **Discover "a new paradigm in educational robotics" inspired from the maker movement: make your own robots!**

The webinar was oriented to lab activities: EDUMOTIVA presented through simulations and video the "lighthouse project" in two versions to exemplify the "old" and "new" paradigm.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

The second one was organized on July 22, 2020, and was hold by University of Siena team (Monica Malvezzi, Maria Pozzi, Tommaso Lisini Baldi) and was entitled **Human-Centered Robotics**. This second webinar was oriented in showing the current development status and trends on robotics, in particular in robots designed to work closely to humans: robots are expected to enter more and more into human environments and thus they need to be safe by design and capable of fluently interacting with human partners. In this webinar, the speakers introduced the concept of human-centered robotics and discussed cutting-edge research findings regarding soft robotic hands and wearable haptic interfaces to connect humans and robots.

The webinars were attended by approximately 70 people. The recording of the first webinar is available on YouTube channel (link).

The feedback from teachers was overall positive and this initiative will be repeated and possibly integrated in spring/summer 2021.

10 List of papers and publications related to INBOTS WP3 activities

- D. Alimisis (2020), Emerging Pedagogies in Robotics Education: Towards a Paradigm Shift. In Inclusive Robotics for a Better Society, José L. Pons (ed.), Pages 123 129, Cham, 2020.
- M. Pozzi, D. Prattichizzo, M. Malvezzi (2020). On-Line Educational Resources on Robotics: A Review. In *Inclusive Robotics for a Better Society. INBOTS 2018. Biosystems & Biorobotics*, José L. Pons (ed.), Vol. 25, pp. 141-147, *Springer, Cham*, 2020.
- Alimisis, D. (2020) Emerging Pedagogies in Robotics Education: Towards a Paradigm Shift. In: Pons J. (eds) Inclusive Robotics for a Better Society. INBOTS 2018. Biosystems & Biorobotics, vol 25. Springer, Cham
- Sapounidis, T., & Alimisis, D. (2020). Educational Robotics for STEM: A Review of Technologies and Some Educational Considerations. In L. Leite, E. Oldham, A. Afonso, V. Floriano, L. Dourado, & M. H. Martinho (Eds.), Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward (pp. 167–190). Nova science publishers.
- Sapounidis T., Alimisis D. (2021). Educational robotics curricula: current trends and shortcomings, EDUROBOTICS 2020 conference proceedings, Springer (accepted for publication).
- Alimisis, D. (2021) Technologies for an inclusive robotics education. Open Research Europe (conditionally accepted for publication)
- Pozzi, M.; Prattichizzo, D.; Malvezzi, M. Accessible Educational Resources for Teaching and Learning Robotics. *Robotics* 2021, *10*, 38. (2021) https://doi.org/10.3390/robotics10010038
- Maria Pozzi, Unnikrishnan Radhakrishnan, Ana Rojo Agustí, Konstantinos Koumaditis, Francesco Chinello, Juan C. Moreno Sastoque and Monica Malvezzi.*Exploiting VR and AR technologies in education and training to Inclusive Robotics* EDUROBOTICS 2020 conference proceedings, Springer (accepted for publication).
- Sofia Almpani and Dimitris Alimisis *Dance & Robots: Designing a Robotics-enhanced project for dance-based STEAM Education Using ENGINO* EDUROBOTICS 2020 conference proceedings, Springer (accepted for publication).
- Britt Östlund *Robots entering the care sector: The case of a new curriculum for the education of assistant nurses in Sweden*, EDUROBOTICS 2020 conference proceedings, Springer (accepted for publication).

References

[1] Carnegie Mellon Robotics Academy. (2013). Carnegie Mellon Robotics Academy. Retrieved October 8, 2019, from https://www.cmu.edu/roboticsacademy/

[2] Yocum, D. (n.d.). EV3 Tutorial — STEMcentric. Retrieved October 8, 2019, from http://www.stemcentric.com/ev3-tutorial

[3] RoboESL, E. P. (n.d.). RoboESL. Retrieved October 8, 2019, from http://roboesl.eu/

[4] Nigel Ward. (n.d.). Mind-storms.com - My EV3 course. Retrieved October 8, 2019, from https://sites.google.com/site/gask3t/lego-ev3/ev3eeb3

[5] Graeme Faulkner, Yaya Lu, Y. C. (n.d.). Fun with Beginner LEGO MindStorms EV3 Robotics. | Udemy. Retrieved October 8, 2019, from https://www.udemy.com/course/fun-with-beginner-lego-mindstorms-ev3-robotics/

[6] Kee, D. (n.d.). Damien Kee. Retrieved October 8, 2019, from https://www.damienkee.com/

[7] INBOTS European Union's Horizon 2020 research and innovation programme. (n.d.). INBOTS – Inclusive Robotics for a better Society. Retrieved October 8, 2019, from http://inbots.eu/

[8] Atmatzidou, S, & Demetriadis, S. N. (2012). Evaluating the Role of Collaboration Scripts as Group Guiding Tools in Activities of Educational Robotics: Conclusions from Three Case Studies. In *2012 IEEE 12th International Conference on Advanced Learning Technologies* (pp. 298–302). https://doi.org/10.1109/ICALT.2012.111

[9] Rummel, N., & Spada, H. (2007). Can People Learn Computer-Mediated Collaboration by Following A Script? In *Scripting Computer-Supported Collaborative Learning* (pp. 39–55). https://doi.org/10.1007/978-0-387-36949-5_3

[10] Fischer, F., Kollar, I., Haake, J., & Mandl, H. (2007). *Scripting Computer-Supported Collaborative Learning* (Vol. 6). Boston, MA: Springer US. https://doi.org/10.1007/978-0-387-36949-5

[11] Kollar, I., Fischer, F., & Hesse, F. W. (2006). Collaboration Scripts – A Conceptual Analysis. *Educational Psychology Review*, *18*(2), 159–185. https://doi.org/10.1007/s10648-006-9007-2

[12] Atmatzidou, Soumela, & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems*, *75*, 661–670. https://doi.org/10.1016/j.robot.2015.10.00

[13] Worsley, M., & Blikstein, P. (2016). Children are not hackers: Building a culture of powerful ideas, deep learning, and equity in the Maker Movement. In *Makeology* (pp. 78–94).

[14] Ge, X., & Land, S. M. (2003). Scaffolding students' problem-solving processes in an Ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development*, *51*(1), 21–38. https://doi.org/10.1007/BF02504515

[15] Forsyth, D. J. (2008). Engaging Readers and Writers With Inquiry: Promoting Deep Understandings in Language Arts and the Content Areas With Guiding Questions. *Journal of Adolescent & Adult Literacy*.

[16] Schmidt, H. G., Loyens, S. M. M., Van Gog, T., & Paas, F. (2007). Problem-based learning is compatible with human cognitive architecture: Commentary on Kirschner, Sweller, and Clark (2006). *Educational Psychologist*. https://doi.org/10.1080/00461520701263350

[17] Atmatzidou, Soumela, & Demetriadis, S. (2017). A didactical model for educational robotics activities: A study on improving skills through strong or minimal guidance. *Advances in Intelligent Systems and Computing*, *560*, 58–72. https://doi.org/10.1007/978-3-319-55553-9_5

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[18] Atmatzidou, Soumela, Demetriadis, S., & Nika, P. (2018). How Does the Degree of Guidance Support Students' Metacognitive and Problem Solving Skills in Educational Robotics? *Journal of Science Education and Technology*, *27*(1), 70–85. https://doi.org/10.1007/s10956-017-9709-x

[19] Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

[20] Clark, R., Kirschner, P., & Sweller, J. (2012). Putting Students on the Path to Learning: The Case for Fully Guided Instruction. *American Educator*, *36*(1), 6–11.

[21] Anewalt, K. (2002). Experiences teaching writing in a computer science course for the first time. *Journal of Computing Sciences in Colleges*, *18*(2), 346–355. Retrieved from http://dl.acm.org/citation.cfm?id=771322.771369

[22] Kalyuga, S., & Sweller, J. (2004). Measuring knowledge to optimize cognitive load factors during instruction. *Journal of Educational Psychology*, *96*(3), 558–568. https://doi.org/10.1037/0022-0663.96.3.558

[23] Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*, *19*(4), 509–539. https://doi.org/10.1007/s10648-007-9054-3

[24] Wecker, C., & Fischer, F. (2006). Fading scripts in computer-supported learning: The role of distributed monitoring. In *Proceedings of the 8th iternational conference on Computer supported collaborative learning* (pp. 764–772).

[25] Wecker, C., & Fischer, F. (2011). From guided to self-regulated performance of domain-general skills: The role of peer monitoring during the fading of instructional scripts. *Learning and Instruction*, *21*(6), 746–756. https://doi.org/10.1016/j.learninstruc.2011.05.001

[26] Chlup, D. T., & Collins, T. E. (2010). Breaking the Ice: Using Ice-breakers and Re-energizers with Adult Learners. *Adult Learning*, *21*(3–4), 34–39. https://doi.org/10.1177/104515951002100305

[27] Velandia, R. (2008). The Role of Warming Up Activities in Adolescent Students' Involvement during the English Class. *Profile Issues in Teachers` Professional Development*, (10), 9–26.

[28] Henslee, A. M., Burgess, D. R., & Buskist, W. (2006). Faculty Forum. *Teaching of Psychology*, *33*(3), 189–207. https://doi.org/10.1207/s15328023top3303_7

[29] Seçer, Ş. Y. E., Şahin, M., & Alcı, B. (2015). Investigating the Effect of Audio Visual Materials as Warm-up Activity in Aviation English Courses on Students' Motivation and Participation at High School Level. In *Procedia - Social and Behavioral Sciences* (Vol. 199, pp. 120–128). https://doi.org/10.1016/j.sbspro.2015.07.495

[30] Juang, Y. R. (2008). Learning by blogging: Warm-up and review lessons to facilitate knowledge building in classrooms. In *Proceedings - ICCE 2008: 16th International Conference on Computers in Education* (pp. 279–283).

[31] Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers and Education*, *72*, 145–157.

[32] Goldman, R. (2004). Using educational robotics to engage inner-city students with technology. *Proceedings of the 6th International …*, *2003*(I), 214–221. Retrieved from http://portal.acm.org/citation.cfm?id=1149151%5Cnpapers2://publication/uuid/65BF6840-A961-4FCE-B0B8-7C8B88AF6FAF

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[33] Herzog-Punzenberger, B., Le Pichon Vorstman, E., & Siarova, H. (2017). *Multilingual education in the light of diversity: Lessons learned. NESET II Report*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2766/71255

[34] Benson, C. (2013). Towards adopting a multilingual habitus in educational development. In *Language Issues in Comparative Education: Inclusive Teaching and Learning in Non-Dominant Languages and Cultures*. https://doi.org/10.1007/978-94-6209-218-1

[35] Olshtain, E., & Nissim-Amitai, F. (2004). Curriculum Decision-making in a Multilingual Context. *International Journal of Multilingualism*, *1*(1), 53–64. https://doi.org/10.1080/14790710408668178

[36] Chou, P.-N. (2018). Skill development and knowledge acquisition cultivated by maker education: Evidence from Arduino-based educational robotics. *EURASIA J. Math. Sci. Technol. Educ*, *14*, 1–9.

[37] Saleiro, M., Carmo, B., Rodrigues, J. M. F., & Du Buf, J. M. H. (2013). A low-cost classroom-oriented educational robotics system. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (Vol. 8239 LNAI, pp. 74–83). https://doi.org/10.1007/978-3-319-02675-6_8

[38] Moran, R., Teragni, M., & Zabala, G. (2017). A Concurrent Programming Language for Arduino and Educational Robotics. In *XXIII Congreso Argentino de Ciencias de la Computación (La Plata, 2017).*

[39] Alimisis D. (2020) Emerging Pedagogies in Robotics Education: Towards a Paradigm Shift. In: Pons J. (eds) Inclusive Robotics for a Better Society. INBOTS 2018. Biosystems & Biorobotics, vol 25. Springer, Cham. https://doi.org/10.1007/978-3-030-24074-5_22

[40] Alimisis, D. (2013). Educational robotics : Open questions and new challenges. *Themes in Science & Technology Education*. https://doi.org/10.1007/s12273-008-8106-z

[41] Schön, S, Ebner, M, and Kumar, S 2014, "The Maker Movement. Implications of new digital gadgets, fabrication tools and spaces for creative learning and teaching", eLearning papers, 39, pp.14-25.

[42] Blikstein, P. (2014). Digital Fabrication and 'Making' in Education The Democratization of Invention. In *FabLab*. Bielefeld: transcript Verlag. https://doi.org/10.14361/transcript.9783839423820.203

[43] Piaget, J. (1973). To Understand is to Invent: The Future of Education. In *International Commission on the Development of Education*.

[44] Papert, S., & Harel, I. (1991). Situating Constructionism. *Constructionism*, 1–12.

[45] Papert, S 1993, Mindstorms: Children,Computers, and Powerful Ideas, London: Basic Books, 2nd Edition.

[46] Sapounidis, T., & Alimisis, D. (2020). Educational Robotics for STEM: A Review of Technologies and Some Educational Considerations. In L. Leite, E. Oldham, A. Afonso, V. Floriano, L. Dourado, & M. H. Martinho (Eds.), Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward (pp. 167–190). Nova science publishers.

[47] Alimisis, D. (2021) Technologies for an inclusive robotics education. Open Research Europe (conditionally accepted for publication).

[48] Kafai, Y and Resnick, M 1996, Constructionism in practice: Designing, thinking, and learning in a digital world, Lawrence Erlbaum Associates, Mahwah, NJ.

[49] Piaget, J 1972, The principles of Genetic Epistemology, N.Y.: BasicBooks

[50] Resnick, M 2007b, "Sowing the Seeds for a More Creative Society", International Society for Technology in Education, pp.18-22.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[51] Resnick, M and Silverman, B 2005, "Some Reflections on Designing Construction Kits for Kids", Proceedings of Interaction Design and Children conference, available at: http://llk.media.mit.edu/papers/IDC-2005.pdf

[52] Resnick, M 2006, "Computer as Paintbrush: Technology, Play, and the Creative Society", In: D. Singer, R. Golikoff, and K. Hirsh-Pasek (eds), Play =Learning: How play motivates and enhances children's cognitive and social-emotional growth, Oxford University Press.

[53] National Education Association 2010, Preparing 21st Century Students for a Global Society: An Educator's Guide to the "Four Cs". https://www.academia.edu/36311252/Preparing_21st_Century_Students_for_a_Global_Society_An_Educators_Guide_to_the_Four_Cs_Great_Public_Schools_for_Every_Student (last accessed 01/03/2021)

[54] Merleau-Ponty, M 2003, Phenomenology of perception, re-edition, routledge, London and New York.

[55] Lakoff, G and Johnson, M 1999, Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Though, Harper Collins Publishers.

[56] Damasio, A.R 1994, Descartes' error: Emotion, Reason and the Human Brain, Avon Books, New York.

[57] Clark, A 1997, Being There: Putting Brain, Body, and World together again, The MIT Press.

[58] Gibson, J 1979, The ecological approach to visual perception, Houghton Mifflin Company, Boston.

[59] Thiel, P 1997, People, Paths and Purposes: Notations for a participatory envirotecture, The University of Washington Press.

[60] Elkins, J 1999, Pictures of the Body: Pain and Metamorphosis, Stanford University Press, Stanford, California.

[61] Hummels, C 2000, "Gestural design tools: prototypes, experiments and scenarios", PhD thesis, TU Delft.

[62] Mantovani, F and Castelnuovo, G 2003, "Sense of presence in virtual training: Enhance skills acquisition and transfer of knowledge through learning experience in virtual environments", Being There: Concepts, effects and measurement of user presence in synthetic environments, G. Riva, F. Davide, W.A IJsselsteijn (Eds.) Ios Press, 2003, Amsterdam, The Netherlands, pp. 168-180.

[63] Dourish, P 1999, "Embodied Interaction: Exploring the foundations of a new approach to HCI", draft paper in preparation for a special issue of Transactions on Computer-Human Interaction on "HCI in the New Millennium" (available online: http://www.dourish.com/embodied/embodied99.pdf)

[64] Spagnolli, A and Gamberini, L 2002, "Immersion/emersion: Presence in hybrid environments", Proceedings of the Fifth Annual International Workshop on Presence, Universitade Fernando Pessoa Press, Porto, pp. 421-434.

[65] Larssen, AT, Robertson, T and Edwards, J 2007, "The feel dimension of technology interaction: exploring tangibles through movement and touch", Proceedings of the 1st international conference on Tangible and embedded interaction (TEI 2007), Baton Rouge, Louisiana, USA, Feb. 15 - 17, pp. 271 – 278.

[66] Borries, FV, Walz, S, and Bottger, M 2007, Space, Time, Place: Computer Games, Architecture and Urbanism: The next Level, Birkhauser, Basel_Boston_Berlin.

[67] Schell, J 2008, The Art of Game Design: A book of lens, Carnegie Mellon University, Morgan Kaufmann Publishers, USA.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[68] Juul, J 2005, Half-real: Video Games between Real Rules and Fictional Worlds, Cambridge MA: The MIT Press.

[69] Salen K and Zimmerman E 2004, Rules of Play – Game Design Fundamentals, The MIT Press Cambridge, Massachusetts London England.

[70] De Gloria, A, Belloty, F, Berta, R, Lavagnino, E 2014, "Serious Games for education and training", international Journal of Serious Games, Vol 1, issue 1, available online: http://dx.doi.org/10.17083/ijsg.v1i1.11

[71] Resnick, M 2007, "All I really need to know (about creative thinking) I learned (by studying how children learn) in kindergarten", C&C '07: Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition, June 2007, pp. 1–6, https://doi.org/10.1145/1254960.1254961

[72] Mayo, MJ 2009, "Video Games: A Route to Large-Scale STEM Education?", Science, 323, pp. 79-82.

[73] Barr, M 2017, "Video games can develop graduate skills in higher education students: A randomised trial", Computers & Education, 113, pp.86–97.

[74] Boris, V 2017, "What makes storytelling so effective for learning?", Harvard Buisness Publicing, available online: https://www.harvardbusiness.org/what-makes-storytelling-so-effective-for-learning/

[75] Ibarra, H and Lineback, K 2005, "What's your story", Harvard Business Review, available online: https://hbr.org/2005/01/whats-your-story

[76] Zak, PJ 2014, "Why your brains loves good storytelling", Harvard Business Review, available online: https://hbr.org/2014/10/why-your-brain-loves-good-storytelling

[77] Harrop, W 2018, "STEM and Storytelling — Integration across the Curriculum", presentation available online: https://www.stemforward.org/stem-storytelling

[78] Sarkisyan, A 2018, "Storytelling in STEM – can changing the narrative (finally) give girls a voice?", "Learnosity" site, available online: https://learnosity.com/storytelling-in-stem-changing-the-narrative

[79] Kuchment, A 2013, "To Attract More Girls to STEM, Bring More Storytelling to Science", available online: https://blogs.scientificamerican.com/budding-scientist/to-attract-more-girls-to-stem-bring-storytelling-to-science/

[80] Siciliano, B.; Khatib, O. Springer handbook of robotics; Springer, 2016.

[81] Haddadin, S.; Croft, E. Physical human–robot interaction. In Springer handbook of robotics; Springer, 2016; pp. 1835–1874.

[82] Ajoudani, A.; Zanchettin, A.M.; Ivaldi, S.; Albu-Schäffer, A.; Kosuge, K.; Khatib, O. Progress and prospects of the human–robot collaboration. Autonomous Robots 2018, 42, 957–975.

[83] Kragic, D.; Gustafson, J.; Karaoguz, H.; Jensfelt, P.; Krug, R. Interactive, Collaborative Robots: Challenges and Opportunities. IJCAI, 2018, pp. 18–25.

[84] Cangelosi, A.; Schlesinger, M. Developmental Robotics: From Babies to Robots; MIT Press, 2015.

[85] Goswami, A.; Vadakkepat, P. Humanoid robotics: a reference; Springer, 2019.

[86] Eppner, C.; Deimel, R.; Alvarez-Ruiz, J.; Maertens, M.; Brock, O. Exploitation of environmental constraints in human and robotic grasping. The International Journal of Robotics Research 2015, 34, 1021–1038.

[87] Masia, L.; Hussain, I.; Xiloyannis, M.; Pacchierotti, C.; Cappello, L.; Malvezzi, M.; Spagnoletti, G.; Antuvan, C.W.; Khanh, D.B.; Pozzi, M.; Prattichizzo, D. Soft wearable assistive robotics: exosuits and supernumerary limbs. In Wearable Exoskeleton Systems: Design, control and applications; Institution of Engineering and Technology., Ed.; 2018; pp. 219–254.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[88] Breazeal, C.; Dautenhahn, K.; Kanda, T. Social robotics. Springer handbook of robotics 2016, pp. 1935–1972.

[89] Pozzi, M.; Prattichizzo, D.; Malvezzi, M. On-Line Educational Resources on Robotics: A Review. InInclusive Robotics for a Better Society. INBOTS 2018. Biosystems & Biorobotics; Pons, J.L., Ed.; Springer, Cham, 2020; Vol. 25, pp. 141–147.

[90] Evripidou, S.; Georgiou, K.; Doitsidis, L.; Amanatiadis, A.A.; Zinonos, Z.; Chatzichristofis, S.A. Educational Robotics: Platforms, Competitions and Expected Learning Outcomes. IEEE Access 2020.

[91] Esposito, J.M. The state of robotics education: proposed goals for positively transforming robotics education at postsecondary institutions. IEEE Robotics & Automation Magazine 2017, 24, 157–164.

[92] Radha, R.; Mahalakshmi, K.; Kumar, V.S.; Saravanakumar, A. E-Learning during lockdown of Covid-19 pandemic: A global perspective. International journal of control and automation 2020, 13, 1088–1099.

[93] Bahasoan, A.N.; Ayuandiani, W.; Mukhram, M.; Rahmat, A. Effectiveness of online learning in pandemic COVID-19. International Journal Of Science, Technology & Management 2020, 1, 100–106.

[94] Class Central: https://www.classcentral.com

[95] 3D Model Creation with Autodesk Fusion 360: https://www.coursera.org/learn/3d-model-creation-fusion-360/home/ welcome

[96] TED, ideas worth spreading: https://www.ted.com/

[97] Sapounidis, T.; Alimisis, D. Educational Robotics for STEM: A Review of Technologies and Some Educational Considerations. Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward; Nova Science Publishers: Hauppauge, NY, USA 2020, pp. 167–190.

[98] De Notaris, D.; Canazza, S.; Mariconda, C.; Paulon, C. How to play a MOOC: Practices and simulation. Entertainment Computing 2021, 37, 100395.

[99] Class Central. The Report: Your source for the latest news and trends in online education. www.classcentral.com/report/ (accessed: 14.12.2020).

[100] Shah, D. (Class Central). By The Numbers: MOOCs in 2020. www.classcentral.com/report/mooc-stats-2020/ (accessed: 14.12.2020).

[101] Committee for the Coordination of Statistical Activities. How COVID-19 is changing the world: a statistical perspective, 2020. unstats.un.org/unsd/ccsa/documents/covid19-report-ccsa.pdf (accessed: 14.12.2020).

[102] Alimisis, D.; Loukatos, D.; Zoulias, E.; Alimisi, R. The Role of Education for the Social Uptake of Robotics: The Case of the eCraft2Learn Project. International Conference on Inclusive Robotics for a better Society. Springer, 2018, pp. 180–187.

[103] Ferrarelli, P.; Villa, W.; Attolini, M.; Cesareni, D.; Micale, F.; Sansone, N.; Pantaleone, L.C.; Iocchi, L.Improving students' concepts about Newtonian mechanics using Mobile robots. International Conference on Robotics and Education RiE 2017. Springer, 2018, pp. 113–124.

[104] https://www.springer.com/gp/book/9783319740942

[105] Modern Robotics: Mechanics, Planning, and Control; Cambridge University Press, 2017.

[106] Malvezzi, M.; Gioioso, G.; Salvietti, G.; Prattichizzo, D. SynGrasp: A MATLAB Toolbox for Underactuated and Compliant Hands. Robotics and Automation Magazine 2015, 22, 52–68.

[107] Richard M. Murray, S. Shankar Sastry, and Li Zexiang. A Mathematical Introduction to Robotic Manipulation. CRC Press, Inc., Boca Raton, FL, USA, 1st edition, 1994.

[108] M. Pozzi, M. Malvezzi, D. Prattichizzo. MOOC on the Art of Grasping and Manipulation in Robotics: Design Choices and Lessons Learned. In Robotics in Education, Wilfried Lepuschitz, Munir Merdan, Gottfried Koppensteiner, Richard Balogh, David Obdrzalek (eds.), Pages 71-78, Cham, 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[109] Otchie, W.O.; Pedaste, M.; Bardone, E.; Chounta, I.A. Can YouTube videos facilitate teaching and learning of STEM subjects in high schools? Bulletin of the Technical Committee on Learning Technology 2020, 20, 3–8.

[110] Devlin, T.J.; Feldhaus, C.R.; Bentrem, K.M. The Evolving Classroom: A Study of Traditional and Technology-Based Instruction in a STEM Classroom. Journal of Technology Education 2013, 25, 34–54.

[111] Rosenthal, S. Motivations to seek science videos on YouTube: Free-choice learning in a connected society. International Journal of Science Education, Part B 2018, 8, 22–39.

[112] Rosenthal, S. Motivations to seek science videos on YouTube: Free-choice learning in a connected society. International Journal of Science Education, Part B 2018, 8, 22–39.

[113] Küster, D.; Swiderska, A.; Gunkel, D. I saw it on YouTube! How online videos shape perceptions of mind, morality, and fears about robots. New Media & Society 2020.

[114] Jham, B.C.; Duraes, G.V.; Strassler, H.E.; Sensi, L.G. Joining the podcast revolution. Journal of Dental Education 2008, 72, 278–281.

[115] Evans, C. The effectiveness of m-learning in the form of podcast revision lectures in higher education. Computers & Education 2008, 50, 491 – 498. DEVELOPMENT, DISRUPTION & DEBATE.

[116] Malan, D.J. Podcasting computer science E-1. ACM SIGCSE Bulletin 2007, 39, 389–393.

[117] DaVia Rubenstein, L. Using TED talks to inspire thoughtful practice. The teacher educator 2012, 47, 261–267.

[118] Romanelli, F.; Cain, J.; McNamara, P.J. Should TED talks be teaching us something? American journal of pharmaceutical education 2014, 78.

[119] Yelamarthi, K.; Drake, E. A flipped first-year digital circuits course for engineering and technology students. IEEE Transactions on Education 2014, 58, 179–186.

[120] https://www.ted.com/talks/adrienne_mayor_the_greek_myth_of_talos_the_first_robot

[121] https://www.ted.com/talks/carl_vause_meet_the_robot_designed_like_an_octopus_tentacle, https://www.ted.com/talks/marc_raibert_meet_spot_the_robot_dog_that_can_run_hop_and_open_doors

[122] https://www.ted.com/talks/kate_darling_why_we_have_an_emotional_connection_to_robots

[123] https://www.ted.com/talks/huang_yi_kuka_a_human_robot_dance_duet

[124] https://www.ted.com/talks/cynthia_breazeal_the_rise_of_personal_robots

125 https://www.youtube.com/user/TEDxTalks

[126] Cañas, J.M.; Perdices, E.; García-Pérez, L.; Fernández-Conde, J. A ROS-Based Open Tool for Intelligent Robotics Education. Applied Sciences 2020, 10, 7419

[127] Avanzato, R.L.; Wilcox, C.G. Work in progress: Introductory mobile robotics and computer vision laboratories using ROS and MATLAB. ASEE Annual Conference and Exposition, Conference Proceedings, 2018, Vol. 2018.

[128] https://www.theconstructsim.com/build-robotics-mooc-based-ros/.

[129] Corke, P. Robotics, Vision and Control: Fundamental Algorithms In MATLAB R Second, Completely Revised; Vol. 118, Springer, 2017.

[130] Miller, A.T.; Allen, P.K. Graspit! a versatile simulator for robotic grasping. IEEE Robotics & Automation Magazine 2004, 11, 110–122.

[131] Gil, A. ARTE: A Robotics Toolbox for Education. arvc.umh.es/arte/index_en.html (accessed: 10.02.2021).

[132] Michel, O. Cyberbotics Ltd. WebotsTM: professional mobile robot simulation. International Journal of Advanced Robotic Systems 2004, 1, 5.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[133] Freese, M.; Singh, S.; Ozaki, F.; Matsuhira, N. Virtual robot experimentation platform v-rep: A versatile 3d robot simulator. International Conference on Simulation, Modeling, and Programming for Autonomous Robots. Springer, 2010, pp. 51–62.
[134] Koenig, N.; Howard, A. Design and use paradigms for gazebo, an open-source multi-robot simulator. 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2004, Vol. 3, pp. 2149–2154.
[135] Yue, H.; Miao, J.; Zhang, J.; Fan, C.; Xu, D. Simulation for senior undergraduate education of robot engineering based on Webots. Computer Applications in Engineering Education 2020.
[136] Yap, Y.L.; Sing, S.L.; Yeong,W.Y. A review of 3D printing processes and materials for soft robotics. Rapid Prototyping Journal 2020.
[137] University, H.; Dublin, T.C. Soft Robotics Toolkit. https://softroboticstoolkit.com/documents (accessed: 16.12.2020).
[138] Ribeiro, A.F.; Lopes, G. Learning Robotics: a Review. Current Robotics Reports 2020, 1, 1–11.
139 https://www.youtube.com/watch?v=g0TaYhjpOfo&t=5s
[140] Dias, J.; Althoefer, K.; Lima, P.U. Robot competitions: What did we learn? [Competitions]. IEEE Robotics & Automation Magazine 2016, 23, 16–18.
[141] Tsagarakis, N.G.; Caldwell, D.G.; Negrello, F.; Choi,W.; Baccelliere, L.; Loc, V.G.; Noorden, J.; Muratore, L.; Margan, A.; Cardellino, A.;et al. Walk-man: A high-performance humanoid platform for realistic environments. Journal of Field Robotics 2017, 34, 1225–1259.
[142] Riener, R. The Cybathlon promotes the development of assistive technology for people with physical disabilities. Journal of neuroengineering and rehabilitation 2016, 13, 49.
[143] Perdikis, S.; Tonin, L.; Saeedi, S.; Schneider, C.; Millán, J.d.R. The Cybathlon BCI race: Successful longitudinal mutual learning with two tetraplegic users. PLoS biology 2018, 16, e2003787.
[144] Eppner, C.; Höfer, S.; Jonschkowski, R.; Martín-Martín, R.; Sieverling, A.; Wall, V.; Brock, O. Lessons from the amazon picking challenge: Four aspects of building robotic systems. Robotics: science and systems, 2016.
[145] Ferri, G.; Ferreira, 478 F.; Djapic, V. Boosting the talent of new generations of marine engineers through robotics competitions in realistic environments: The SAUC-E and euRathlon experience. OCEANS 2015-Genova. IEEE, 2015, pp. 1–6.
[146] Franchi, M.; Fanelli, F.; Bianchi, M.; Ridolfi, A.; Allotta, B. Underwater Robotics Competitions: The European Robotics League Emergency Robots ExperienceWith FeelHippo AUV. Frontiers in Robotics and AI 2020, 7, 3.
[147] Chen, X. How Does Participation in FIRST LEGO League Robotics Competition Impact Children's Problem-Solving Process? Robotics in Education; Lepuschitz, W.; Merdan, M.; Koppensteiner, G.; Balogh, R.; Obdržálek, D., Eds.; Springer International Publishing: Cham, 2019; pp. 162–167.
[148] https://www.youtube.com/watch?v=g0TaYhjpOfo
[149] K. Schwab, The Fourth Industrial Revolution . Crown, 2017.
[150] D. Alimisis, D. Loukatos, E. Zoulias, and R. Alimisi, 'The Role of Education for the Social Uptake of Robotics: The Case of the eCraft2Learn Project', in Inclusive Robotics for a Better Society , Cham, 2020, pp. 180–187, doi: 10.1007/978-3-030-24074-5_30.
[151] M. Pozzi, D. Prattichizzo, and M. Malvezzi, 'On-Line Educational Resources on Robotics: A Review', in Inclusive Robotics for a Better Society , Cham, 2020, pp. 141–147, doi: 10.1007/978-3-030-24074-5_25.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[152] P. Ferrarelli et al. , 'Improving Students' Concepts About Newtonian Mechanics Using Mobile Robots', in Robotics in Education , vol. 829, W. Lepuschitz, M. Merdan, G. Koppensteiner, R. Balogh, and D. Obdržálek, Eds. Cham: Springer International Publishing, 2019, pp. 113–124.
[153] J. Martín-Gutiérrez, C. E. Mora, B. Añorbe-Díaz, and A. González-Marrero, 'Virtual Technologies Trends in Education', EURASIA J MATH SCI T , vol. 13, no. 2, Jan. 2017, doi: 10.12973/eurasia.2017.00626a.
[154] M.-B. Ibáñez and C. Delgado-Kloos, 'Augmented reality for STEM learning: A systematic review', Computers & Education , vol. 123, pp. 109–123, Aug. 2018, doi: 10.1016/j.compedu.2018.05.002.
[155] F. Bellalouna, 'New Approach for Industrial Training Using Virtual Reality Technology', Procedia CIRP , vol. 93, pp. 262–267, 2020, doi: 10.1016/j.procir.2020.03.008.
[156] P. Milgram and F. Kishino, 'A taxonomy of mixed reality visual displays', IEICE TRANSACTIONS on Information and Systems , vol. 77, no. 12, pp. 1321–1329, 1994.
[157] A. Suh and J. Prophet, 'The state of immersive technology research: A literature analysis', Computers in Human Behavior , vol. 86, pp. 77–90, 2018.
[158] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, 'A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda', Computers & Education, vol. 147, p. 103778, 2020.
[159] L. Chittaro and F. Buttussi, 'Assessing knowledge retention of an immersive serious game vs. a traditional education method in aviation safety', IEEE transactions on visualization and computer graphics, vol. 21, no. 4, pp. 529–538, 2015.
[160] E. Krokos, C. Plaisant, and A. Varshney, 'Virtual memory palaces: immersion aids recall', Virtual Reality, vol. 23, no. 1, pp. 1–15, 2019.
[161] P. Carlson, A. Peters, S. B. Gilbert, J. M. Vance, and A. Luse, 'Virtual training: Learning transfer of assembly tasks', IEEE transactions on visualization and computer graphics , vol. 21, no. 6, pp. 770–782, 2015.
[162] N. Vaughan, N. John, and N. Rees, 'ParaVR: Paramedic Virtual Reality Training Simulator', in 2019 International Conference on Cyberworlds (CW) , 2019, pp. 21–24.
[163] A. L. Butt, S. Kardong-Edgren, and A. Ellertson, 'Using game-based virtual reality with haptics for skill acquisition', Clinical Simulation in Nursing , vol. 16, pp. 25–32, 2018.
[164] S. Shorey, E. Ang, E. D. Ng, J. Yap, L. S. T. Lau, and C. K. Chui, 'Communication skills training using virtual reality: A descriptive qualitative study', Nurse Education Today , vol. 94, p. 104592, 2020.
[165] H. McFaul and E. FitzGerald, 'A realist evaluation of student use of a virtual reality smartphone application in undergraduate legal education', British Journal of Educational Technology , vol. 51, no. 2, pp. 572–589, 2020.
[166] S. Webel, U. Bockholt, T. Engelke, N. Gavish, M. Olbrich, and C. Preusche, 'An augmented reality training platform for assembly and maintenance skills', Robotics and autonomous systems , vol. 61, no. 4, pp. 398–403, 2013.
[167] N. Gavish et al. , 'Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks', Interactive Learning Environments , vol. 23, no. 6, pp. 778–798, 2015.
[168] C. Catal, A. Akbulut, B. Tunali, E. Ulug, and E. Ozturk, 'Evaluation of augmented reality technology for the design of an evacuation training game', Virtual Reality , pp. 1–10, 2019.
[169] E. Rojas-Muñoz et al. , 'Evaluation of an augmented reality platform for austere surgical telementoring: a randomized controlled crossover study in cricothyroidotomies', NPJ Digital Medicine , vol. 3, no. 1, pp. 1–9, 2020.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[170] A. L. Simeone, M. Speicher, A. Molnar, A. Wilde, and F. Daiber, 'LIVE: the human role in learning in immersive virtual environments', in Symposium on Spatial User Interaction , 2019, pp. 1–11.

[171] D. Allcoat and A. von Mühlenen, 'Learning in virtual reality: Effects on performance, emotion and engagement', Research in Learning Technology , vol. 26, 2018.

[172] Y. Rahman, S. M. Asish, N. P. Fisher, E. C. Bruce, A. K. Kulshreshth, and C. W. Borst, 'Exploring Eye Gaze Visualization Techniques for Identifying Distracted Students in Educational VR', in 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR) , 2020, pp. 868–877.

[173] H. Tobar-Muñoz, S. Baldiris, and R. Fabregat, 'Augmented reality game-based learning: Enriching students' experience during reading comprehension activities', Journal of Educational Computing Research , vol. 55, no. 7, pp. 901–936, 2017.

[174] C.-M. Chen and Y.-N. Tsai, 'Interactive augmented reality system for enhancing library instruction in elementary schools', Computers & Education, vol. 59, no. 2, pp. 638–652, 2012.

[175] C. Erbas and V. Demirer, 'The effects of augmented reality on students' academic achievement and motivation in a biology course', Journal of Computer Assisted Learning , vol. 35, no. 3, pp. 450–458, 2019.

[176] D. Sahin and R. M. Yilmaz, 'The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education', Computers & Education , vol. 144, p. 103710, 2020.

[177] J. J. Roldán, E. Peña-Tapia, A. Martín-Barrio, M. A. Olivares-Méndez, J. Del Cerro, and A. Barrientos, 'Multi-robot interfaces and operator situational awareness: Study of the impact of immersion and prediction', Sensors , vol. 17, no. 8, p. 1720, 2017.

[178] L. Pérez, E. Diez, R. Usamentiaga, and D. F. García, 'Industrial robot control and operator training using virtual reality interfaces', Computers in Industry , vol. 109, pp. 114–120, 2019.

[179] M. Haruna, M. Ogino, and T. Koike-Akino, 'Proposal and Evaluation of Visual Haptics for Manipulation of Remote Machine System', Front. Robot. AI 7: 529040. doi: 10.3389/frobt , 2020.

[180] M. Peral-Boiza, T. Gomez-Fernandez, P. Sanchez-Gonzalez, B. Rodriguez-Vila, E. J. Gómez, and Á. Gutiérrez, 'Position Based Model of a Flexible Ureterorenoscope in a Virtual Reality Training Platform for a Minimally Invasive Surgical Robot', IEEE Access , vol. 7, pp. 177414–177426, 2019.

[181] F. Wang et al. , 'The application of virtual reality training for anastomosis during robot-assisted radical prostatectomy', Asian Journal of Urology , 2019.

[182] S. Knopp, M. Lorenz, L. Pelliccia, and P. Klimant, 'Using industrial robots as haptic devices for vr-training', in 2018 IEEE conference on virtual reality and 3D user interfaces (VR) , 2018, pp. 607–608.

[183] A. Mariani, E. Pellegrini, N. Enayati, P. Kazanzides, M. Vidotto, and E. De Momi, 'Design and evaluation of a performance-based adaptive curriculum for robotic surgical training: a pilot study', in 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) , 2018, pp. 2162–2165.

[184] N. Raison et al. , 'Competency based training in robotic surgery: benchmark scores for virtual reality robotic simulation', Bju international , vol. 119, no. 5, pp. 804–811, 2017.

[185] D. H. de la Iglesia, A. S. Mendes, G. V. González, D. M. Jiménez-Bravo, and J. F. de Paz Santana, 'Connected Elbow Exoskeleton System for Rehabilitation Training Based on Virtual Reality and Context-Aware', Sensors , vol. 20, no. 3, p. 858, 2020.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

[186] F. Grimm, G. Naros, and A. Gharabaghi, 'Closed-loop task difficulty adaptation during virtual reality reach-to-grasp training assisted with an exoskeleton for stroke rehabilitation', Frontiers in neuroscience , vol. 10, p. 518, 2016
[187] R. Crespo, R. García, and S. Quiroz, 'Virtual reality application for simulation and off-line programming of the mitsubishi movemaster RV-M1 robot integrated with theoculus rift to improve students training', Procedia Computer Science , vol. 75, pp. 107–112, 2015.
[188] M. Theofanidis, S. I. Sayed, A. Lioulemes, and F. Makedon, 'Varm: Using virtual reality to program robotic manipulators', in Proceedings of the 10th International Conference on Pervasive Technologies Related to Assistive Environments , 2017, pp. 215–221.
[189] V. Román-Ibáñez, F. A. Pujol-López, H. Mora-Mora, M. L. Pertegal-Felices, and A. Jimeno-Morenilla, 'A low-cost immersive virtual reality system for teaching robotic manipulators programming', Sustainability , vol. 10, no. 4, p. 1102, 2018.
[190] Y. S. Pai, H. J. Yap, S. Z. M. Dawal, S. Ramesh, and S. Y. Phoon, 'Virtual planning, control, and machining for a modular-based automated factory operation in an augmented reality environment', Scientific reports , vol. 6, p. 27380, 2016.
[191] N. H. Christensen et al. , 'Depth cues in augmented reality for training of robot-assisted minimally invasive surgery', in Proceedings of the 21st International Academic Mindtrek Conference , 2017, pp. 120–126.
[192] A. Chowriappa et al. , 'Augmented-reality-based skills training for robot-assisted urethrovesical anastomosis: a multi-institutional randomised controlled trial', BJU international , vol. 115, no. 2, pp. 336–345, 2015.
[193] C. A. Jara, F. A. Candelas-Herías, M. Fernández, and F. Torres, 'An augmented reality interface for training robotics through the web', 2009.
[194] M. Cheli, J. Sinapov, E. E. Danahy, and C. Rogers, 'Towards an augmented reality framework for k-12 robotics education', 2018.
[195] T. Krajník, V. Vonásek, D. Fišer, and J. Faigl, 'AR-drone as a platform for robotic research and education', in International conference on research and education in robotics , 2011, pp. 172–186.
[196] C. P. Quintero, S. Li, M. K. Pan, W. P. Chan, H. M. Van der Loos, and E. Croft, 'Robot programming through augmented trajectories in augmented reality', in 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) , 2018, pp. 1838–1844.
[197] M. Ostanin, S. Mikhel, A. Evlampiev, V. Skvortsova, and A. Klimchik, 'Human-robot interaction for robotic manipulator programming in Mixed Reality', in 2020 IEEE International Conference on Robotics and Automation (ICRA) , 2020, pp. 2805–2811.
[198] G. Asín-Prieto et al. , 'Haptic adaptive feedback to promote motor learning with a robotic ankle exoskeleton integrated with a video game', Frontiers in Bioengineering and Biotechnology, vol. 8, p. 113, 2020.
[199] O. Mubin, F. Alnajjar, N. Jishtu, B. Alsinglawi, and A. Al Mahmud, 'Exoskeletons With Virtual Reality, Augmented Reality, and Gamification for Stroke Patients' Rehabilitation: Systematic Review', JMIR rehabilitation and assistive technologies , vol. 6, no. 2, p. e12010, 2019.
[200] K. Nagai, 'Learning while doing: practical robotics education', IEEE Robotics & Automation Magazine , vol. 8, no. 2, pp. 39–43, 2001.
[201] D. Alimisis, 'Educational robotics: Open questions and new challenges', Themes in Science and Technology Education , vol. 6, no. 1, pp. 63–71, 2013.
[202] V. Potkonjak et al. , 'Virtual laboratories for education in science, technology, and engineering: A review', Computers & Education , vol. 95, pp. 309–327, 2016.
[203] Guang-Zhong Yang, Bradley J. Nelson, Robin R. Murphy, Howie Choset, Henrik Christensen, Steven H. Collins, Paolo Dario, Ken Goldberg, Koji Ikuta, Neil Jacobstein, Danica Kragic,

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073

Russell H. Taylor, Marcia Mcnutt, Combating COVID-19—The role of robotics in managing public health and infectious diseases Science Robotics, Mar 2020.

204 https://www.lhfconnect.net/

205 Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., & Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *14*(4), 419-422.

206 https://www.nytimes.com/2019/06/07/education/learning/high-school-manufacturing-robotics.html

207 https://unstats.un.org/unsd/ccsa/documents/covid19-report-ccsa.pd f

208 https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/DDN-20200604- 1

209 Crick, T., Knight, C., Watermeyer, R., & Goodall, J. (2020, September). The impact of COVID-19 and "Emergency Remote Teaching" on the UK computer science education community. In *United Kingdom & Ireland Computing Education Research conference.* (pp. 31-37).

210 Holowka, Peter. "Teaching robotics during COVID-19: Machine learning, simulation, and aws deepracer." *17th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA 2020*. 2020.

211 Yang, W. J., & Du, F. F. (2020, December). Comparison of Live Teaching Methods Based on the Live Classroom System and the Video Conference System in the Context of the COVID-19 epidemic: A Case Study of a Robotics Teaching Course. In *2020 6th International Conference on Social Science and Higher Education (ICSSHE 2020)* (pp. 599-604). Atlantis Press.

212 Birk A, Dineva E, Maurelli F, Nabor A. A Robotics Course during COVID-19: Lessons Learned and Best Practices for Online Teaching beyond the Pandemic. Robotics. 2021; 10(1):5. https://doi.org/10.3390/robotics10010005

213 Rico Mockel, Lucas Dahl, Dean Boonen, Desiree Parren and Yiyong Gou, Robotics Education under COVID-19 Conditions with Educational Modular Robots, EDUROBOTICS 2020 Conference Proceedings, Springer, accepted for publication.

214 Christina Pasalidou and Nikolaos Fachantidis Distance Learning in the Era of COVID-19: Supporting Educational Robotics with Augmented Reality, EDUROBOTICS 2020 Conference Proceedings, Springer, accepted for publication.

215 https://www.tc.columbia.edu/faculty/pb2755/

216 http://cmkfutures.com/gary/

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 780073