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INBOTS
Inclusive Robotics for a better Society

INBOTS WHITE PAPER

ON

INTERACTIVE ROBOTICS EDUCATION PROGRAMS & LEARNING ACTIVITIES

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v.02			
v.03			

1 Executive summary

Robotics has considerably improved industrial processes, and is expected to become soon an important part of our daily life, since it is starting to face more human-centred problems (Bruno Siciliano & Khatib, 2016). Robots are becoming more suitable to work alongside with humans and are not anymore confined to the industrial environment. This paradigm shift not only rises very stimulating and interdisciplinary questions about socio-economical, legal, and ethical impact of robotics on the society, but also challenges educators to promote highly accessible educational material on robotics-related topics.

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 it presents challenges. The availability of accessible learning resources could foster the knowledge diffusion, but also the discussion and the collaboration between such manifold realities.

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 2019, the 10th edition of RIE was in Wien. 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). 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.

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.

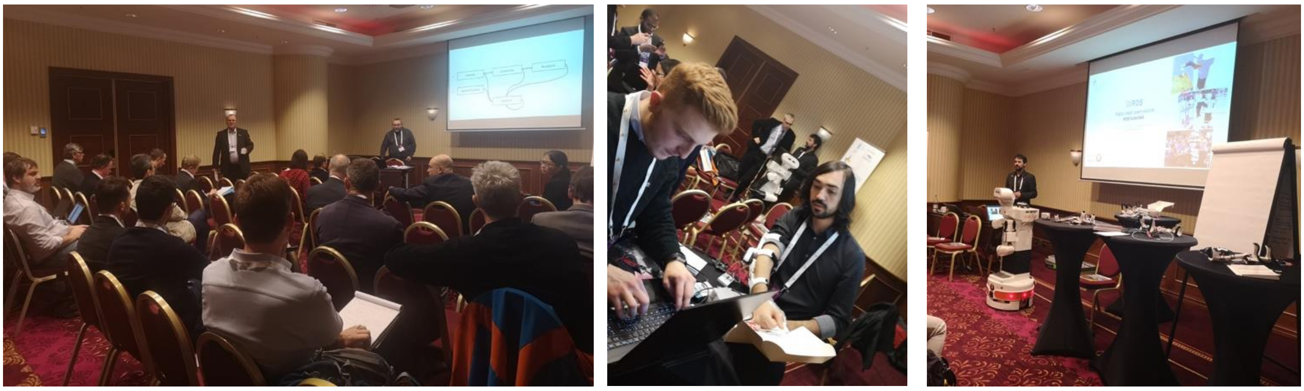
Resources can be classified according to their type:

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

In the first part of INBOTS project, we conducted an analysis of the state of the art and in this deliverable we summarize 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.

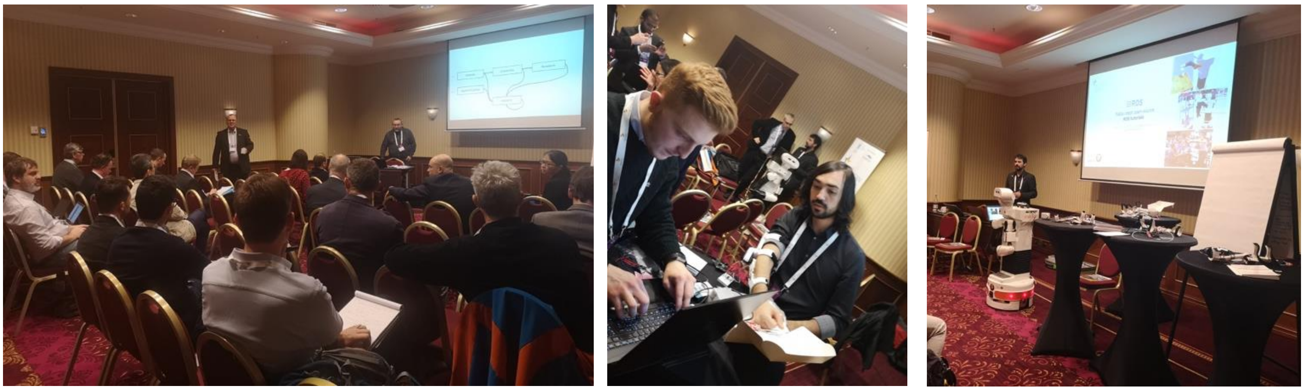
We also established connections with COST Action CA16116 - Wearable Robots for Augmentation, Assistance or Substitution of Human Motor Functions WG 5 - Education and Dissemination, with the DIH^2 Network (DIH^2 is a network of 26 DIHsm, the aim of the network is to spark incremental and disruptive innovations in Manufacturing SMEs and Mid-Caps), and with EU Robotics Topic Group on Education and Training.

We organized a workshop[1] within the first INBOTS conference in Pisa (in collaboration with COST Action CA16116 WG5), and two workshops during the European Robotics Forum[2] (see



a) *b)* *c)*

Figure 1, organised in collaboration with COST Action CA16116 WG5 and EU Robotics Topic Group on Education and Training), in which we discussed several aspects related to resources for robotic education, e.g: the current needs of education programs at all educational levels, from pre-school to university, the most suitable strategies, examples of curricula and learning materials able to fulfil these needs and spread the knowledge of robotics at different levels in the society, etc. During these events we had the possibility to discuss with experts from both the robotics and education communities.



a) *b)* *c)*

[1] http://inbotsconference2018.org/workshops/session-3-promote-highly-accesible-and-multidisciplinaty-education-programs/

[2] https://www.eu-robotics.net/robotics_forum/index.html

Figure 1: Some pictures from the workshops organised during the 2019 European Robotics Forum. a) discussion on educational tolos, b) Hands-on demonstration with the EDUEXO[3] robotic exoskeleton kit, c) introduction to the hands-on demonstration with TIAGO[4] robot provided by PAL robotics

In the second part of the project the discussion on the available educational resources will be further promoted with other workshops, events, conferences and other initiatives (e.g. third INBOTS Conference, Maker Faire in Rome, European Robotics Forum, etc.). While in the first part of the project we focused mainly on educational tools within the educational system, in the second part we will focus more on training and educational tools beyond the educational system.

Based on the information collected in the first part of the project, the objectives of this report are mainly three:

- 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 plan exchange programs.
- 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 document is organized as follows: in Section 2 we introduce an analysis of the available resources for teaching and learning robotics integrated in the educational system, i.e. from primary schools to universities. In Section 3 we summarize the main resources and best practices that we identified beyond schools and universities, both for specific people categories (e.g., teachers) and for the wide public. Specific resources links are reported in Appendix A (for schools), B (universities) and C (general public, YouTube thematic channels about robotics education and dissemination).

All the three Sections will be integrated and maximized in the next 18 months, in particular in Section 3 a more detailed analysis of training resources beyond school and universities, and in particular for employees training in companies will be provided. The specific resources listed in the Appendices will be also updated in the second part of the project.

[3] https://www.eduexo.com/

[4] https://tiago.pal-robotics.com/

2 Available resources and training needs for teaching and learning robotics in schools and universities

2.1 Educational Robotics in pre-academic education

The first steps of Educational robotics (ER) started in the 1960s with the work of Seymour Papert, who later developed the Logo programming language (Papert, 1980). Papert expanded Piaget's ideas on constructivism by promoting the view that learning is more effective when students are activated by building specific meaningful objects. Later, Papert's ideas provided the base of the first commercial robots that entered the classrooms like those developed by LEGO and MIT Media Lab. Having the foundations in the socio-cultural Vygotsky theories along with Papert's constructionism and Piaget constructivism, ER aims to develop high-level intellectual skills and knowledge through problem solving, discovery and collaboration (Blanchard, Freiman, & Lirrete-Pitre, 2010).

Over the last decade, ER has attracted the interest of teachers and researchers as a powerful teaching tool that supports learning and enables the development of students' cognitive and social skills (Alimisis, 2013). Educational Robotics appears to be a practical learning tool that enables students to express their ideas and imagination by developing simple or advanced mechanisms and robotic entities. Especially, the connection of ER with play and enjoyment is considered to be an important factor that encourages children and enables intrinsic motivation especially in primary education (Ryan & Deci, 2000; Theodosios Sapounidis & Demetriadis, 2013). ER activities focus on the research and analysis of a simple or a complex real-world problem that enables students to directly observe the results of their solution and effort. This appears to promote creativity and problem-based learning by combining abstract design ideas, into one construction (Druin & Hendler, 2000). Thus, students go from the "learn about technology" to the "learning with technology" (Carbonaro, Rex, & Chambers, 2004). This powerful tool is considered as cross-thematic and facilitates teaching mainly in Science, Technology, Engineering and Mathematics (STEM) education (Alimisis, 2013) (Rogers & Portsmore, 2004). In most cases ER mechanical constructions are combined with a simple physical-tangible or graphical programming environments that let users to make these robotic mechanisms to interact with the environment (e.g., (Theodosios Sapounidis & Demetriadis, 2017), (Erwin, Cyr, & Rogers, 2000).

Gender and age factors in STEM education

Studies working with children and adults have shown that the factors that most probably affect user preferences in novel learning environments are age and gender (e.g., (Sapounidis & Demetriadis, 2013; Sullivan & Bers, 2013), (Zuckerman & Gal-Oz, 2013)). On the one hand, age is related with accumulated knowledge and experience with technology and therefor appears to be a factor that is related with user preferences and attitude about learning and robotics (Sapounidis, Stamelos, & Demetriadis, 2016). Younger children tend to be less exposed to technology while older ones seem to be more familiar with technology and computers (Sapounidis & Demetriadis, 2013). Thus, it appears that we need different tools and interfaces to better support the learning process for the different age groups. For example, tangible user interfaces seem to be quite promising for young children mostly because they can reduce the age threshold for participation in ER and programming activities (Theodosios Sapounidis & Demetriadis, 2013). Although there are a few studies examining the advantages of different technologies in ER, there is a lack of research into mixed technologies and hybrid systems. Such systems may combine for example different interfaces (graphical - tangible) and different technologies (e.g., open source hardware / software) in one platform. The adoption of mixed technologies and hybrid systems with which different age groups will not need to learn to use more than one system to meet their educational needs in ER might reduce users' cognitive load. Since, learning the subject matter and simultaneously learning how to use a new system are processes which use identical cognitive resources (Baddeley, 2017) (Stamovlasis & Tsaparlis, 2012).

On the other hand, gender is another factor that probably affects inclination, attitude and preferences on learning with technology (e.g., (Atmatzidou & Demetriadis, 2016) (Sapounidis, Stamovlasis, & Demetriadis, 2018). The social psychology literature accepts that the two genders have different preferences and behavior in pair and group activities (e.g., ,(Margrett & Marsiske, 2002), (Benenson, Apostoleris, & Parnass, 1997), (Africano et al., 2004)) and have different attitudes and motivations (Inkpen, 1997), (Quaiser-Pohl, Geiser, & Lehmann, 2006), (Volman, Eck, Heemskerk, & Kuiper, 2005). Studies about technology have shown that girls have stronger preference for tangible user interfaces though is more probable to struggle with ER and programming, whereas boys seem to be more self-confident (Nourbakhsh, Hamner, Crowley, & Wilkinson, 2004) (Theodosios Sapounidis et al., 2018) (Atmatzidou & Demetriadis, 2016). The reason is probably that boys tend to play computer games more than girls do and thus girls are less familiar with computer technologies and graphical user interfaces (Volman et al., 2005), (Quaiser-Pohl et al., 2006). Studies focusing especially on games have shown that girls are in favor of playing games with stronger social interaction (Hartmann & Klimmt, 2006), (Volman et al., 2005), which might be better supported by certain technologies like tangible user interfaces (e.g., (Schneider, Jermann, Zufferey, & Dillenbourg, n.d.), (M. Horn, Crouser, & Bers, 2012)). Interestingly, females' attitude and preferences about technology and computers becomes less positive while getting older because of the formation and influence of gender and cultural stereotypes (Colley & Comber, 2003). Therefore, it is supported that the earlier kids become aware of technology, the fewer gender-related stereotypes will then be developed (Metz, 2007), (Steele, 1997). Hence, the incorporation of ER and programming at an early age might prevent the formation of negative gender stereotypes (Metz, 2007; Sullivan & Bers, 2013). In any case research on gender effects in programming and ER is very limited because these domains are quite new (Sullivan & Bers, 2013).

Supporting collaboration in robotics projects

One of the ER benefits appears to be the opportunities offered for collaborative learning and social interaction. Collaborative learning assumes 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 gain access to the knowledge, ideas and skills of others team members. Although the importance of students' collaborative learning has been highlighted by many researchers mainly for cognitive, social and metacognitive (generally speaking, metacognition refers to higher-order thinking skills (Metcalfe, 1994)) reasons, recent studies have revealed that if students are left without teachers' support might fail to engage in fruitful collaboration, affecting their performance and learning outcome (Atmatzidou & Demetriadis, 2012). To better support group members during interaction, teachers and scientists have proposed the use of collaboration scripts (Rummel & Spada, 2007). Collaboration scripts are didactic scenarios which are considered as scaffolds intending to improve collaboration by structuring and specifying the way the group members interact with one another (Fischer, Kollar, Haake, & Mandl, 2007) (Kollar, Fischer, & Hesse, 2006). 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 (Rummel & Spada, 2007) (Kollar et al., 2006).

In view of the above, we argue that systematic introduction of collaboration scripts at the domain of ER might have a significant impact on students' active participation, collaboration skills, engagement, and probably learning (e.g., (Atmatzidou & Demetriadis, 2016)).

How much guidance?

Failure is an important part of the learning process. Though, trial-and-error efforts are welcome in the constructivist approach, and some frustration is inevitable when learners are engaged in robotic projects. Concurrently, novices coming into a robotics lab need a considerable amount of support and facilitation before they can start making their own projects (Worsley & Blikstein, 2016). Learners, especially the novices, should be carefully introduced to the lab activities and not to be exposed to excessive levels of frustration (Worsley & Blikstein, 2016) in order to avoid disappointment and discouragement. In addition, 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, in order to maximize learning outcomes (e.g., (Ge & Land, 2003) (Forsyth, 2008) (Schmidt, Loyens, Van Gog, & Paas, 2007)). Simultaneously, other researchers believe that the constructivism model which facilitates the knowledge construction through discovery and exploration of real word challenging problems is fully compatible with the idea of guided learning (Schmidt et al., 2007). 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 (Atmatzidou & Demetriadis, 2017) (Soumela Atmatzidou, Demetriadis, & Nika, 2018).

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. (Kirschner, Sweller, & Clark, 2006). 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 (Clark, Kirschner, & Sweller, 2012). On the other hand, there are researchers who believe that strong guidance can cause workload on both students and teachers (Anewalt, 2002) and possibly may be totally unnecessary when students acquire a specific level of knowledge about the taught field (Kalyuga, 2007; Kalyuga & Sweller, 2004). By combining these two trends we can assume that 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 consider the level of the students (novice or experienced) as well as the difficulty of the new knowledge to be taught. Finally, a special care should be made to "fade out" the guidance when the trainees begin to acquire the required knowledge and skills (Wecker & Fischer, 2006, 2011). 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 on the domain.

2.1.1 Literature review on Educational Robotics

A literature review on the latest (last 10 years) tools and resources for school teachers and students was conducted by EDUMOTIVA. Here the used searching methodology and the main outcomes of the literature review are summarized, whereas the obtained results are listed in Appendix A.

2.1.1.1 SEARCHING METHODOLOGY

The paper search and selection process started with manual search via Google Scholar.

Search terms

The used search terms were general keywords related with educational robotics. We searched for articles with the following keywords in their title:

a) "Educational robotics";
b) "Educational robotics" and "review";
c) "Review", "Education" and "robots".

Based on the retrieved results, we identified and focused on the two most common educational robotics systems (Lego/Arduino) and an emerging user interface for robot programming (tangible user interfaces). Thus, we continued our search with the items:

d) "Educational robotics" and "Lego";
e) "Educational robotics" and "Arduino";
f) "Educational robots" and "tangible programming".

Inclusion – Exclusion criteria

Item	Inclusion criteria	Exclusion criteria
a)	• The article is journal paper • The paper was published in the last decade (2008-2018)	• Conference, report or book chapter • Paper published before 2008
b)	• The paper published the last decade (2008-2018)	• Paper published before 2008
c)	All items were retrieved	No exclusion criteria
d)	• The paper published the last decade (2008-2018)	• Paper published before 2008
e)	• The paper published the last decade (2008-2018)	• Paper published before 2008
f)	All items were retrieved	No exclusion criteria

Data extraction and coding

In total, 69 papers fulfilled the criteria.

2.1.1.2 OUTCOMES OF THE LITERATURE REVIEW

Here we present the robotic kits and constructions that are described in the recorded papers, thus we do not list systems like mBot or Codey Rocky by makeblock ("Makeblock: Global STEAM Education Solution Provider," n.d.) that we did not found in the extracted papers. Also, we excluded products that we found that clearly stated that are discontinued or not supported anymore (e.g., SRV-1 (Cummins, Azhar, & Sklar, 2008)).

The literature review showed that there are too many robotic kits, ranging from cheap small and single function kits to LEGO Mindstorms to very expensive humanoid robots costing thousands of dollars (Mubin, Stevens, Shahid, Mahmud, & Dong, 2013). Particularly, humanoid robots are also used in many technical applications like programming and in non-technical applications like children therapy (e.g., Nao Robot (Shamsuddin et al., 2012) music (e.g., Tiro robot (Han, Kim, & Kim, 2009)) and language teaching (e.g., Robovie robot (Kanda, Hirano, Eaton, & Ishiguro, 2004)).

We separated the recorded ER systems in seven categories:

- Open hardware robot;
- DIY or Assembly Robotic kits;
- Brick based;
- Pre-assembled;
- Simple actions or specific purpose;
- Humanoid robots;
- Based on Tangible programming.

Although several robotics systems for educational purposes exist, most of these systems are expensive and require configuration and installation of specific software. These might cause difficulties for schools with limited funding and teachers with no suitable training (Junior et al., 2013). Recently, the design of robotic systems for education appears to be guided by four basic requirements (Junior et al., 2013):

(a) Low-Cost;
(b) Appealing;
(c) Simple (assembly, operation – programming, maintenance);
(d) Open source.

Systems that might meet the above criteria are educational robots based on open source hardware-software, like Arduino-based ones. Arduino is an educational tool that offers open source hardware and software, has a vigorous community of users, and is quite cheap (Pan & Zhu, 2018).

In the related literature, it is noted that the majority of studies on educational robotics were not conducted as part of the classroom program, instead, they took place as afterschool activities or summer camp programs (Sierra Rativa, 2019). Thus, there is a strong need to validate the value of each system in real classroom setting (Benitti, 2012).

With few exceptions, it seems that there is no clear separation of the tools according to the educational needs of each age group. It is characteristic that many systems in the literature do not make any reference to the age they are addressing. It is evident from the literature that the cost of purchasing ER systems is an important factor and at the same time the educational needs of different age groups differ and currently are completely isolated. It is characteristic that in the best educational systems, where different tools exist for different age groups, there is almost complete isolation with no interoperability. So, children must constantly use and learn new systems that do not communicate. Therefore, different age groups cannot collaborate - work together and exchange for example a piece of programming code. An example of this approach can be Snapino ("SNAPINO® - Elenco," n.d.) which uses the Arduino core in a way probably more appropriate for younger children. Thus, a solution that might bridge all the above requirements is to develop open source hardware for robots' construction and hybrid open source interfaces that combine tangible and graphical user interfaces for the programming. In this way, it is possible to:

(a) involve age groups that cannot currently engage in activities by reducing the age threshold for participation;
(b) create educational material that allows also older children to use the same tools;
(c) enable both young and older children to work together in missions and exercises;
(d) reduce the cost of purchasing different systems for each age group.

The most commonly used open source and non-open source platforms appear to be Arduinos and Lego, respectively. Both systems seem to have similar capabilities in robotics education, but the low cost of Arduino robotics allows teachers to adopt a one-to-one approach, in which each student has one robot to work with (Chou, 2018). Regarding programming, when students use Lego, they need to learn the Lego programming language and, recently, Scratch. Similarly, with Arduinos they might use Arduino IDE and a Scratch like environment, such as Scratch for Arduino S4A, Snap4Arduino, Ardublock, or make simulations with Tinkercad. In any case, the Scratch compatibility is very important because Scratch is commonly used in many elementary schools.

2.1.2 Examples of best practices and tools for teaching robotics and teaching with robots at schools

2.1.2.1 SUMMARY OF RESULTS OF THE SURVEY

Besides the literature review previously summarized, in the first phase of INBOTS project we planned to identify the main resources and best practices for teaching robotics and teaching with robots at schools, in Europe and beyond. With this aim we prepared an online survey to collect examples of best practices and tools.

The survey[5], was distributed to project partners, through mailing lists, project website and during project initiatives (first INBOTS conference in Pisa in 2018, 2019 European Robotics forum).

In the project we asked, for each initiative, to specify:

- Type of initiative (e.g. course, laboratory, network, project, challenge, etc.);
- The country where it was organised;
- The language;
- If the initiative is local or if it is remotely accessible (e.g. MOOC, video lectures, etc.)
- The age of students involved in the initiative;
- A brief description of the initiative;
- Links to initiative website and/or video.

At the time this document is delivered we collected 33 contributions from 19 countries.

Distribution: In this survey we collected information from 15 EU countries and 4 countries outside EU. Most of the resources that we identified were locally available (70.6%) and in their national language (77.5%). Fewer resources were available on line (29.4%) and in English language (23.5%).

[5] https://docs.google.com/forms/d/e/1FAIpQLSc4PN1DVxd-ehUG7YG5Fg5SchgKhsChT6nfoEXXNqMGnNMYgw/viewform

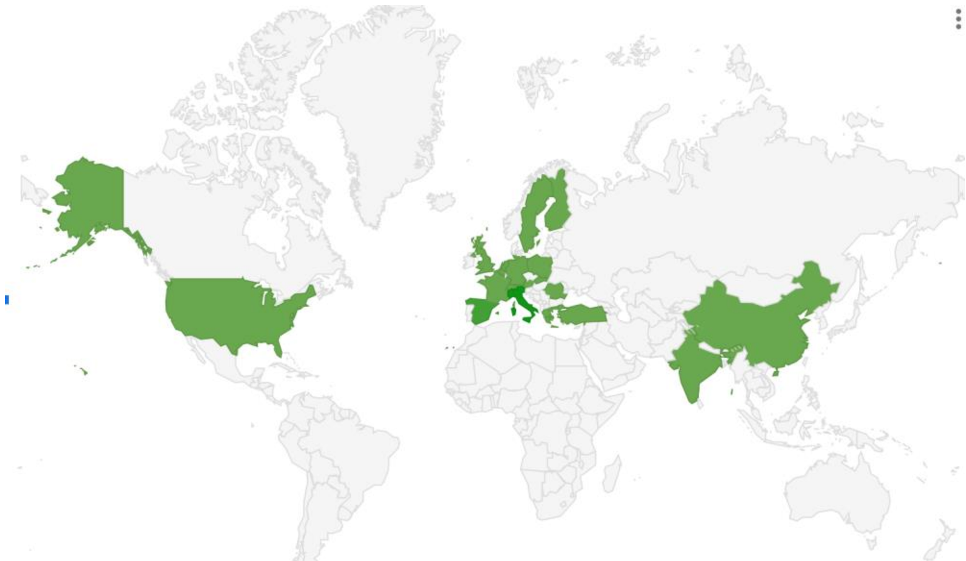


Figure 2: survey on educational resources for schools, distribution of countries where the collected initiatives were organised.

We collected data relative to quite different initiatives: courses, projects, networks, challenges, etc. On one side, with such a heterogeneous set of resources it is difficult for us to realise an exhaustive classification. On the other side, the richness and diversity of responses demonstrate the interest and enthusiasm about learning robotics and learning with robots in all the age levels. In the following we briefly summarizes the common aspects and potentialities of the main types of initiatives that we collected.

Challenges/contests: this type of initiatives is becoming quite popular across Europe and beyond. This type of initiatives involves students with different ages and presents some interesting aspects and potentialities:

- Students often work in groups: this aspect allows participants to develop team-working skills.
- Contests and challenges give the possibility to meet other teams, from the same country or from other countries, exchange experiences and ideas, build friendship, networks and connections.
- Challenges and contests have fixed deadlines, specific goals, which are usually defined so that they are affordable. Typically, challenges are based on standardized platforms and kits, so that experiences can be more easily shared.
- Often challenges are combined with other initiatives like seminars or lectures.

Projects/networks: the survey pointed out different types of projects related to educational in and with robotics. There are project involving more countries, but also projects more local. The common interesting aspect that came out from the analysis of the answer is that they typically involve different types of subjects: schools, universities, companies, etc., and the activities that they promote encourage the connection among them (by means of workshops, courses, student exchange, etc.).

Spin-off, companies specialised in educational robotics are present in different countries across Europe and offer different types of services to schools: they organise courses, lectures, laboratory activities. Some of the companies develop and distribute robotic kits for educational robotics. They also play an important role in organising courses and lectures for teachers.

Courses/lectures/laboratories: with respect to challenges and contests, these activities have not a competitive nature and do not force the students into predefined frameworks. Within these activities both the students and the teachers have more freedom in the setup of the experiments, the groups in the classroom can work on different sub-projects at the same time, there are less constraints, projects are open-ended and more suitable for research and scientific training.

2.1.2.2 QUALITATIVE ANALYSIS OF EXISTING EMINENT TRAINING RESOURCES CATEGORIZED IN 3 AGE LEVELS (EDUMOTIVA)

Selecting the resources

The main criterion for selecting the resources is their accessibility, since one of the main goals of this document is the creation of a list with easily accessible materials. Popularity was another parameter – which is also related to the criterion of accessibility of available resources.. Terms that were employed as keywords are "STEM/STEAM educational resources", "STEM/STEAM educational tools", "STEM/STEAM learning scenarios", and "STEM/STEAM teaching materials". Age was another criterion since the selected resources should be proper for certain age ranges (4-6, 7-11, 12-17) and educational groups (primary education, secondary education). Finally, personal knowledge and experience on implementing specific educational resources was used as a lens for filtering and evaluating the detected resources.

A database of resources

As a result, several well-known technologies (and their corresponding resources) were identified and included in the database available at this link

Criteria for the quantitative analysis

Together with the literature review reported in Section 2.1.1, that is mainly focused on the available educational robots, we conducted a study on the existing resources for teaching and learning robotics and with robotics in schools. These include worksheets, lessons, manuals and technical instructions that can be used to perform activities with educational robots. The resources were categorized into three age levels (A: 4-6, B: 7-11, C: 12-17).

Based on the analysis of the resources, several criteria were highlighted as significant parameters of the learning process. First, it is important to focus on creating learning experiences that can "promote young people's creativity, critical thinking, team work as well as problem solving" (Schön, Ebner, & Kumar, 2014) and therefore support skill development rather than plain knowledge acquisition[6]. The development of students' social and cognitive skills should be also part of the equation (Alimisis, 2013). In this direction, it is also important to create educational activities that encourage role allocation and role rotation and thus promoting collaboration and knowledge exchange[1]. Moreover, the involvement/engagement of students in simple or more complex real-world research and problems can enhance their creativity since they can enable the shift from conceptual-based design ideas to more concreate solutions and constructions (Druin & Hendler, 2000). Additionally, it is important for Educational Robotics to provide a hands-on open-source learning environment, supporting the shift from the "black-box" paradigm to a "white-box" one and thus the shift from "learners as consumers" to "learners as makers" (Alimisis, 2013). Finally, the factors of play and enjoyment are highlighted as significant, especially in primary education, since they encourage and motivate young learners to get involved in the learning process (Ryan & Deci, 2000) (Theodosios Sapounidis & Demetriadis, 2013).

[6] eCraft2Learn/H2020 research project (2017-18), https://project.ecraft2learn.eu, last accessed 2018/10/21.

All the above considerations will be used as lenses through which the listed resources will be analysed. The aim is to highlight best resources, gaps and needs and therefore to shape recommendations and guidelines for designing future educational resources.

Age range 4-11

Most of the resources that are intended for educating younger learners (age range 4 – 11) such as Bee -bot/ Blue-bot resources, Pro-Bot resources, and Thymio robot resources are in form of manuals and technical instructions, enriched in some cases with video material, and therefore provide specific and close guidelines. Pro-Bot robot resources incorporate also material with ideas and activities that can be performed by and through the use of the robot (e.g., draw specific shapes and paths), while Thymio robot resources contain some projects that combine the use of the robot with papercraft activities (e.g., decorate the robot), promoting imagination and creativity. A dynamic 3D pdf file is also incorporated on the latter, permitting the exploration of robot's components through the interaction with robot's digital 3d model. Resources for Root robot contain instructions and graphical representations on how to use robot, as well as several code-based activities of increasing difficulty, intended for different age groups. Cubelet robot resources provide specific instructions on how to use the product but also support creativity through some guidelines, in form of tips, motivating young learners to create different configurations and thus experimenting with the robot. To assist this procedure, the aforementioned resource provides also some, so called, "recipes", intended to inspire teachers and/or young learners, while motivate sharing their ideas through social media.

Kubo robot has a variety of resources, providing instructions as well as tutorials to familiarize users to product utilities, but also material in form of lesson plans and worksheets that tend to create a less straightforward and more creative educational process. Lesson plans provide ideas on how to present the robot to the class and motivate students to be engaged in different activities, while worksheets aim to assist students to outline their experience through specific tasks and questions. Similarly, Ozobot Bit robot resources include material in various forms such as technical instructions, videos and tutorials. Tutorials are divided in age groups and in two different versions of handouts, namely educator and student version. The former includes specific guidelines, divided in seven chapters (from preparation stage and introduction to group activities), while the latter incorporates graphical material that is useful for experimenting with the robot. Handouts for elder students (age range 6-11) contain instructions and lessons that use a deconstructive method to teach block-based coding. Neuron robot has also a variety of downloadable recourses in form of guide for educators, case studies divided in lesson plans and student worksheets, as well as a formulated curriculum based on Science Standards of Primary Schools in China and STEAM Standards, and some checklists of problems and teaching. The proposed case studies vary from playful to more meaningful, engaging young learners to real-world problem-solving activities.

All the above are well organized resources with a lot of information on how to use (and in some cases program) each of the robots, but they tend to create a straightforward and predefined teaching process and experience. Resources that contain worksheets tend to support critical thinking through tasks and questions on the general process. However, almost all the aforementioned resources support the development of social skills through team working oriented activities. Moreover, they are promoting knowledge acquisition and students' engagement to the learning process through playful activities. In some cases (e.g. Neuron), the proposed activities are related to real-world problems, but it is argued that these activities can be marginally applied to this age range. Very simple activities such as "make the robot move" or "create a route for the robot" are easier to be grasped and therefore are more meaningful for younger learners. Creativity is also promoted through some papercraft and tasks related to drawing or/and sketching as well as through open instructions that aim to trigger students' imagination. Apart from Thymio robot resource that provides information on how the robot is inside but not in a tangible and physical way, none of the above resources is related to a white box paradigm. However, considering the age group for which these resources have been created, this factor might not be that significant. Some of the resources (e.g. Root) aim to provide a more open source learning environment through material related to text-based coding activities (intended for learners over 12 years old) which modify and extend robots abilities but still these activities do not involve a hands-on learning process.

Age range 7-11

Most of the resources of the previous category are intended to familiarize young learners with fundamental principles of robotic through playful and tangible activities. The resources contained in this category aim additionally to familiarize learners with fundamental principles of coding.

Codey Rocky robot resources contain a quick start guide with some basic tutorials for programming robot's behaviour by using block-based coding language (scratch), engaging young learners to a more interactive learning environment. M-bot robot resources have also several instructions for assembling the robot and thus familiarizing learners with the basic components (motors, sensors etc.) of the robot. Unlike Codey Rocky, mBot resources provide also video tutorials, presenting some basic tasks and activities that can be performed by the learners. This kind of resource do support skill development through playful practices since learners are engaged to constructing and programming logic, but there are limitations as far as creativity and critical thinking are concerned. Similarly, the resources for Milo the robot (Milo the science rover project, Milo's motion sensor, etc.) contain assembling instructions, video tutorials as well as worksheets for students. Again, in these examples of resources there are limitations as far as creativity is concerned since the assembling parts are prefabricated (Lego WeDo 2.0 Core Set) permitting the creation of specific projects. Unlike, mBot, resources for Milo, and especially the provided worksheets, aim to promote critical thinking through engaging learners to scenario-based activities concerning some real-world problems (e.g., create a robot that detects life to another planet scenario). Still, none of the aforementioned resources does promote a hands-on open source learning environment. Even though there are activities that engage learners to construction processes, there are still unexplored areas as far as cabling and electronics are concerned.

Age range 12-17

Resources that were found in Lego WeDo website, and are intended for learners over 12 years old (Make a puppet project, Make a security gadget project), contain some instructions on the learning process but also some worksheets that aim to engage learners on a problem solving process. Through the provided material, learners are challenged to define the design problem as well as the design criteria, and thus they are introduced to a brainstorming process. They are also encouraged to share their idea in the class, supporting the development of their social skills. Resources provided by Carnegie Mellon Robotics Academy (Introduction to mobile robotics – robotic engineering resource, Introduction to programming – LEGO Mindstorms EV3 resource etc.) are interactive online guides that contain step-by-step design processes of basic or/and more advanced projects, videos and scenarios for more activities, thorough analysis on how the corresponding hardware and software work, samples of coding, building instructions as well as references and worksheets with questions that aim to break down the entire experience into rather distinctive parts and processes. This rather rich material does sustain problem-solving through engaging learners to real-world research and problems, but they are rather limited as far as the parameters of creativity and critical thinking are concerned due to the adoption of a rather straightforward strategy. This strategy might also not encourage learners to develop their explorative behaviour, turning the entire learning experience to plain knowledge acquisition. On the contrary, resources from Roboesl project (The Roborail project, Go to park project, etc.) aim to support self-directed action and adopt a more independent learning strategy. Each of the manuals and technical instructions, as well as the worksheets contain a real-based problem scenario, but, instead of having a step-by-step and straightforward solution, several examples are provided, aiming to trigger learners critical thinking and encouraging experimentation. The contained activities promote team work and encourage discussion among the members of the team, developing learners' social skills. All the aforementioned resources provide information on how robots work but they give limited information on how robots are inside since they are based on prefabricated modules (Lego Mindstorms).

Resources for Arduino-based projects (Make your first Arduino, eCraft2Learn projects, etc.) promote the "white box" paradigm since they incorporate instructions related to circuits and electronics construction process, enhancing the shift from "learner as a consumer" to "Learner as maker". Apart from this aspect, resources from Arduino hub site contain step by step instructions and video on how to create a specific project based on less or more real-world problems. Since they are based on a DIY (Do-It-Yourself) logic and process, they support the development of different skills (crafting, programming). Worksheets from eCraft2Learn project promote creativity and critical thinking by triggering learners not only to find solutions on the proposed scenario but also to choose the electronic parts that they will need to create the requested project/artefact. Like Roboesl resources, eCraft2Learn resources aim also to support collaboration among team members as well as role allocation. Learners are triggered not only to think how to program their artefact but also how to create it from scratch. Both resources encourage the shift from a concept to a concrete construction, a method which can be tricky, especially if learners are not familiar with such methods and strategies.

2.1.3 Intermediate conclusions

- Identified gaps and needs:
    - Resources and tools identified during the analysis of survey answers and the desk research are heterogeneous in terms of typology, language, age of students involved, availability. Providing an organised classification of resources could be useful to help teachers and in general people involved in education in finding the best solution for their training need.
    - There is also a specific need for training resources and initiatives for teachers.

- Suggestions to improve existing initiatives.
    - Robotics is rapidly evolving, and the educational system needs to be continuously updated as this development is going on. To facilitate this continuous update, connections between schools and roboticists (companies, universities) should be encouraged through specific projects. Open days, workshops, and courses are important in this respect, and there are European Projects (e.g., ER4STEM[7]) and single institutions (e.g., Politecnico di Milano with the TechCamp@POLIMI[8]) that are already promoting these types of initiatives. Robotics, however, usually remains an "extra" activity that is not included into the schools' curricula.

- Analogies and differences between different countries:
    - The analysis did not point out relevant differences among EU countries in terms of resources and initiatives.

[7] http://www.er4stem.com/
[8] https://techcamp.polimi.it/

2.2 Robotics in academic education

There is a growing need of experts in the field of robotics, as well as of proper educational resources to train them. In this part of the paper, we focus on resources targeted to university students, from Bachelor to Ph.D.

2.2.1 Examples of best practices for teaching robotics at an academic level

Nowadays, almost any Bachelor, Masters or Ph.D. program in Information, Mechanical or Bio Engineering offers one or two courses of Robotics. Listing them would take long and would not give useful information to the reader, also because educational curricula change quickly and largely depend on the country.

Therefore, on the one hand we decided to search for educational programs, courses or summer/winter schools that are entirely dedicated to robotics, and on the other we analysed in detail educational resources that are available, in different formats, on-line.

2.2.1.1 CURRICULA AND SCHOOLS FOCUSED ON ROBOTICS

Through a questionnaire[9] that we developed and specialized websites such as Masterstudies.com[10], we retrieved information on degrees and schools entirely devoted to Robotics. The preliminary results indicate that there is a majority of Master's degrees and PhD courses that focus on robotics, while Bachelor's degrees are usually less specialized.

Among the Master's Degrees we list ten of the most significant ones:

- Master in Robotics and Control, Umeå University, Faculty of Science and Technology, Sweden.
- Master in Mechatronics and Robotics, South Ural State University, Russia.
- Master in Robotics and Intelligent Systems, Örebro University, Sweden.
- Masters in Control and Robotics in Signal and Image Processing (CORO SIP), Centrale Nantes, France.
- Master's programme in Systems, Control and Robotics, KTH Stockholm, Sweden.
- Master in Robotics and Advanced Construction, Institute for Advanced Architecture of Catalonia – IAAC, Barcelona, Spain.
- Master Course on Computational Neuroscience and Cognitive Robotics - University of Birmingham School of Psychology.
- Master's Degree in Advanced Robotics, Jaume I University (Universitat Jaume I), Barcelona, Spain.
- EPFL Master in Robotics, EPFL, Lausanne, Switzerland.
- EMARO+ Master's programme, Centrale Nantes (France), Warsaw University of Technology (Poland), University of Genoa (Italy), Jaume I University (Spain)."

The latter initiative deserves special attention, as it is a Master that crosses different European countries and "is designed to promote a high-quality educational offer in the area of advanced and intelligent robotics"[11]. Its objective is to teach students how to deal with robotic systems as a

[9] Questionnaire on Robotics Education in Universities: https://docs.google.com/forms/d/e/1FAIpQLScZWUYZHXPSSS4ua9m4EAAKzvq_P2cDhYIE6fwUIfw6eb_pFQ/viewform?usp=sf_link
[10] Masterstudies.com: https://www.masterstudies.com
[11] EMARO+: https://master-emaro.ec-nantes.fr/about/

whole, mastering mathematical modelling, control engineering, computer engineering, and mechanical design.

Several summer and winter schools on robotics related topics are organized every year, but we will list here only those that had more success in terms of number of participants or of subsequent editions over the years:

- Summer School on The Regulation of Robotics in Europe: Legal, Ethical and Economic Implications, Scuola Superiore Sant'Anna, Pisa, Italy. http://www.europeregulatesrobotics-summerschool.santannapisa.it/news/results-are-out
- Winter School on Wearable Robots, EU COST Action network CA16116, http://www.europeregulatesrobotics-summerschool.santannapisa.it/news/results-are-out
- Summer School on Soft Manipulation (2017), SOMA EU Project, IEEE Robotics and Automation Society, http://soma-project.eu/index.php/events/188-soma-summer-school-on-soft-manipulation-registration-is-open
- Summer School on Control of Surgical Robots (COSUR 2018) organized by Altair Robotics Lab, in collaboration with the ERC project ARS (Autonomous Robotic Surgery) and the European project SARAS (Smart Autonomous Robotic Assistant Surgeon), http://metropolis.scienze.univr.it/altair/events/summer-school-on-control-of-surgical-robots-cosur-2018/

2.2.1.2 ON-LINE EDUCATIONAL RESOURCES ON ROBOTICS: A REVIEW

The growing need of experts in the field of robotics lead to an increase of the number of books and on-line courses on topics related to Robotics, thought for different levels of education. An interesting initiative is represented, for example, by RoboticsCourseware[12], that is an open repository of robotics course materials.

Teaching methodologies can benefit from recently introduced tools, including MOOCs (Massive Open Online Courses) (Yuan & Powell, 2015) and repositories for multimedia material such as video lectures and e-books. If well organized, such material can boost the self-learning of students, with easily retrievable and reliable information.

A relevant advantage of on-line courses is that they tackle also very specific subjects, that a student couldn't get with traditional learning means. This aspect makes them particularly suitable also for teaching robotics related topics at a University level, as professors can create educational material regarding the specific research area they are studying (P Corke, Greener, & Philip, 2016), (Pozzi, Malvezzi, & Prattichizzo, 2019). The absence of a direct contact between the teacher and the learner, however, may lead to uncertainties on what is learnt, so this type of resources needs to be carefully designed and organised (Reich, 2015). Therefore in (Pozzi et al., 2019) we proposed to structure on-line courses around three levels of learning (Figure 3).

[12] Robotics Courseware: http://www.roboticscourseware.org, last access: 28/04/2019

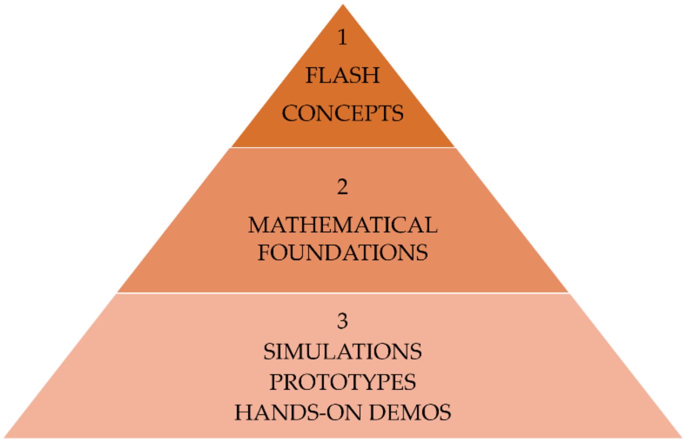


Figure 3 Levels of learning (Pozzi et al., 2019).

We decided focus on resources whose target are undergraduate or graduate students. Studying robotics at an academic level requires a basic knowledge of mathematics, programming, and physics. We aim at analysing useful resources that build upon such previous knowledge and explain basic and more advanced concepts related to robotics.

The complete list of the analysed resources is available in Appendix B of this paper. They include MOOCs, YouTube Playlists, Toolboxes, Micromasters and Specializations (see Figure 4) and, in the following, we will give a qualitative analysis of our findings, dividing them based on the addressed topics (see Figure 5).

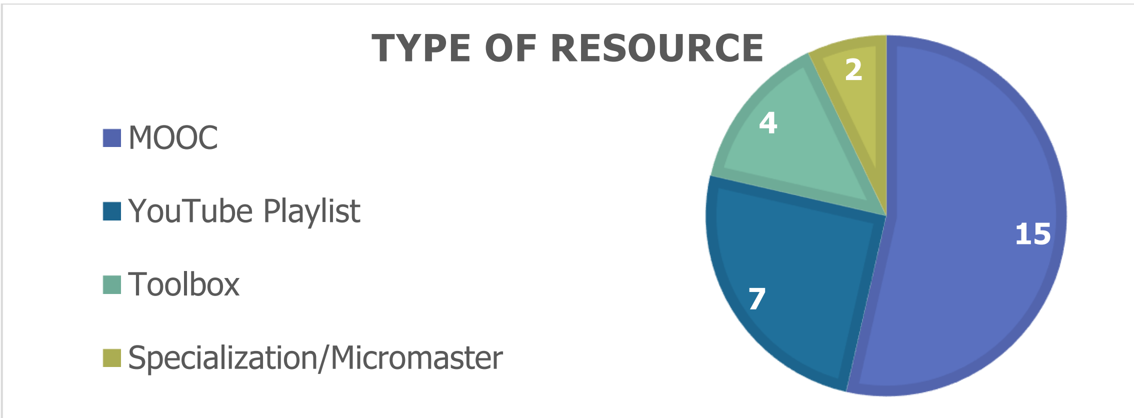


Figure 4 Type of on-line educational resource on Robotics

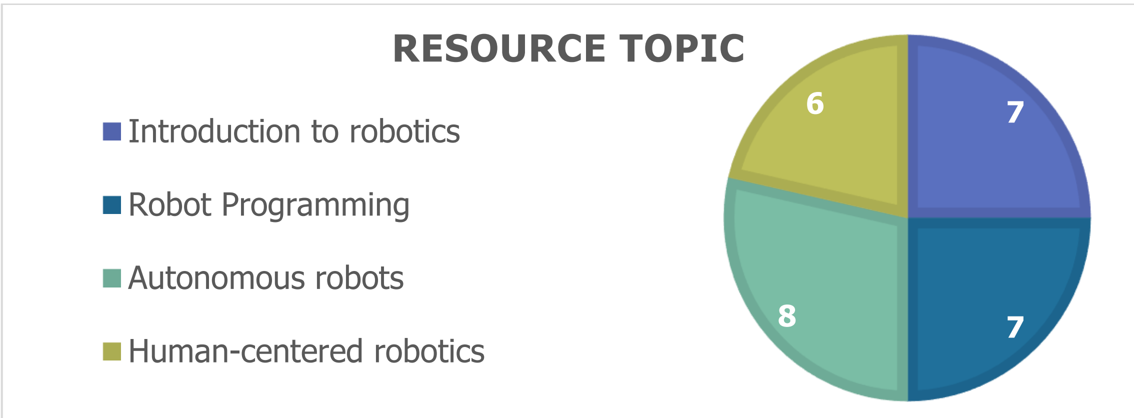


Figure 5 Main topics of on-line educational resources on Robotics

Introduction to robotics

Robotics: modelling, planning and control is probably one of the most famous books introducing the basic concepts of robotics (B Siciliano, Sciavicco, Villani, & Oriolo, 2009). Based on it, at the beginning of 2017, Siciliano launched his MOOC on Robotics Foundations I - Robot Modelling, delivered through the Federica.EU portal. Also Corke developed an introductive MOOC on robotics (P Corke et al., 2016), based on his book Robotics, Vision and Control (Peter Corke, 2017). Another MOOC that explains the "core techniques for representing robots that perform physical tasks in the real world" is available on edX[13] and is taught by Ciocarlie. Besides MOOCs, there are also YouTube Playlists that can be very useful for students that want to explore robotics for the first time. One of the most popular Introduction to Robotics courses on YouTube is the one by Khatib. It was recorded in 2008 during the CS223A course of the Stanford Computer Science Department. Another playlist that is on-line since 2008 is the Lecture Series on Robotics by Amarnath. More recently, in 2014, De Luca shared the videos of his Robotics I course on YouTube and the lectures are closely related to the slides and exercises available at his homepage.

Robot programming

There are on-line educational resources that specifically target robot programming. One of the first toolboxes that was released for modelling and controlling robots is the Robotics Toolbox for MATLAB (Peter Corke, 2017), that reached version 10.3 in August 2018 and provides functions that are useful for the study and simulation of robotic manipulators, including kinematics, dynamics, and trajectory generation. Recently, ROS, the open-source Robot Operating System has become a widely used framework in both research and industry. ROS website itself offers several tutorials and a vast documentation, but also specific courses on it have been developed. *Programming for Robotics (ROS)* by Fankhauser et al., for example, is available on YouTube since 2017. The company The Construct is specialized in delivering courses on ROS and the Robot Ignite Academy provides paid courses on ROS for Beginners, Robot Navigation, and Machine Learning for Robots. There are also toolboxes and simulators that are specific for teaching specific aspects of robotics, such as SynGrasp and GraspIt!, thought for grasp analysis (Malvezzi, Gioioso, Salvietti, & Prattichizzo, 2015) (Miller & Allen, 2004).

Autonomous robotics

The MOOC entitled *Control of Mobile Robots*, delivered by Egerstedt in Coursera[14] since 2013, was one of the first MOOCs on robotics (de la Croix & Egerstedt, 2014). In February 2016, Coursera presented its first Robotics Specialization, consisting of a series of six courses from University of Pennsylvania, mostly focused on aerial and mobile robots. Also edX offers several robotics micromasters and courses. The micromaster on Robotics includes two introductory parts on kinematics and dynamics and two specific parts on vision for robotics and legged robots. Among edX self-paced and archived courses on robotics there are *Autonomous Mobile Robots* by ETH Zurich, and *Underactuated Robotics* by MIT. Recently, a course on *Evolutionary Robotics* has been uploaded on YouTube in by Bongard. It was recorded during real lectures and it explains how evolutionary algorithms can be used to implement controllers for autonomous robots. In 2017, Park and Lynch published their book Modern Robotics: Mechanics, Planning, and Control, that is enriched with more than 90 videos covering all the chapters of the book. This contribution tackles introductory as well as more advanced topics.

Human centred robotics

In this section, we analyse on-line educational resources that tackle the problem of having robots able to interact with humans and, more in general, with human environments. In 2018, an on-line

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[13] edX: https://www.edx.org
[14] Coursera: https://www.coursera.org

course on *The Art of Manipulation and Grasping* was published (Pozzi et al., 2019). It introduces grasp modelling and control as well as the SynGrasp MATLAB Toolbox. The video lectures are available on YouTube. The act of grasping and manipulating tools is the ultimate interface of a robotic system with the environment and it is one of the most complex tasks in industrial, service and humanoid robotics. If we want robots to interact with humans and with unstructured environments, it is fundamental to allow them to pick and handle objects: this is why a course on this subject was needed. This year, Coursera published a course on *Collaborative Robot Safety: Design and Deployment*, whereas edX released two MOOCs by TU Delft dealing with human centred robotics problems: *Mind of the Universe – Robots in Society: Blessing or Curse?*, that analyses the challenges behind the question "How can AI and robots be combined, developed, used and regulated, so that they complement and contribute to our society, instead of posing a threat?", and *Responsible Innovation: Ethics, Safety and Technology*, that teaches how to deal with ethical questions, implications for society and new risks risen by new technologies. Recently, Corke announced a course on *Introducing Robotics: Robotics and Society* that will be delivered by FutureLearn and aims at giving an overview of "how robots are used today" and "how they might help solve the big issues of our time".

2.2.2 Intermediate conclusions

From the analysis of existing local and on-line courses on Robotics, we can conclude that:

- Most of local courses are either inside more generic degrees, or inside master's degrees and Summer/Winter Schools entirely devoted to robotics.
- The number of educational resources dealing with human-centred and interactive robotics issues are rather new and still less widespread than courses on the control of autonomous robots, such as aerial and mobile robots.
- Especially for on-line resources, that are accessible for a wider public, it is important that the teaching material is well structured and organised. For example, different levels of learning can be considered.

The availability of learning and training platforms is desirable to increase the knowledge, but also the awareness of people that need to design, program and interact with robots.

3 Available resources and training needs beyond school and university

In this section, we analysed the available training and learning resources, tools and needs outside the educational system. Our analysis is based on a research on the state of the art and on the result of a questionnaire that was distributed within project consortium and during project meeting and workshops. Results of this analysis presented in this deliverable are still preliminary, we are going to continue the collection of data also in the second part of the project and to provide a more complete analysis in Deliverable 3.2.

3.1 Companies

Even if robot market is continuously increasing, the adoption of automated systems is still mostly limited to large enterprises. Robot adoption is increasing in manufacturing (mainly in automotive and electronic/electrical sectors and still limited to large enterprises), but it is extending also in other sectors, for instance in logistics and healthcare. Besides the costs, another important aspect that limits the adoption of robots, especially in small and medium enterprises (SME) is that employees need to acquire specific skills (Baygin, Yetis, Karakose, & Akin, 2016) (Tupa, 2017).

In other terms, the diffusion of robots needs also to change job profiles and skills requirements. As the production process, in the Industry 4.0 perspective, is becoming dynamic and variable, workers will no longer be asked to perform repetitive operations: they will have to perform varied and mostly unstructured tasks and to manage dynamically changing production requirements. Robots will support workers in hard and unergonomic operations, and either substitute them in hazardous tasks. Workers, on the other hand, will be asked to control and sometimes program robots and automation systems, and to interact with them at different levels. Some tasks will be carried out by workers remotely rather than directly, in some tasks humans and robots will have to collaborate, sharing the workspace. In healthcare section applications, for example in rehabilitation, the robotic device needs to be adapted, programmed and controlled based on the needs of each individual patient.

Workers will use tools with more complex and various features for training and support in executing tasks, including, for instance, cameras, geolocation systems and online access to a full database of technical data. The use of augmented reality technologies will increase both in training and in task execution.

To efficiently manage this transformation, employees need to have specific qualification and to be updated with specific training. The training process of workers that interact with robots and automation systems in companies is therefore an important aspect to be considered (Richert, 2016).

Notwithstanding the tools and resources available at different education levels (discussed in section 2), from the analysis of the state of the art, we realised that educational curricula often do not provide the demanded skills, particularly for technical professions, and their update rate is not enough synchronized with the technological development. In general, there is a mismatch between the skills required by companies and the educational systems that are in charge of delivering them. Several studies in different countries showed that the next generation workforce is caught between higher demand on the one hand for bachelor's degree qualifications, and, on the other, the fact that many of these degrees do not qualify them for the jobs in which demand is strong.

One solution to reduce this gap consists in providing specific training activities, like courses, lectures and workshops, to the employers (Gualtieri, et al., 2018). Such training activities can be organised within the company, or provided by external resources, as for instance robot suppliers or universities. Also, highly accessible on-line resources, like e-books, video-lectures and MOOCs are useful tools for this type of training.

Training resources and tools for workers can be broadly divided into the following main typologies:

- Internal courses provided by internal trainers;
- Internal courses provided by external trainers (e.g., universities, public institutions, robotic system suppliers, etc.);
- External courses, provided by schools or universities, organised by other public or private institutions, provided by other companies;
- On-line resources that the workers can attend autonomously (video lectures, MOOCs, etc.).

Other type of initiatives, combining theoretical and 'on-the-job' training, like apprendships or internships, can help to provide the needed skills to employees and to reduce the gap between the skills that can be provided by the educational system and the ones that are required in companies.

It is therefore important to point out that to reduce the skill gap, tighter connections and interactions between companies and educational institutes are necessary. Examples of programmes promoting this aspect are the Marie Curie Networks, whose aim is "*to train a new generation of creative, entrepreneurial and innovative early-stage researchers, able to face current* *and future challenges and to convert knowledge and ideas into products and services for economic and social benefit*", and, previously, the Marie Curie Industry Host Fellowships (Mc Sweeny, 2000; Mc Sweeny, 2000)

Another aspect to consider is that the availability of more uniform and standardised skills and credentials would enable better communication between companies and higher education institutes, and could help SMEs, that often do not have the resources to develop their own training programs.

3.2 Teachers

The searching method reported in Section 2.1.1 has provided interesting findings related to teachers' needs. The emergence of open software and inexpensive low-cost open hardware movement allows skilled teachers and hobbyists to develop low-cost robots for teaching and learning (Saleiro, Carmo, Rodrigues, & Du Buf, 2013). Unfortunately, open source hardware/software for ER is lacking the **appropriate documentation** support and this makes many educational robotics projects difficult for teachers to follow (Moran, Teragni, & Zabala, 2017). In general, for open source ER constructions is very hard to find detailed **curriculum** and organized detailed **user instructions**. Simultaneously, for both open and not open source tools it is very difficult to find **collaboration scripts** to use during students' projects and detailed instructions for the **teachers on how to scaffold students' work**. In the examined literature we noted that there are some general educational robotics curricula with the scope to enhance teaching of math, physics or other scientific topics for early and middle high school students (e.g., (Goldman, 2004). However, these efforts are quite limited and are based on certain ER platforms with limited applicability on other platforms.

Teachers and students need first to learn about the potential benefits of educational robotics to motivate, engage and involve others. At the same time, teachers need to learn how to make appropriate use of the documentation. In detail:

(a) particularly those without a technical background, need to have the tools available to learn themselves to use the guidelines
(b) they need to learn to use collaboration scripts, to separate children into efficient groups to achieve better learning outcomes
(c) they must be aware of *scaffolding* to enable learners to learn efficiently and faster without losing their interest.

3.3 Non-roboticists, general public

Through the questionnaire, we identified different initiatives about robotic training and dissemination in Europe and beyond. The interest of the society on this topic is sensibly increasing and such initiatives are attracting a lot of people.

From the analysis of the data that we collected, we could identify some interesting information channels that appear to be particularly effective to inform the general public about robotic development:

- **Fairs**. These initiatives are attracting a great amount of public: 105000 registered people attended Maker Faire in Rome in 2018 edition, the "Festival della Robotica", held in Pisa, attracted 10000 visitors in the first edition in 2017 and 15000 the second one. In these events specific workshops discussing interdisciplinary themes are organised.

- **Courses**. Several courses are locally available for different types of attendees: DIYers, unemployed people that need to improve their skills, courses for people involved in healthcare, etc. Such courses are organised by universities, schools, companies, and sometimes supported by public institutions.
- **YouTube channels**. YouTube is not only a medium for dissemination and entertainment, but it is also recognized as a potential environment for learning. Several robotics channels are available, and robots are often the subjects of videos provided by scientific channels. Some of the robotic devoted channels aim at disseminating the latest development by means of engaging videos that attract a lot of public and the interest of media: at the beginning of 2019, KUKA channel counts about 23 million of views, Boston Dynamics 185 million, ABB channel 7 million, etc. Even if such resources have not been developed as an educational tool, they are useful to introduce people to robotics, and to show the main robot elements. There are also several specific and thematic channels that can be used by the general public to learn basic concepts of robotics or simply enjoy DIY applications. In Appendix C we collected some relevant YouTube channels on robotics.
- **MOOCs**. We analysed this type of resource in the chapter devoted to universities, however, some of them are available and affordable also for people that have not a specific technical background. These courses focus for instance on DIY robots, fundamentals of robot programming, specific applications in healthcare, but also more general and multidisciplinary themes, e.g. the role of robots in the society, robots in the literature, etc.

4 Preliminary conclusions

In this document we reviewed the state of the art on robotics' education resources, tools, programs and learning activities, for different targets. In the following we summarize the main outcomes in terms of main available resources, the identified needs and gaps, and the contribution of INBOTS WP3.

School

- **Available resources**. 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 a classification of such material.
- **Identified 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.
- **INBOTS WP3 contribution and ongoing activities**. We are going to continue the monitoring 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

- **Available resources**. Different courses, curricula, training resources and tools are available. In this document we focused on highly accessible on-line resources, and on summer and winter schools.
- **Identified 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 diffusion could be improved and optimized through dedicated websites and repositories.
- **INBOTS WP3 contribution and ongoing activities**. We are going to continue the monitoring of available resources and to make them available through the project website.

Companies

- **Available resources**. Due to robotic spreading 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.
- **Identified 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.
- **INBOTS WP3 contribution and ongoing activities**. We are going to further analyse the state of the art and the available tools. We are going to promote initiatives and networks between educational institutions and companies, to reduce the skill gap.

Non-roboticists, general public

- **Available resources**. In this category we collected all the 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.

- **Identified gaps and needs.** Since 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.
- **INBOTS WP3 contribution and ongoing activities**. We will keep monitoring the main resources updated with the most relevant initiatives. We are going to contribute to such initiatives by attending and organising seminars and workshops.

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Appendix A: Robots for Educational Robotics

This Appendix lists the outcomes of the literature review described in Section 2.1.1.

Open hardware robots

- Thymio robot (Riedo, Retornaz, Bergeron, Nyffeler, & Mondada, 2012). This is the first version of thymio.
- Thymio II (Riedo, Chevalier, Magnenat, & Mondada, 2013)
- Cover 3 age groups (6+, 9+, 12+) with different programming languages
- E-puck by GCtronic and EPFL (Mondada et al., 2009)
- R-one robot (McLurkin, Rykowski, John, Kaseman, & Lynch, 2013)
- GoGo Board (Arnan Sipitakiat, Blikstein, & Cavallo, 2004)
- MAGABOT ("magabot | IDMind," n.d.)
- The MIT SEG ("MIT Printable Robot," n.d.)
- Infante (Saleiro et al., 2013)
- Miniskybot (Gonzalez-Gomez, Valero-Gomez, Prieto-Moreno, & Abderrahim, 2012)

DIY or Assembly Robotic kits

- Arduino Robot ("Arduino Robot," n.d.)
- AdMoVeo (Alers & Hu, 2009) it is also based on Arduino platform
- Multitasking robot (Filho, Almeida, & Martins, 2011)
- Boe-Bot Robot (Mukai & McGregor, 2004) ("Boe-Bot Robot | Parallax Inc," n.d.)
- ActivityBot 360° Robot ("Robotics | Parallax Inc," n.d.)
- SumoBot Robot ("Robotics | Parallax Inc," n.d.)
- Crawler Kit ("Robotics | Parallax Inc," n.d.)
- Parallaxy Telepresence Robot ("Robotics | Parallax Inc," n.d.)
- Bot'n Roll ONE ("Bot'n Roll ONE A - botnroll.com," n.d.)
- Servobotics Robotic Arm RA by Images SI ("Six Servomotor Robotic Arm," n.d.)
- Lynxmotion Arms AL5A, AL5B, AL5D ("Lynxmotion - Robotic Arms," n.d.)
- OWI Robotic kits ("Robotics Kits - OWI Inc. dba: RobotikitsTM Direct," n.d.)
- AREXX Engineering ("ROBOT ARM - DOCUMENTATION & SOFTWARE WEBSITE," n.d.)
- Mark III ("Robot Kits, Electronics, Parts, Motors, and Sensors | Junun Robotics," n.d.)
- Pololu Robotic kits ("Pololu - Robot Kits," n.d.)
- Pi Swarm robot (Hilder, Naylor, Rizihs, Franks, & Timmis, 2014)
- CotsBots (Hall, Bergbreiter, & Pister, 2003)
- Robomote (Dantu et al., 2005)
- MICAbot (McMickell, Goodwine, & Montestruque, 2003)
- Kobot (Turgut, Gökçe, Çelikkanat, Bayindir, & Sahin, 2007)

Brick-based robots

- Mindstorms EV3 ("MINDSTORMS EV3 - Produkte - Mindstorms LEGO.com," 2017)
- Lego Wedo ("Shop WeDo 2.0 products – LEGO Education," n.d.)
- VEX IQ Kits ("Kits & Bundles - Shop All Products - VEX IQ - VEX Robotics," n.d.)
- Palm Pilot (it was based on Palm handheld) (Reshko, Mason, & Nourbakhsh, 2002)
- Robotis kits like: Robotis Gp, Robotis Dream II, Robotis STEM e.t.c. ("ROBOTIS Shop," n.d.)

- Fischer-technik robots like ROBOTICS TXT Discovery ("ROBOTICS TXT Discovery Set - fischertechnik," n.d.)
- GARCIA robot by acroname was based on BrainStem technology and it no longer active ("Garcia | Acroname," n.d.)

Pre-assembled robots

- Khepera IV by K-Team (Soares, Navarro, & Martinoli, 2016)
- Koala by K-Team (Nirmal Singh, Chatterjee, Chatterjee, & Rakshit, 2011)
- Bee-Bot (Janka, 2008)
- iRobot Create 2 (iRobot, 2016)
- Old K-Team Robots like: Hemisson, K-Junior e.t.c ("Old Products – K-Team Corporation," n.d.)
- Robotino ("Education and Research Robots: Robotino® - Learning Systems - Festo Didactic," n.d.)
- WowWee (Wowwee-Group, 2016)
- Amigobot ("AmigoBot: a mobile robot built for research and education," n.d.)
- Tomy I-Sobot ("i-SOBOT," n.d.)

Robots for simple actions or of specific purpose

- OWI Weasel Robot ("Pololu - OWI-9910 Weasel," n.d.). It makes only two actions: line following and wall hugging.
- Kilobot by Kteam (Rubenstein, Ahler, Hoff, Cabrera, & Nagpal, 2014)
- Alice (Estier, Caprari, & Siegwart, 2001)
- TERMES (Petersen, Nagpal, & Werfel, 2011)

Humanoid robots

- Nao Robot (Shamsuddin et al., 2012)
- Tiro robot (Han et al., 2009)
- Robovie robot (Kanda et al., 2004)

Robots based on tangible programming

- Tangible Programming using "strings" (Patten, Griffith, & Ishii, 2000)
- Tangible Programming Brick (McNerney, 2001)
- Electronic Blocks – roBlocks (Wyeth & Purchase, 2003)
- GameBlocks (Smith, 2007)
- Tern– Tangicons (M. S. Horn & Jacob, 2007)
- PROTEAS kit (T. Sapounidis & Demetriadis, 2011), (T. Sapounidis & Demetriadis, 2012)
- Algorithmic Bricks (Kwon, Kim, Shim, & Lee, 2012)
- Dr. Wagon (Chawla, Chiou, Sandes, & Blikstein, 2013)
- Robo-Blocks (A Sipitakiat & Nusen, 2012)
- KIBO (Sullivan, Elkin, & Bers, 2015)
- T-Maze (Wang, Zhang, & Wang, 2011)
- E-Blocks, TanProRobot (Wang, Zhang, Xu, Hu, & Qi, 2016)
- Primo ("Primo toys," n.d.)
- Code-a-pillar ("fisher-price Code-a-pillar," n.d.)

Appendix B: On-line educational material on Robotics

B.1 Introduction to Robotics

- B. Siciliano. Robotics foundations I - Robot Modelling. Università degli Studi di Napoli Federico II, 2017, Federica.EU. The course is now archived, but it is possible to book the participation to the next edition. https://federica.eu/c/robotics_foundations_i_robot_modelling.
- P. Corke. Introducing Robotics. Queensland University of Technology, FutureLearn. https://www.futurelearn.com/programs/robotics (last access: 28/04/2019)
- M. Ciocarlie. Robotics. Columbia University, 2018, edX. https://www.edx.org/course/robotics-2 (last access: 28/04/2019)
- O. Khatib. Introduction to robotics. Stanford Computer Science Department, 2008, YouTube. https://www.youtube.com/watch?v=0yD3uBshJB0 (last access: 28/04/2019)
- C. Amarnath. Lecture series on robotics. Department of Mechanical Engineering, IIT Bombay, 2008, YouTube. https://www.youtube.com/watch?v=DaWMvEY3Qgc&list=PL2A735F42FA18D5DD (last access: 28/04/2019)
- A. De Luca. Robotics I – lectures and notes. Sapienza Università di Roma, 2014, YouTube. http://www.diag.uniroma1.it/~deluca/rob1_en.php (last access: 28/04/2019)
- University of Reading, Begin Robotics, FutureLearn, https://www.class-central.com/course/futurelearn-begin-robotics-3410 (last access: 28/04/2019)

B.2 Robot Programming

- P. Corke. Robotics Toolbox 10.3, 2018. http://petercorke.com/wordpress/toolboxes/robotics-toolbox (last access: 28/04/2019)
- P. Fankhauser, D. Jud, and M. Wermelinger. Programming for robotics (ROS). Eidgenossische Technische Hochschule (ETH) Zurich, 2017, YouTube. https://www.youtube.com/watch?v=0BxVPCInS3M (last access: 28/04/2019)
- Siena Robotics and Systems Lab (Università degli Studi di Siena). SynGrasp Toolbox. http://sirslab.diism.unisi.it/syngrasp/ (last access: 28/04/2019)
- Columbia University Robotics Group. GraspIt! https://graspit-simulator.github.io/ (last access: 28/04/2019)
- A. Gil. Arte: A robotics toolbox for education. Miguel Hernandez University (UMH), 2012, http://arvc.umh.es/arte/index_en.html#download
- ROS Courses by Ignite Academy, https://www.robotigniteacademy.com/en/ (last access: 28/04/2019)
- TU Delft, Hello (Real) World with ROS – Robot Operating System, edX. This course was archived, future dates must be announced. https://www.edx.org/course/hello-real-world-with-ros-robot-operating-system

B.3 Advanced Courses on Robotics

B.3.1 Autonomous Robotics

- M. Egerstedt. Control of mobile robots. Georgia Institute of Technology, 2013, Coursera. https://www.coursera.org/learn/mobile-robot (last access: 28/04/2019).
- Coursera. Robotics specialization. University of Pennsylvania, 2016.

https://www.coursera.org/specializations/robotics#about (last access: 28/04/2019).

- edX. Micromaster on Robotics. https://www.edx.org/micromasters/pennx-robotics (last access: 28/04/2019).
- R. Siegwart, M. Chli, M. Hutter, D. Scaramuzza, and M. Rufli. Autonomous mobile robots. ETH Zurich, edX. https://www.edx.org/course/autonomous-mobile-robots (last access: 28/04/2019).
- R. Tedrake, R. Deits, and T. Koolen. Underactuated robotics. Massachusetts Institute of Technology, 2015, edX. https://www.edx.org/course/underactuated-robotics-mitx-6-832x-0 (last access: 28/04/2019).
- J. Bongard. Evolutionary robotics. University of Vermont, 2018, YouTube. https://www.youtube.com/playlist?list=PLAuiGdPEdw0iRhEnF5yPuqegKVjKktDni (last access: 28/04/2019).
- K.M. Lynch and F.C. Park. Modern Robotics: Mechanics, Planning, and Control, 2017. http://hades.mech.northwestern.edu/index.php/Modern_Robotics (last access: 28/04/2019).
- Technische Universität München, Autonomous Navigation for Flying Robots, edX. https://www.class-central.com/course/edx-autonomous-navigation-for-flying-robots-1911 (last access: 28/04/2019).

B.3.2 Human-centred Robotics

- D. Prattichizzo, M. Pozzi, M. Malvezzi. The art of grasping and manipulation in robotics, 2018, YouTube. http://sirslab.dii.unisi.it/GraspingCourse/index.html (last access: 28/04/2019).
- B. Carlisle and A. Sivadas. Collaborative robot safety: Design and deployment. University at Buffalo, The State University of New York. Coursera. https://www.coursera.org/learn/collaborative-robot-safety (last access: 28/04/2019).
- J. Van den Hoven. Responsible innovation: Ethics, safety and technology. Delft University of Technology (TU Delft), edX. https://www.edx.org/course/responsible-innovation-ethics-safety-and-technology (last access: 28/04/2019).
- V. Dignum, J. Bieger, and R. Mercuur. Mind of the universe - robots in society: Blessing or curse? Delft University of Technology (TU Delft), 2018, edX. https://www.edx.org/course/mind-of-the-universe-robots-in-society-blessing-or-curse (last access: 28/04/2019).
- A. Cangelosi and M. Schlesinger. Developmental robotics. University of Manchester (UK) and Southern Illinois University, Federica.EU. The course is now archived, but it is possible to book the participation to the next edition. https://federica.eu/c/developmental_robotics (last access: 28/04/2019).
- P. Corke, J. Sergeant, E. Pepperell, and O. Lam. Introducing robotics: Robotics and society. Queensland University of Technology, soon available, https://www.futurelearn.com/courses/robotics-and-society (last access: 28/04/2019).

Appendix C: YouTube Channels on Robotics education and dissemination

Youtube Channel	Subscribers (May 2019)	Link	Type
Simone Giertz	1570580		Entertainment
Boston Dynamics	1276033		Robotic company
James Bruton	657001		Education-entertainment
How to Mechatronics	268377		Education-DIY
DroneBot Workshop	89681		Education-DIY
KUKA - Robots & Automation	98588		Robotic company
Hanson Robotics Limited	30203		Company
ABBRobotics	34064		Robotic company
VEX Robotics	20082		Education
SoftBank Robotics Europe	17650		Robotic company
Universal Robots	10493		Robotic company
RobotshopTV	6902		Company
Rethink Robotics	5902		Robotic company

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