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Research paper

Educational Robotics as a boundary object: Towards a research agenda

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ABSTRACT

Educational robotics has become each time more present in the educational experiences of children and young people. Nonetheless, often, the way in which robotics is introduced in educational settings has been considered as unnecessarily narrow. The paper aims at widening the scope of Educational Robotics and expanding the pedagogical possibilities of this field. To this end, the paper draws on the outcomes of two case studies carried out with primary and secondary school children aimed at investigating their views about robots. These studies allow framing and identifying five themes we believe are particularly relevant to rethink the pedagogy of Educational Robotics. Using these themes as cornerstones for reflection, we delineate a set of dimensions and paths to move Educational Robotics beyond the focus on technical skills but instead explore its potential as a boundary object to involve children in reflective processes around the ethical, social and cultural implications of emerging intelligent technologies.

1. Introduction

Educational robotics (ER) has become each time more present in the educational experiences of children and young people. This trend is outlining a new educational landscape, which has led to increasing research efforts aimed at investigating the educational impact of robotics and examining its limits and potentials (Anwar & Bascou, 2019; Bascou & Menekse, 2016; Benitti, 2012)

Within this latter line, several researchers stressed that often the way in which robotics is introduced in education is unnecessarily narrow (Alimisis & Kynigos, 2009; Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). On the one hand, this issue may affect the variety of population interested in robotics, excluding children with diverse cultures, interests and learning preferences (Turkle & Papert, 1992). On the other hand, this narrow focus also runs the risk of shaping robotics as a merely technical field, without considering its intertwined articulations with society. This risk has been already identified in Human–Robot Interaction (Riek & Howard, 2014), with a growing number of researchers highlighting the need to provide practitioners with guidance to address the ethical and social concerns derived by the evolution of robots (Riek & Howard, 2014; Sullins, 2015; Zawieska, 2020). However, it received limited attention in ER, where the limits, the scope and the interdisciplinary articulations of the discipline have been poorly questioned and problematized.

Building on this perspective, our research aims at widening the scope of ER, not merely for making it appealing to a broader spectrum of population, but mainly to expand the boundaries and pedagogical possibilities of this field. Specifically, our goal is to understand children's views about robots to guide researchers and practitioners in rethinking the pedagogy of ER and exploiting its potential for crossing boundaries with other disciplines and facilitate dialogue between different actors (children, teachers, experts, etc.).

To this end, our research builds on a child-centred research approach (Clark, 2005) and on the notion of Intermediate-Level Knowledge (Barendregt et al., 2018; Höök & Lowgren, 2012). On the one hand, the child-centred research approach aimed at digging into the articulation between robotics and society by focusing on how children construct meaning about what is a robot and what it can do in society. Specifically, we ran two studies with primary and secondary school children to investigate their views about robots through a set of Art-Based methods (Barone & Eisner, 1997). On the other hand, we used the notion of Intermediate-Level Knowledge, understood as actionable knowledge situated in-between general theories and particular artefacts (Barendregt et al., 2018). This concept helped us in reflecting on the outcomes of our studies to construct knowledge to guide researchers and practitioners in the effort of rethinking ER.

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In the paper, we first present an overview of current research on ER and on children's perceptions about robots. Subsequently, we describe the methodology and outcomes of the two studies. In the discussion, by building a reflexive dialogue between our findings and current practices in ER, we identify a set of themes and opportunities for future research in the field.

The main contribution of the paper is the framing and identification of five themes aimed at opening spaces to move ER beyond the focus on technical skills but instead explore its potential as a *boundary object* (Star Leigh & Greisemer, 1989) to involve children in reflective processes around the ethical, social and cultural implications of emerging intelligent technologies.

2. Towards multiple pathways into educational robotics

Educational robotics has gained increasing weight in formal and non-formal education (Alimisis, 2013). Nowadays, most schools and after-school initiatives have integrated educational robots in their programs. This tendency is creating a new educational landscape that requires research efforts for better understanding the limits, potentials and controversies of these tools.

Following this need, an increasing number of studies investigated the impact of ER on young learners' skills. This knowledge is well summarized in different systematic reviews (Anwar & Bascou, 2019; Bascou & Menekse, 2016; Benitti, 2012). The outcomes of these studies identify relevant trends. First, they highlight that most research on ER focuses on the learning of STEM (Science, Technology, Engineering, Mathematics) or the development of skills such as teamwork or problem-solving. Second, they point out the beneficial aspects of hands-on learning experiences with robots in enhancing skills such as the understanding of abstract concepts, scientific enquiry, teamwork, interest and curiosity towards STEM. Third, they identify the growing concerns related to the unnecessarily narrow approaches through which robotics is often introduced in educational settings (Anwar & Bascou, 2019). A compelling example of this narrow focus is described by Rusk et al. (2008) who point out how projects that just instruct children to program robots that run faster may run the risks of makings children with diverse cultures, interests and learning preferences becoming uninterested in the domain.

Building on these limitations, several researchers explored strategies and tools to offer new perspectives to ER and broaden its audience and target groups (Cavallo et al., 2004; Lammer, Weiss, & Vincze, 2015; Oliveira, Ferreira, Celestino, Ferreira, & Abrantes, 2012; Qi, Huang, & Paradiso, 2015; Rusk et al., 2008; Searle & Kafai, 2015; Sullivan & Bers, 2018). Within this line, we broadly identified three main approaches through which researchers tackled the effort to broaden ER.

On the one hand, a large corpus of research is exploring novel pedagogical strategies to design projects that can appeal to a broader variety of children. This quest responds both to the long-standing need to promote epistemological pluralism in computer education (Turkle & Papert, 1992) as well as to the effort to diversify the possible hooks to enhance students' engagement in the field. Rusk et al. (2008) suggest four strategies for engaging a broader range of learners in robotics: projects focused on themes instead than on challenges; projects combining art and engineering; projects encouraging storytelling; organizing exhibitions, rather than competitions. Within this line, effective strategies can be identified in projects that explore the possibilities of merging different artistic languages with robotics. For instance, Sullivan and Bers (2018) combine robotics, music, dance and culture in the project "Dances from Around the World" with preschool children. Similarly, Cavallo et al. (2004) work with children to combine dance and robotics. Qi et al. (2015) combine circuitry, paper-craft and painting to explore the diversity of materials for robotics. Oliveira et al. (2012) and Alessandri and Paciaroni (2012) combine storytelling and robotics and propose children to use robots to reproduce fictional narratives.

On the other hand, some ER initiatives address learners' differences through the lens of identity and culture categories and propose projects aimed at underrepresented ethnic groups. These approaches build on the contributions of research related to broadening participation of underrepresented communities in computing (Eglash, Gilbert, & Foster, 2013; Ryoo, Margolis, Lee, Sandoval, & Goode, 2013) and aim at incorporating robotics "as part of their cultural heritage rather than outside of it" (Eglash et al., 2013). Meaningful examples can be found in the works of Searle and Kafai (2015) and Kafai, Searle, Martinez, and Brayboy (2014). Searle and Kafai (2015) combine the analysis of students' perceptions about computation with a bricoleur-friendly approach to computing using e-textile. Kafai et al. (2014) also use e-textile and propose the concept of ethnocomputing to increase access and participation of indigenous communities in computer science.

Finally, building on ideas akin to the notion of "justice-centred pedagogy" proposed by Vakil (2018), some ER projects explore robotics in its intersection with socio-political issues. For instance, Lammer et al. (2015) build on children's interests for societal issues and propose a pedagogical structure to engage children in the creative process of designing robots that respond to real world problems. Instead, the ECS curriculum (Goode, Chapman, & Margolis, 2012) proposes activities to stimulate students' reflections on the ethical and social tensions derived from the technology impact on society. These projects, by integrating robotics "*with other forms of social, cultural and creativity based motivations*" (Bascou & Menekse, 2016), offer refreshing perspectives to ER and enable different viewpoints from which to look at its use in educational activities.

3. Using the notion of boundary object to think about ER

Several of the aforementioned projects exemplify the active effort to create bridges between robotics and other disciplinary fields. A useful way to think about this quest is through the notion of *boundary objects* proposed by Star Leigh and Greisemer (1989). The authors conceptualize this term in their research in the Museum of Vertebrate Zoology. Specifically, they point out how the creation of this kind of objects managed to successfully translate between different viewpoints in contexts where participants come from distinct social worlds and heterogeneity and cooperation are central issues. Boundary objects are therefore entities that are flexible enough to be used in different ways by different communities, allowing to fulfil a bridging function between multiple contexts and enhance the capacity of an idea to translate across culturally defined boundaries.

This notion, in the context of the current research provides a lens to think about ER initiatives that do not only cross the boundaries of different disciplines but also facilitate the dialogue among heterogeneous actors (e.g. children, teachers, experts, etc.). In the practice, this means encompassing both the intertwined relation of robotics with society as well as understanding the discourses and meanings that different actors attribute to robotics, in order to think about ER initiatives capable of working as *boundary objects*. For the purpose of this study, we specifically focus on children's perspectives in order to understand their discourses and imaginaries about robotics.

4. Children's perceptions of robots

Previous research has already explored children's attitudes and opinions towards robots (Bartlett, Estivill-Castro, & Seymon, 2004; Beran & Ramirez-Serrano, 2011; Blancas et al., 2017; Bumby & Dautenhahn, 1999; Liu, 2010; Precel & Mioduser, 2012; Woods, 2006). The results of these studies report positive attitudes of young people towards robots and towards the learning of robotics. Furthermore, they pointed out the role of the robot's appearance in determining different types of conceptualizations about their capabilities and functions. As reported by Woods (2006) and by Bartlett et al. (2004), children tend to attribute abilities to feel emotions, understand humans and have feelings to robots that have humanoid or animal characteristics. On the contrary, robots that look like machines are perceived as incapable of having emotions and understanding humans. Similarly, children who had the experience of interacting with a social robot reported a vision of the robot as "alive" and capable of having a series of abilities such as thinking, feeling and acting (Beran & Ramirez-Serrano, 2011). In the same way, also children's drawings of robots tended to anthropomorphize them, combining the use of human characteristics with geometric elements (Blancas et al., 2017; Bumby & Dautenhahn, 1999), including both gender features as well as weapons equipment.

These studies delineate a certain coherence in the views of young people around robots. Nonetheless, all these studies focus on understanding youth imaginaries to design social robots that interact with children. However, none of them applies the understanding of children's views to the field of ER.

5. The studies

To deepen on the children's and teenagers' perceptions around robots, we carried out two studies with primary and secondary school students. Our goal was to better understand their views of robots to derive insights capable of enabling different perspectives to ER. Specifically, we aimed at answering the following research questions: *What are the participants' views about what a robot looks like, what it does and what it can do? How do children and teenagers characterize robots' abilities and roles? How can this analysis inform the design of new pedagogical strategies in the field of educational robotics?*

The first study was carried out as an extra-curricular workshop with a small group of 8 primary school students. The second study was performed with 15 secondary school students and was framed within a curricular project about digital fabrication technologies.

5.1. The methodological approach

In both cases, our methodological approach was informed by Art-Based methods (Barone & Eisner, 1997; Hernandez, 2008) and multimodal analysis (Jewitt, 2013; Kress, 2010). These frameworks informed the process of involving the students in the creation of a fictional audiovisual narrative about robots and in the analysis of their productions and creative processes.

5.1.1. Eliciting children's and teenagers' understandings about robots: An art-based approach

To elicit participants' views about robots we employed art-based methods both as a tool to support an enhancement of perspective (Barone & Eisner, 1997), as well as a strategy to facilitate children's engagement. Specifically, we used audiovisual production with students to explore different ways of producing knowledge, hence accessing nuances of meanings that may not be visible through other types of research. In the two studies, we employed different artistic techniques to grasp different nuances of children's understandings around robots and to guide them in the production of the audiovisual narrative. Specifically, we used the following techniques: drawing robotic characters, writing a collaborative story, building elements of the stage and the characters, writing a literary script and recording the final video. The general structure was applied in both studies but we adapted it to the specificities of each context.

5.1.2. Collecting and analysing children's productions and creative processes: A multimodal approach

Data collection and analysis was informed by multimodality, understood as an interdisciplinary approach to analyse communication and interaction beyond the limit of verbal language to instead encompasses the different resources that people use to construct meaning (Jewitt, 2013). Specifically, we build on the notion of *motivated sign* (Kress, 2010), which recognizes that when someone produces a sign, this person is projecting their individual interests in the world through their choices among the available resources. This idea, in our context, suggests that the analysis of the tangible and intangible resources (e.g. materials, cultural references, etc.) used by children can reveal their interests, values and imaginaries about robots. Hence, we adopted a multimodal perspective to analyse the students' productions and derive the possible values, concepts and ideas embedded in them.

In the study with primary school students, our analysis encompassed both children's productions as well as their creative processes. We documented children's creative process according to the Reggio Emilia's technique to document learning processes. This technique considers pedagogical documentation as "traces" of learning that the teacher carries out to research the movement of children's understanding [51]. Following this model, during each session, the first author was taking pictures of relevant moments. Subsequently, just after each session, she was taking notes on a diary, briefly describing the unfolding of the session and documenting the behaviour of the children. The notes were later transcribed and complemented with related reflections and associated pictures. Finally, children's productions were also documented through pictures after the ending of the session.

Instead, in the study with the secondary school, due to the greater number of students, the curricular context and the intermittent presence of the researcher, the analysis focused mainly on the produced narratives and the final videos. To analyse the produced narratives two researchers independently coded the children's stories according to a bottom-up thematic approach. The outcomes were subsequently shared and discussed until a common agreement was achieved. Instead, considering the characteristics of the videographic format, the analysis of the videos was structured according to the different scenes that compose them. One researcher repeatedly viewed each scene to transcribe the dialogues and making screenshot and descriptions of the visual, kinetic and sound elements that characterize them. These transcriptions were subsequently coded by two researchers according to a bottom-up thematic approach.

5.2. Case 1: Primary school

The study was carried out in a primary school located in Barcelona and unfolded through 12 sessions. For a summary of the sessions see Table 1, a detailed report of the study is available in (anonymized for review). Each session lasted 1 h and was carried out in extracurricular hours. We counted with the participation of eight 10–11 years old students (6 girls; 2 boys). Participants voluntarily signed up for the workshop based on a call previously made by the school. In all the sessions, the first author was the only facilitator and researcher.

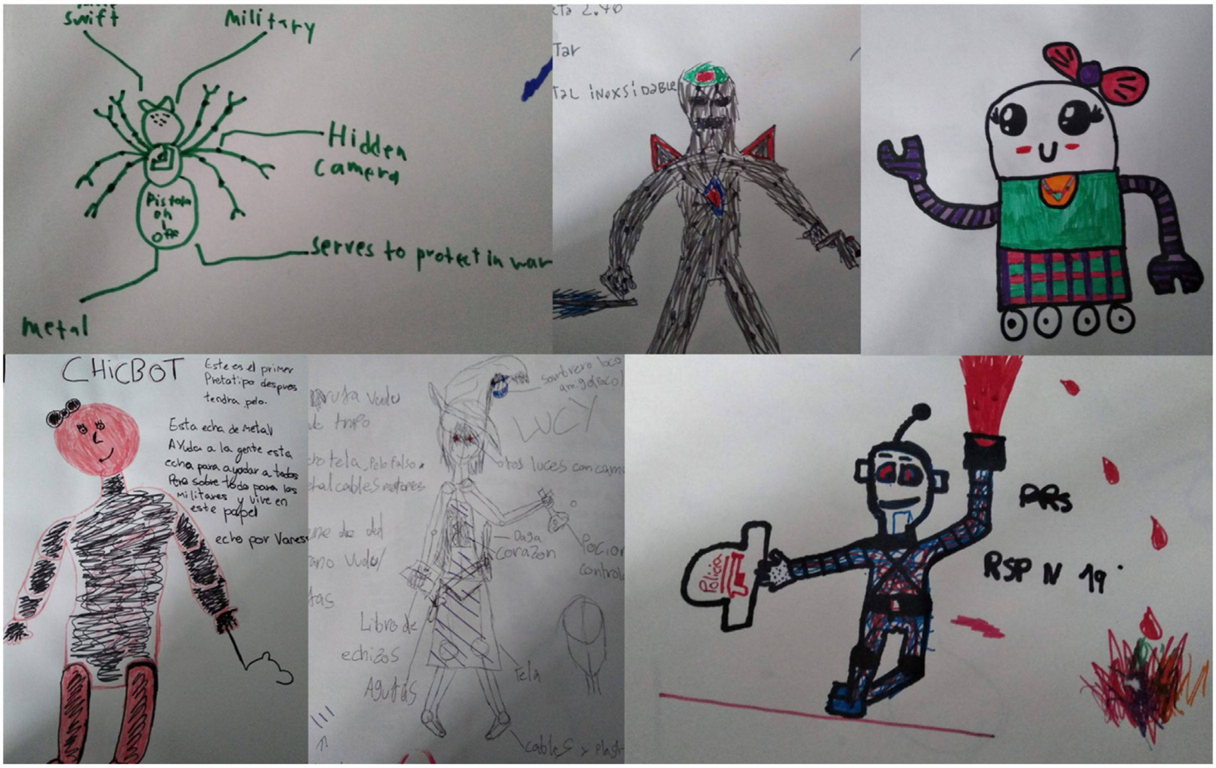

Fig. 1. The drawings (from left to right): Swift the spider, TX.0, Paula, Chicbot, the Vodoo Witch and the Police Robot.

Table 1
Summary of the workshop sessions.

Sessions	Content
1	Introduction of the project, drawing and definition of robotic characters
2	Collaborative writing of a story with all the characters created in the previous session.
3–4	Introduction to programming with Mbot robots
5	Improvisation of the story and definition of the production calendar
6–7	Construction of the characters and the elements of the stage
8–9	Collaborative writing of the literary script
10–12	Video recording

Table 2
The collaborative story.

The collaborative story
Paula lives happily with her family in their planet. TX.0 with his army invades the planet and they take Paula to jail in Spain separating her from her family. Paula wants to return to her planet. In jail, she meets Chicbot, who comes from the future to help her. Chicbot tells Paula that she has to look for the Vodoo Witch to get help. Chicbot and Paula manage to escape from prison and to find the witch. The witch has a pot where she sees that the only way to defeat TX.0 is to find Swift the spider. Then, with the Chicbot's teletransportation machine they go where Swift the spider is, but he is sleeping. The witch makes a potion that wakes up the Spider. The Spider trains everyone to fight against the army of TX.O. The robots manage to defeat the army. The Spider explodes on top of TX.0 and the war is over and they take Paula back to her planet.

5.2.1. Primary school: Results

A total of 6 students participated in the first session (3 boys, 3 girls). In this session, the facilitator gave a general introduction about the idea of collaboratively creating an audiovisual narrative about robots. Subsequently, the children began to design their robots and create a short description of each of them. A total of 6 characters were created: "Swift the spider", "TX.0", "Paula", "Chicbot", "the Vodoo Witch" and "the Police Robot No. 19" (Fig. 1). In the second session, two more students joined and all children started to work together to create a collaborative story with their robots as characters (Table 2). Successively, the characters were used as models for the realization of three-dimensional prototypes (6th and 7th session) for the video (Fig. 2). All the created characters were modelled using craft materials. Finally, the children wrote a literary script and shoot the video.

5.2.2. Data analysis

All created robots, except in the "spider Swift", all have humanoid characteristics. Five of them have classic facial features and four of them have a humanoid skeleton. Only the robot Paula has a mixed configuration (machinic body and humanoid facial features). This tendency towards anthropomorphizing robots is contrasted with their materiality. In the descriptions, all the characters are made of metal, eventually combined with other materials. The use of the materials as agent for constructing meaning was also maintained in sessions 7 and 8 where all the three-dimensional prototypes included the use of silver paper to attribute the metallic aspect. These characteristics are indicative of the construction of an imaginary about "what a robot is like" linked to the mixing and co-presence of humanoid and machinic elements, in which, both the forms, as well as the materials, cover a central role in the process of constructing meaning about robotic identities.

Furthermore, in five of the six cases, the drawings or descriptions of the robots are linked to imaginaries related to fighting, defence, use of weapons and violence: Swift the spider forms part of the army and has several features to defend and attack in case of war, the Police Robot No. 19 has a special arm for firing lava and the Voodoo Witch has a set of powers and abilities to defend against enemies. Finally, Chicbot, although designed to help humanity, it is currently used only for military purposes. Instead, TX.0 aims at killing everybody and dominating the world. This trend is indicative of the features that build the children's

Fig. 2. The 3D models of the characters.

imaginaries about "what a robot does and what it can do" and what is its role within the social context.

In their representations, all students chose to draw a robot whose gender corresponds to their gender. This characteristic indicates a possible projective intention in the realization of the drawings (i.e. drawing something that 'has to do with me'). This is particularly evident, for example, in the description of Paula where the girl explains that 'Paula is a 10-years old girl like me'.

This attribution of gendered traits to robots introduces the relevance of gender representations in robotics. Boys and girls used different visual and cultural references for their robots. For example, when choosing the materials for the creation of three-dimensional prototypes, the boys worked mainly with cardboard and silver paper. The girls, instead, combined silver paper, textile materials and organic materials (e.g. hair). At the same time, both, in the initial descriptions, as well as in the story and the video, the girls' characters tended to be inserted in a minimally social and affective context, e.g. Paula has parents, the Voodoo Witch has a friend, and Chicbot has a dog. Instead, "male" robots do not have any kind of relation to a social-emotional context.

These characteristics are reflected in the roles that different characters assume in the story. The story follows a relatively linear structure and employs different classic narrative functions. At the same time, the characters assume traditional roles of fairy tales: TX.0 has the role of the one-dimensional villain, whose objectives are intrinsically evil; Paula covers the role of the princess in trouble who 'has to be saved'; the Witch, Chicbot and the Spider assume the roles of the helpers; the Police Robot covers the role of the antagonist helper. In this distribution, children replicated classic gender stereotypes both in the assignation of the different roles as well as in the features attributed to the helpers. While Chicbot and the Witch act as helpers thanks to their knowledge (i.e. Chicbot knows the future and the Witch can make potions), the Spider trains the team for the fight.

These differences in the treatment of male and female characters are reinforced in the dialogues of the video. Specifically, the female robots have a much more humanized presence through a greater number of dialogues aimed at emphasizing their personal and emotional situations; i.e. the Witch explains that she always hated TX.0, Paula speaks about 'tears of true sadness' for missing her family, etc. Male characters, instead, do not explicitly speak about their feelings and emotions. However, although the emotional and sentimental part appears more in female characters, all robots are provided with their own will, agency and capacity to have desires, feelings and emotions. For example, TX.0 wants to conquer the world; Paula suffers for the separation from her parents, cries and finally rejoices at the moment of the reunion; Chicbot, the Witch, and the Spider are characterized by their ability to plan and organize, but also show agency and emotions. These features, again, indicate a strongly humanized characterization of the robots.

5.3. Case 2: Secondary school

The study was carried out in a secondary school located in Barcelona. The study was framed within a curricular project about digital fabrication technologies. In the study, we proposed to the students to create a robotic theatrical project using different tools of digital manufacturing and record a final video of their productions. The overall project lasted 50 h during 3 months and was structured in three phases (summarized in Table 3). Throughout the three months, the students worked in small groups of 2 to 4 participants with the help of the researcher and the school's technology teachers as facilitators.

5.3.1. Secondary school: Results

Fifteen students (13–14 years old) participated in the study. The students were divided into five groups. All of them managed to carry out the Ideation stage of the project and produced 5 fictional stories about robots. Nonetheless, only 2 groups managed to finish the entire production process and a total of 2 videos were produced.

5.3.2. An overview of the produced stories

The stories created by the students allowed observing a series of underlying themes: (1) The positioning of robots on the dichotomous axis of good and evil; (2) The roles, characteristics and capacities that they attributed to robots and (3) The relationships articulated between robots and between humans and robots.

The majority of the stories (4 out of 5) are structured around the dichotomy of "the good versus the evil". Within them, however, we can identify some differences. One story introduces a dystopian future where robots attack humans. By contrast, three stories propose a positive view of robots. In one of them, the narrative is intertwined with the theme of bullying and the robot acts as a magical element that helps a child that is bullied. In the other one, robots act as saviours to help humans against the villain. Finally, in the latter, humans are "the evil side" and do not allow two robots to live together. Only one story proposes a different structure by focusing on a child's ability in building robots to rescue himself from bullying.

The students' stories propose different viewpoints around the characteristics attributed to robots. In three stories, robots are created by humans and do good or evil depending on the humans who control them. Robots, therefore, are presented as lacking their own will and serving as tools subordinated to humans. On the contrary, in two stories, robots have a will of their own, act out of their intentions, make decisions, plan, and have emotions and feelings. These differences determine different relationships between robots and between humans and robots.

In the first three stories, robots do not relate to each other and their relationships with humans respond to a more or less

Table 3
Structure of the secondary school's workshop.

Stage	Activities	Total time	Facilitators
Ideation	– Creation of the robotic characters for their projects (each student made a drawing of a robotic character) – Collaborative writing of a story with the created characters	4 h	Researcher
Approaching the technological tools	– Introduction to 3d modelling (TinkerCad) – Introduction to programming (Mbot and Arduino)	20 h	Researcher (6 h) + technology teachers
Creation and production of the project	– Collaborative writing of the literary script – Creation of the characters and stages elements for the video – Development of at least one technological artefact for the story – Recording and editing of the video	26 h	Researcher (10 h) + technology teachers

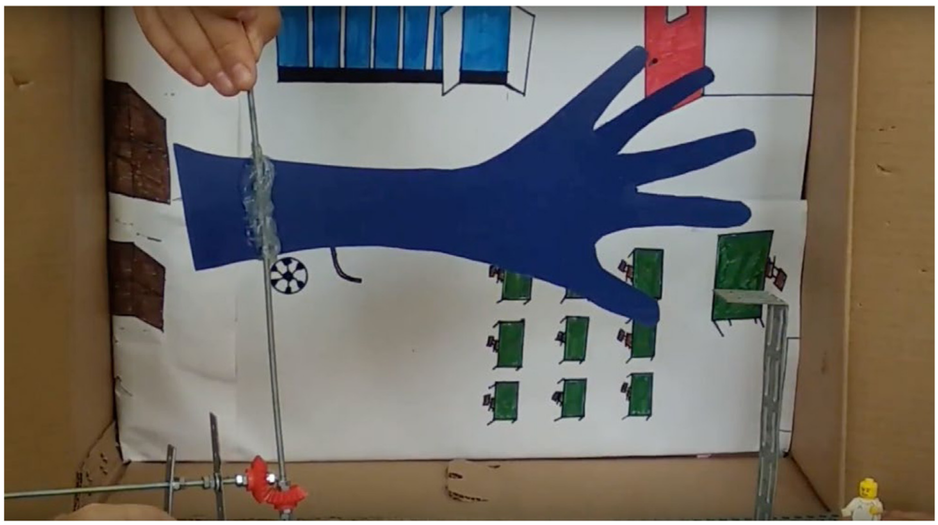

Fig. 3. Video 1, Classroom scenes.

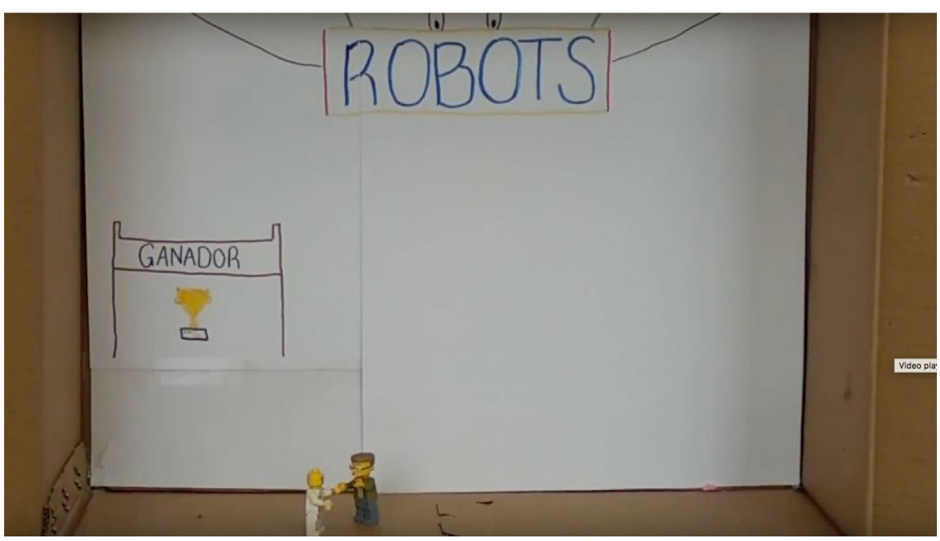

Fig. 4. Video 1, conference scene.

implicit hierarchy. Specifically, in two stories, the human protagonists are those who create and control the robots, which are instruments in their hands. Instead, in the other one, the protagonist finds the robot by chance and decides to use it for his purposes, establishing a symbiotic relationship with it. Conversely, the stories that propose robots as autonomous beings describe them as having different types of relationships between each other: they fall in love, have friends, enemies, etc. In one story, the relationship between robots and humans is horizontal and robots mobilize to help humans. Instead, in the other one, humans have an oppressive role, hindering the development of a loving relationship between two robots.

These different ways of imagining what a robot can do, feel, and its ways of relating are indicative of the coexistence of different models and ideas around what a robot is and what it can do. At the same time, it is relevant to emphasize the composition of groups in terms of gender. In particular, the groups that proposed a more humanized vision of robots are made up exclusively of girls, while the groups that propose a more mechanical vision are made up mostly of boys.

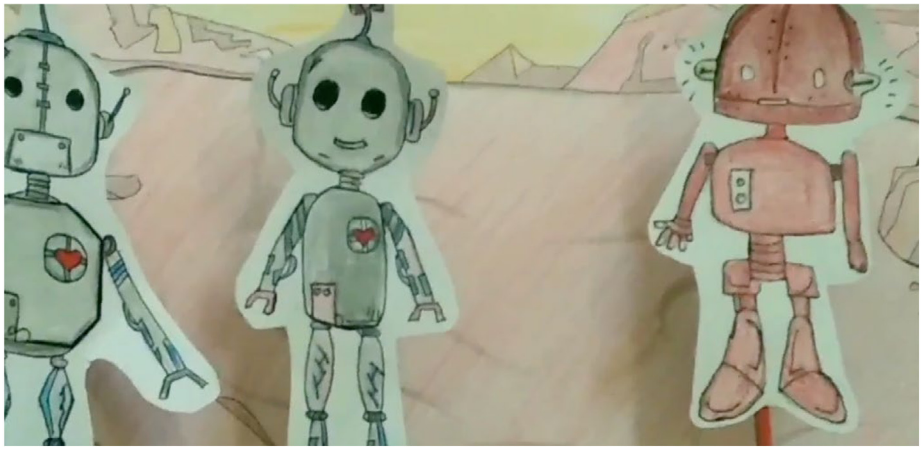

Fig. 5. Video 2, Mars scene.

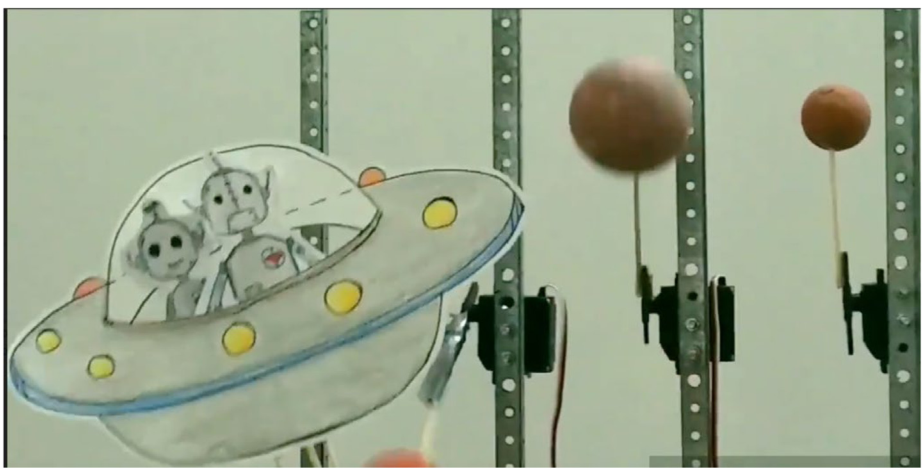

Fig. 6. Video 2, travel scene.

5.3.3. Video analysis: Video 1

The first video was realized by a group of 2 boys and a girl. The video lasted 3 min and tells the story of Charlie, a boy who is bullied at school and decides to create 'a robot to protect him from bad people'. The robot, called Hostiometer (slap-o-metre) captures the interest of the technology teacher, who decides to invite Charlie to participate in a robotics conference. At the conference, even if Charlie initially did not trust his ability to create robots, he ends up winning the robot competition. Two entrepreneurs offer him a job as a robot creator in their companies. Therefore, Charlie decides to accept the job in the company that he likes the most. Charlie's robots become famous around the world and, when he returns to school, his classmates admire him instead of bullying him.

Classmates: 'Now you are very famous, you are a great creator of robots, you are the best in the world'

Charlie: 'Thanks'.

The video is structured in 4 scenes. The 1st, 2nd and 4th scenes of the video are set-up in a classroom (Fig. 3); while the 3rd takes place at the robotic conference (Fig. 4). These locations set the story in the present and in a daily context, hence framing robots as part of our everyday lives.

At a visual level, all scenes are composed of backgrounds made of poorly detailed drawings. The humans are represented with puppets manipulated by the children. The robot, instead, is characterized by a different size and materiality. Specifically, the "Hostiometer" is made out of a plastic hand and a gear system that allows to manipulate the hand and use it to slap "bad people". Its size responds to the human scale, hence determining an evident visual primacy. At the same time, its realization denotes a more elaborate technical and creative work than the characters or the background.

Both the visual primacy of the robot and the story make visible different discourses that students are reproducing. The robot and Charlie's ability are the keys of the child's rescue and social revenge. The child's technological skills allow him to redefine his role and identity in his social context. Being able to create robots is described as a transformative competence in the process of social and professional recognition. This construction can be contextualized within the broader sociocultural framework of the educational discourse on STEM disciplines, professional opportunities, and narratives of the "self-made technologist" (e.g., the man who gradually builds from his garage what will be a great technological empire). Finally, alongside with this discourse, all the characters associated with technological competences are male figures, evidencing the weight of gender stereotypes in this field.

5.3.4. Video analysis: Video 2

The second video was realized by a group of 3 girls and lasted 1:30 min. The video presents the story of two robots, Harry and Ross, that live on Mars and are sent by their boss to the Earth for helping humans that have been affected by a virus and have lost their capability to feel. The robots travel to the

Fig. 7. Video 2, prison scene.

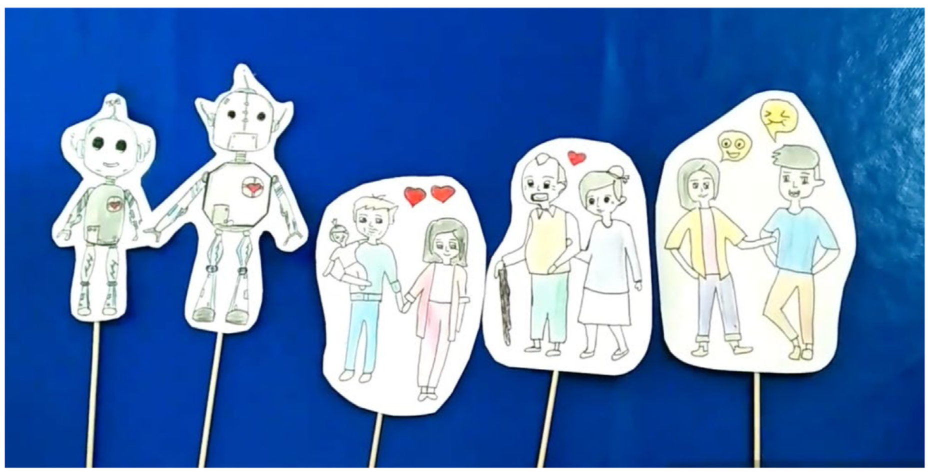

Fig. 8. Video 2, Earth scene.

Earth, but, once there, they are kidnapped by a villain, Black, an evil man who wants the humans to be always fighting. Black forces Harry and Ross in a prison with other robots. Nonetheless, they manage to escape, fighting Black, eliminating the virus and restoring happiness on Earth.

The video is structured in 6 scenes. The main locations depicted are the planet Mars (Fig. 5), the travel in the solar system (Fig. 6), the villain's prison (Fig. 7) and planet Earth (Fig. 8). At a visual level, all the scenes are characterized by detailed drawings. The robots have a conventional appearance that combines humanoid and machinic elements. Several traits characterize them as friendly: they have cute expressions and the two protagonists have a heart on their chest. This aesthetic is contrasted with Black, who is represented as a human being with various attributes typical of the villain (Fig. 7). These graphic choices, the dialogues and the narrative further strengthen the role of robots as saving heroes, one-sidedly good and willing to risk their harmlessness for the good of humans.

Regarding the visual and material choices, the travel scene (Fig. 6) offers additional space for reflection. Starting from the initial requirements of using at least one technological element in their story, the three girls decided to use the Arduino and servo motors to create a background that represents the solar system. This choice creates a strong contrast with the use of cardboard and drawings to represent all the other elements. Furthermore, their technological creation only appears for a few seconds in this scene. This choice can offer interesting clues to think about the characteristics of technical materials and the potential uses they suggest (or not).

The overall video makes visible imaginaries around robots linked to the narrative models of the saving hero typical of certain audiovisual productions. Within this, is relevant to highlight that the descriptions of robots are fully humanized. The choice to locate the robots on another planet suggests a vision of the robots as autonomous beings, that are not at the service of humans but are almost part of another species that has its own habitat. At the same time, the presence of the "boss" that gives orders, suggests the existence of social hierarchies in the robotic world. Finally, the characteristics of the proposed mission suggest the robots' awareness about the importance of feelings and their willingness to help humans.

6. Discussion

The creation of the stories and the realization of the audiovisual narratives made visible different nuances of the children's and adolescents' ways of constructing meaning about what is a robot and what it can do in society. To trace some form of intermediate-level knowledge (Barendregt et al., 2018), we organized these outcomes around five deeply interrelated themes:

(1) The coexistence of opposite imaginaries about "what is a robot and what it can do" and the relevance of anthropomorphization;

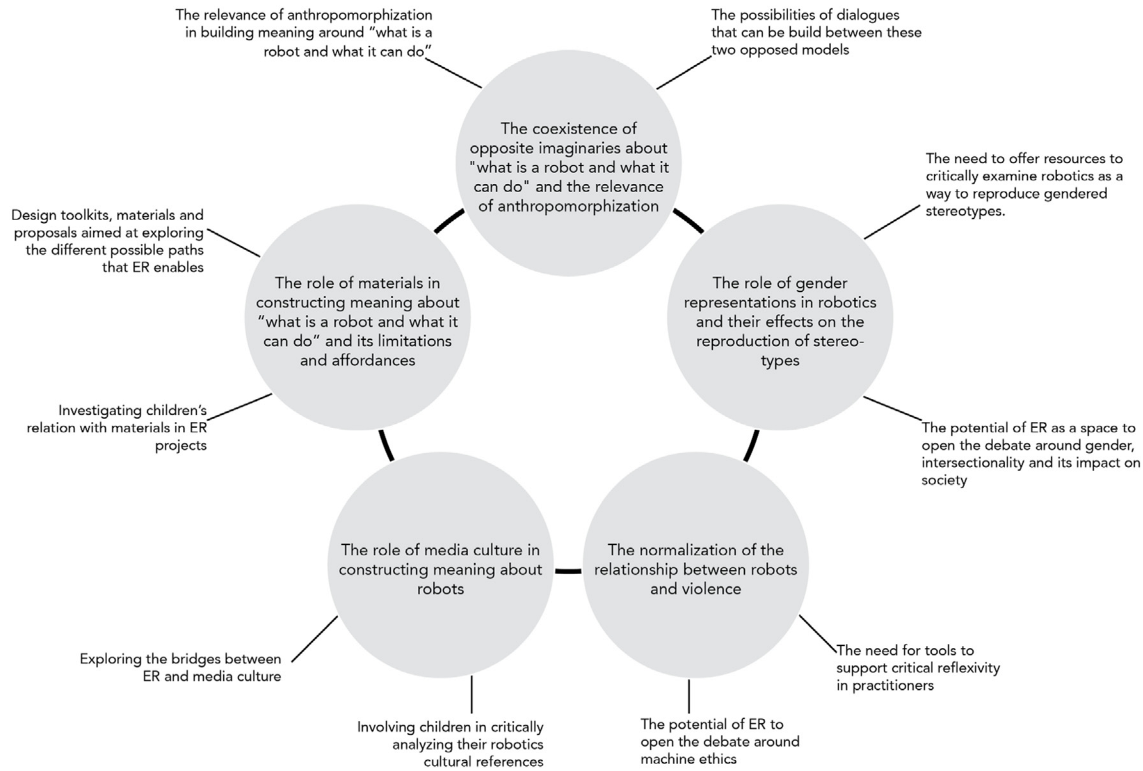

Fig. 9. Summary of identified themes and dimensions.

(2) The role of gender representations in robotics and their effects on the reproduction of stereotypes;
(3) The normalization of the relationship between robots and violence;
(4) The role of media culture in constructing meaning about robots;
(5) The role of materials in constructing meaning about "what is a robot and what it can do" and its limitations and affordances.

These themes, in addition to being a reflex of the complex network of socio-cultural references around robots, also offer a fertile terrain to enable different discourses and practices in ER. Specifically, we will focus on exploring the potential of robotics as a boundary object (Star Leigh & Greisemer, 1989) to speak about a broader range of social and ethical issues. To this end, each theme will be discussed in relation to the outcomes of our research and related literature. Through this discussion, we will identify a series of possible dimensions and paths to expand researchers and practitioners' views around the educational possibilities of ER (for a summary see Fig. 9).

6.1. The coexistence of opposite imaginaries about what is a robot and what it can do and the relevance of anthropomorphization

The reported cases showed how the creation of audiovisual stories allowed making visible different imaginaries around robots. Specifically, two opposing models emerged. On the one hand, the primary school children and two groups of secondary school students depicted robots as autonomous beings, capable of feeling and making decisions. Instead, the other three stories proposed imaginaries of robots as functional machines created by humans. These opposing models open space for reflections on the pedagogy of ER. Specifically, we identified two possible dimensions:

(1) The relevance of anthropomorphization in building meaning around "what is a robot and what it can do"
(2) The possibilities of dialogues that can be built between these two opposed models

6.2. The relevance of anthropomorphization in building meaning around "what is a robot and what it can do"

Consistently with studies on attitudes towards robots (Blancas et al., 2017; Bumby & Dautenhahn, 1999; Woods, 2006), we identified a tendency towards anthropomorphizing robots in their physical appearance and in their abilities. This trend was particularly evident in younger children and girls. Although children's tendency to attribute agency to non-animated objects is well known (Ackermann, 2000), this way of making meaning around robots offers an interesting standpoint to look at ER.

On the one hand, this understanding can offer a fertile ground to discuss with children the limits of our anthropocentric way of seeing the world and, hence, exploring notions around post-humanistic perspectives (Braidotti, 2015). In other words, robotics can be used as boundary objects to open complex debates with children around questions such as: *"Why do we use humans as referents when we think of robots?" "Why do we think in intelligence and artificial intelligence in relation to humans' skills?" "What if we explore other perspectives on robotics and artificial intelligence?"* etc.

On the other hand, following a diametrically opposite direction, other projects can build on children's tendency to subjectify robots, i.e. as in the case where a young girl decided to create a robot that is *"a 10 years old girl like me"*. As stated by Ackermann (2000), children's ability to personify things allow "*putting empathy and creative imagination at the service of intelligence*". Hence, interesting possibilities can employ "robots as avatars" for projects linked to self-knowledge and emotional disclosure, e.g. use robots to speak about oneself.

Finally, further considerations should address the representations of the machine that are offered to children. Although attributing agency to machines can offer interesting standpoints to spark creativity, on the other side, using living metaphors to speak about machines may also end up running the risk of "black-boxing" the functioning of robotics (Kynigos, 2008; Villani, Bonnet, & Rondepierre, 2018). Hence, further attention should be devoted to the way in which representations of robots can be constructed or deconstructed. Relevant research on this topic can be found in the works of Boraita, Henry, and Collard (2020) and Collard, Henry, Hernalesteen, Jacques, and Frenay (2020) who investigate the limits and risks of the dominant representations in ER.

6.3. The possibilities of dialogues that can be built between these two opposed models

The coexistence of opposing models about robots (i.e. humanized vs. functional machines) opens spaces for debating with children on controversial topics related to intelligent technologies. Possible research could deepen on children's representations about the functioning of everyday intelligent technologies. An interesting example of this research could be found in the work of Charisi, Habibovic, Andersson, Li, and Evers (2017) who explore children's views on self-driving cars. Additionally, researchers and educators can widen the scope of ER and create bridges with literature, social science and philosophy. Possible projects could involve children in exploring the complexities that emerge when thinking about intelligent technologies, i.e.: the ethical and political agenda in technology design; the limits between humans and machines; the concept of cyborg; the hopes, fears and fantasies about the actual and future abilities of intelligent technologies, etc. Examples of this kind of research can be found in the work of Payne and Williams (2019) who designed a curriculum to teach AI and ethics to children. Furthermore, additional explorations could employ well-formulated philosophical and speculative questions or thought experiments such as the Moral Machine (Awad et al., 2018).

6.4. The role of gender representations in robotics and their effects on the reproduction of stereotypes

The reported cases showed different nuances related to gender representations in robotics and their effects in students' creative processes and in the reproduction of stereotypes. In the primary school's story, boys and girls used different visual and cultural references in the representations of their robots, i.e. the choice of materials, the roles of the characters, etc. On the one hand, these representations often reiterated gender stereotypes that are commonly present in fictional narratives (Cekiso, 2013). On the other, they highlighted that boys and girls may be interested in working with different referents. These intertwined relationships between gender, robotics, stereotypes and imaginaries were also reflected in the secondary school's case. First, the groups of female students preferred anthropomorphic views of robots. Instead, the groups of male students depicted robots as functional machines. Second, as the first video highlights, technological competences were strongly shaped by gender biases (i.e. all the characters with technological skills were male).

The gendered dimension of ER is widely acknowledged and debated. Although, we suggest the outcomes of the presented cases can open paths to move research on gender and ER beyond the effort to only make STEM appealing for girls (Vakil, 2018). Possible research can address:

(1) The need to offer resources to critically examine robotics and ER as ways to reproduce gender stereotypes.
(2) The potential of ER as a space to open a general debate around gender, intersectionality and its impact on society

6.4.1. The need to offer resources to critically examine robotics as a way to reproduce gendered stereotypes

In our studies, participants reported stereotyped gender representations related both to their imaginaries about robots as well as to their representations of the relation between gender and technological competences. This tendency confirms the criticism of gender representations in robotics identified in the literature. As Riek and Howard (2014) pointed out, the lack of diversity in robot morphology and behaviour – particularly regarding gender and ethnicity – requires critical and ethical questions and new ways of designing. For instance, most female robots (e.g. gynoids/fembots) and AI interfaces (e.g. Alexa, Siri) can reinforce problematic gender hierarchies (Hannon, 2016). Similarly, most masculine robots reiterate a stereotypical view of masculinity (e.g. strong, musculate, etc.). At the same time, the social narratives around technological competences also reinforce stereotyped views. This panorama identifies robotics as an active medium in the reproduction of gender stereotypes and biases. Hence, tools and proposals to help children in questioning and subverting current gender stereotypes in robotics are needed.

Within this field, educators can tackle the phenomenon from different perspectives. Possible projects can involve children in critically analysing the socio-cultural discourses around robots (i.e. *How do robots are represented in media culture? What are the features that characterize them? How gender is embedded and represented both in fictional as well as in already existing robots or intelligent interfaces?*). Collaboratively enquiring on these aspects with children could serve as a trigger to foster a critical understanding of the relation between intelligent technology and systems of gender and race. Furthermore, these reflections could enable children in designing robots capable of offering other representations of robotics.

On the other hand, other projects may explore the representations embedded in ER kits and practices. For instance, even if our results are not robust enough to make a strong claim, our cases seem to indicate the possibility of a relationship between gender and the tendency to anthropomorphize robots. The girls' tendency to prefer anthropomorphized views of robots open questions about the practices employed in mainstream ER. If girls tend to prefer fictional views of robots, why do most ER projects use tools that build upon the "machinery" model of robots and only a few projects address its anthropomorphized and fictional potential? This question opens reflections that are at the same time political, pedagogical and concerned with the materiality of the projects. Although it is not in the scope of the paper to deepen into these topics we suggest some relevant explorations. On the one hand, further research could address meta-reflexive approaches aimed at involving practitioners to critically examine the kind of practices they employ in ER and the imaginaries to which these proposals respond to and why. On the other hand, additional research could involve children in critically examining these questions and the current models and tools employed in the pedagogy of ER.

6.4.2. The potential of ER as a space to open the debate around gender, intersectionality and its impact on society

The complex relationships that surround robotics and gender allow opening spaces to explore ER as a boundary object to discuss with children complex ethical and social issues situated in the relation between gender and intelligent technologies. Examples of these possibilities can be found in using robotics to speak about gender beyond its binary dimension as well as to explore the notion of intersectionality and discuss on the impact of technology in society and its role in perpetuation privileges and oppression that derives from the belonging of each individual to multiple social categories (e.g. gender, race, socio-economic status, etc.). Relevant proposals in this direction can be found in the concept of justice-centred computing (Vakil & Higgs, 2019) or in the curriculum developed by Payne (2019).

6.5. The normalization of the relationship between robots and violence

Our studies confirmed the tendency towards associating robots with topics related to violence, war and fight. In both cases, almost all the stories were associated with concepts related to violence. The primary school children chose to characterize almost all their characters with weapons-like features and their story described a fight between two sides. Similarly, almost all the stories of the secondary school students also feature robots as associated with defence or attack. This trend confirms the weight that violence-related discourses have on children's and teenagers' imaginaries (Aran-Ramspott & Alsina, 2013). Furthermore, it can be helpful to understand the features that children attribute to what a robot does, what it can do and what is its role in society. Finally, it indicates a process of normalization in the relationship between robots and violence, which opens questions about the relationship between robotics and ethics in children's imaginaries.

This theme evidences the urgent need for a pedagogy of ER capable of offering a critical perspective on the normalization of violence. Within that, we identified two possible dimensions:

(1) The need for tools to support critical reflexivity in practitioners
(2) The potential of ER to open the debate around machine ethics

6.5.1. The need for tools to support critical reflexivity in practitioners

Often, some ER projects propose violence-associated imaginaries in their unfolding, e.g. asking children to program fights between robots. Although these projects aim at engaging children by responding to part of their interests, they nonetheless run the risk of reinforcing biased and violent imaginaries in an a-reflexive way. This tendency confirms the need for tools to foster critical reflexivity for practitioners. Particularly, we suggest that research should explore strategies to support practitioners in critically examining their own practices and the imaginaries and discourses that they are reproducing, the implications that these carry and their possible consequences.

6.5.2. The potential of ER to open the debate around machine ethics

From a pedagogical perspective, youth's tendency to associate violence and robots could serve as a starting point to debate around topics such as the normalization of violence and complex issues related to machine ethics. In the described cases, for instance, it would have been interesting to use children's productions as a starting point to open the debate around their construction of violence-related representations of robots (e.g. Why are all your robots provided with weapons?). Following this direction, possible projects could aim at reflecting with children on how they build these imaginaries and why (e.g. How do they learn to see robots in this way? Why are these kinds of narrative engaging for them?). Moreover, additional research could explore strategies to involve children in the debate and critical practice around complex issues related to machine ethics, e.g. autonomous weapons systems, ethical and social responsibilities in designing and using intelligent technologies.

6.6. The role of media culture in constructing meaning about robots

Much of our results highlight the weight of media culture in shaping children's and teenagers' representations of robots. As Bruckenberger et al. (2013) pointed out the expectations of naïve users towards robots are influenced by media representations. Specifically, as our study highlights, children's understandings mainly build on previous experiences with fictional robots, which led them to reproduce certain gender stereotypes or construct narratives around violence and fight.

These outcomes confirm the well-established idea that media and storytelling have a crucial role in the processes of meaning construction. Furthermore, these findings open the debate on the role of the media in educating children about robots and its relationship with ER. In our studies, even if all the students had participated previously in other ER activities at the school, their media culture seems to cover a much stronger role than their previous experiences with robotics in constructing meaning about robots. This evidence asks for further research to better understand and reflect on this phenomenon. Potential research dimensions could address:

(1) Involving children in critically analysing their robotics cultural references
(2) Exploring the bridges between ER and media culture

6.6.1. Involving children in critically analysing their robotics cultural references

Children's cultural references about robots could serve as a starting point to engage them in critically analysing how they learnt to see robots in this way and why. Furthermore, additional research paths could involve children in identifying the kind of narratives that the media build around robots. As Bartneck (2004) states, movies and literature tend to propose narratives that associate robots with concepts such as "robots will take over the world" or "robots want to be like humans". Hence, relevant projects could focus both on analysing with children the kind of narratives that are reinforced or missed in the media context as well as exploring strategies to build other imaginaries and discourse about robots.

6.6.2. Exploring the bridges between ER and media culture

Our results, if faced with traditional pedagogical models in ER, identify a gap which may be worth methodological explorations. Specifically, despite the weight of media culture on meaning-making about robots, most ER projects for youth tend to neglect this aspect in their programs. Few attempts in this direction could be found in projects that combine ER and storytelling (Alessandri & Paciaroni, 2012) as well as in projects that merge audiovisual creation with robotics.

6.7. The agency of materials in constructing meaning about "what is a robot and what it can do", its limitations and affordances

The study with primary school students highlighted the relationship between form and materials in the process of building robotic identities and reported some differences between boys and girls in the choice of materials (i.e. the use of textiles and organic materials). Similarly, the second video of the secondary school students also offers insights worth further reflection. The girls' choice to employ drawings to construct the overall narrative and using technical elements just as a background of one scene, seems to indicate that the group decided to use technology only because it was a requisite of the course. Nonetheless, they did not consider it useful for their goal of telling a story.

These observations open paths for different perspectives in reflecting on the role and agency of materials in ER. As proposed by new materialisms frameworks, agency does not only belong to humans. Instead, materials should be considered as active actors in the world (Barad, 2003). This view, framed in the context of the pedagogy of new technologies, suggests that employed materials have an active role in the relationship that is established with the children that are using them as well as in determining children's understanding about what "working with technology" means (Malinverni, Schaper, & Valero, 2020). Facing these considerations with the outcomes of our research ask for reflection on the role of materiality in ER, its affordances, limitations and the space for epistemological pluralism (Turkle & Papert, 1992) that they offer. Potential research directions could address:

(1) Investigating children's relationships with materials in ER projects
(2) Design toolkits, materials and proposals aimed at exploring the different possible paths that ER enables

6.7.1. Investigating children's relationships with materials in ER projects

Further research should investigate the affordances and cultural values that ER materials carry as well as the ways in which children enter (or not) in relation with them. ER toolkits offer affordances that could lead to reinforce certain imaginaries and neglect others, i.e. widely used ER toolkits such as the Lego Mindstorm present a configuration that inevitably recalls some Hollywood-driven stereotypes on robotics such as being ''grey, boxy, masculine'' (Riek & Howard, 2014). Hence, a critical analysis of these material features is needed to question the imaginaries and discourses that they reproduce and the kind of projects that they afford. Additionally, further research should deepen on understanding the ways in which different children enter in relation to different materials in ER projects (Malinverni et al., 2020).

6.7.2. Design toolkits, materials and proposals aimed at exploring the different possible paths that ER enables

All the aforementioned themes trace possibilities to broaden the scope of ER. On the one hand, they confirm the need for tools and strategies to broaden the scope of ER and support epistemological pluralism in the practice. On the other hand, they point out the need to increase research efforts aimed at supporting a robotic literacy capable of encompassing its social and ethical dimensions. The former aspect has already been addressed by relevant innovation related to the materiality of the employed ER toolkits, e.g. Lilypad (Buechley & Eisenberg, 2008); Makey-makey (Silver, Rosenbaum, & Shaw, 2012). Nonetheless, we consider that further explorations in this field are still needed. The second strand, instead, has received much lesser attention. Hence, this gap requires a design and research effort aimed at designing novel toolkits and materials capable of embedding the ethical and social dimension of robotics within its design.

7. Conclusions

The article describes two studies with primary and secondary school students aimed at investigating the participants' views about robots. To this end, we used an art-based approach, involving children in the production of audiovisual narratives about robots. Our findings allowed identifying five key themes that were used to open paths aimed at moving ER beyond the focus on technical skills to instead explore its potential as a boundary object to involve children in reflecting around the ethical, social and cultural implications of emerging intelligent technologies.

This approach allowed making visible the potential of robotics as a boundary object and how different ways of working and organizing knowledge around the same tools and materials may serve purposes that go beyond the focus on technicalities to, instead, shape projects that allow children to speak about themselves, reflect on the role of technology in society or think about broader social phenomena.

Furthermore, the presented studies shed light on the fact that the ethical and social concerns related to intelligent technologies tend to be neglected in mainstream educational practices. This lack is particularly critical since the children that tomorrow will design or use technology will have to make extremely complex ethical decisions about the systems that surround them. Further research should therefore address questions such as: *How can we work on complex ethical issues linked to robotics with young people? How can we make these topics interesting, accessible and relevant for them? Which strategies and tools can support an ethical and critical sensitivity in young learners?* Possible inputs for this research can be found in Maguth's proposal (2012) to integrate social studies into STEM-focused curricula or in exploring concerns arising from roboethics research (Riek & Howard, 2014; Sullins, 2015; Zawieska, 2020). Finally, additional research should also deepen in critically analysing how robotics is currently taught in school and extracurricular activities to understand the inertias that hinder a change in the employed pedagogical models. Within this line, we suggest that ethnographic studies of ER programs are needed to build a more encompassing view of the phenomena.

8. Selection and participation

Participants voluntarily signed up for the activities based on a call previously made at the participating schools. Both parents and children agreed to participate in the study by signing informed consent.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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