Children as Robot Designers

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ABSTRACT

We present the design process of the robot YOLO aimed at stimulating creativity in children. This robot was developed under a human-centered design approach with participatory design practices during two years and involving 142 children as active contributors at all design stages. The main contribution of this work is the development of methods and tools for child-centered robot design. We adapted existing participatory design practices used with adults to fit children’s development stages. We followed the Double-Diamond Design Process Model and rested the design process of the robot on the following principles: low floor and wide walls, creativity provocations, open-ended playfulness, and disappointment avoidance through abstraction. The final product is a social robot designed for and with children. Our results show that YOLO increases their creativity during play, demonstrating a successful robot design project. We identified several guidelines that made the design process successful: the use of toys as tools, playgrounds as spaces, the emphasis of playfulness for child expression, and child policies as allies for design studies. The design process described empowers children’s in the design of robots.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Design research, robotics, creativity

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Figure 1: Creative storytelling play between children and YOLO robots.

1 INTRODUCTION

Children are avid adopters of technology and use technological tools in educational settings as well as during play [1, 2]. Novel interactive technologies, such as social robots, bring new potential for children’s learning, growing, and playing [3]. In this paper, we detail the process of designing a social robot *for* and *with* children, honoring human-centered design practices. The final goal for this robot is to stimulate the creative abilities of children during play.

Adopting human-centered practices for interactive technology designs gives voice to human needs, capabilities, and behaviors. This can lead to increased usability and value of products [4]. That said, designers of social robots are often hard-pressed to include users in meaningful ways in the design process, but end up bringing them only in later stages of evaluation, when most of the design choices have been implemented with no space for major changes. The reasons behind this approach are numerous, including (1) the need for multidisciplinary teams to work together through a long iterative process, (2) a hard-to-strike balance between engineering development and user experience research, (3) and the difficulty in finding representative participants for human-centered design of robots, e.g., such as the case of children or populations with special needs [5, 6].

Figure 2: Children using cube-toys as stand-ins for group storytelling creation during a free play activity. This study was part of the observation of children's playful behavior described in Section 4.1 in which groups of children used the cube-toys as their characters during stories.

Figure 3: During the body-storming session, children were instructed to express personalities using only their bodies, refraining from using words. This primed them to use motion to illustrate their ideas. For example, they enacted personality traits, such as "grumpy", as can be seen in the figure. This was part of the co-design study detailed in Section 4.2.

When focusing on children, there are additional challenges in finding human-centered methods that account for their developmental stage and empower their expressive and communicative abilities throughout the design process. For example, traditional media, such as interviews and questionnaires, are usually not the best approach with children [7].

1.1 Contribution

The main contribution of this work is the development of methods and tools for child-centered design of a social robot, based on adult-centered design. This resulted in a child-centered process that used *methods and tools* that empowered children's voices in the design of social robots. We rested our design on several identified design guidelines that made the design process successful: *object choice*, *playfulness*, *child spaces*, and *child policies*. We used objects appropriated to children, such as toys and craft materials, to create our design tools. Playfulness was at the core of all activities to stimulate children's expression and communication. Familiar spaces, such as school playgrounds and schoolyards, were the stage where the design process unfolded. Child policies related to ethical, legal, and administrative aspects, were considered from the beginning as influential factors for methods and tools choice during studies. Our child-centered design practices proved to be efficient in delivering a robot that can stimulate creativity in children during play-times, demonstrating the success criteria of our project. This design process also empowered children in making design choices for a robot that is meant to be used by them.

The resulting design is of a small non-anthropomorphic robotic toy named YOLO (Your Own Living Object) that uses movement and lights as expressive channels and has an affordance to be grabbed and moved around by children while they play [11, 12]. According to the movement generated by children while grabbing the robot, YOLO can provide new ideas for their stories. It does so by using holonomic movement. With movement, the robot can either *imitate the previous movement* made by children thus elaborating on a given story-line (convergent thinking stimulation); or can *perform a different movement*, setting an intention to change the course of the story (divergent thinking stimulation). This motivates children to consider the robot's ideas in their stories, stimulating creative abilities. An illustration of the interaction can be seen in Figure 1.

This report is on a two-year-long field design research, involving 142 children, and adopting a multidisciplinary approach in which a team of psychologists, computer scientists, mechanical and electrical engineers work together. We detail on the methods, tools, and guidelines for designing a social robot with children. We conclude that our design approach was successful as our results showed that the robot YOLO indeed stimulated creativity in children during playtimes.

2 BACKGROUND

In this Section, we review the literature on existing robots for children, the design process of robots, and the roles children take during participatory design.

2.1 Robots and Children

Research on social robotics for children can be divided into three major design categories: (1) off-the-shelf robots, (2) robotic design kits, (3) and robots that emerge from design research. Off-the-shelf robots are used as pre-designed research platforms (often designed by and for adults) that can be programmed for a particular research goal. Examples of commercial robots used with children are NAO [13] and Pepper [14], Jibo [15], Cozmo [16], Zeno [17], KASPAR [18], Keepon [19, 20], etc.

Robotic design kits are used as tools to foster learning in different knowledge domains. This category falls into "digital manipulatives" [21], defined as computationally-enhanced versions of traditional toys for children as new tools for learning and growing [22, 23]. Examples are LEGO Mindstorms® derived from Programmable Bricks [24], Magix [25, 26], Block Jam [27], Topobo [28], Smart Tiles [29], Digital MiMs [30], Boda Blocks [31], and others [32].

Robots derived from design research included children on some edges of the design process. For example, with Shybo robot, children (and their parents) were involved from an early stage in the design process, informing the application scenario for this robot by using survey methods. In addition to this, children were also testers of the final prototype participating in field studies. Another example is the

Table 1: Design Process of the robot according to the Double-Diamond Model of Design [8], describing the roles of children [9], study goal and type, methods and techniques used [10], and the major outcomes of the human-centered design with children.

	STAGE I: DISCOVER ⇒	STAGE II: DEFINE ⇒	STAGE III: DEVELOP ⇒	STAGE IV: DELIVER
Children's Roles	Children as informants	Children as design partners	Children as testers	Children as users
Study Goal	Investigate the emergence of creativity and how it can be stimulated	Involve children in the design of the social behaviors during storytelling	Improve and refine the robot's AI and physical shape	Final evaluation of a creativity stimulation robot for play-times
Study Type	• Expert interviews and observation • Literature review • Observation	• Co-design with children	• Refinement of the robot software • Refinement of the robot physical embodiment	• Experimental study
Methods & Techniques	• Interviews • Literature review • Behavioral observation	• Sketching • Puppeteering • Body-storming	• Co-discovery • Direct observation • Active involvement	• Storytelling • Behavior observation and analysis
Outcomes	• Storytelling as the activity for creativity stimulation • Contrast and Mirror as the creativity training techniques for the robot • Personality as the basis for the robot's social behavior to increase story narratives	• Identification of behavior patterns designed by children as input for the design of the robot's behavior	• Selection and refinement of behaviors for the robot to improve the software. • Adaptation of the robot's physical shape to children's play manipulations	• Stories created with the robot were more original and thus, more creative

involvement of children in the design process of Ranger [33] and Cellulo [34] to inform interaction patterns by using the wizard-of-oz (WoZ) technique. With Curlybot, children were invited as testers of the final technology to study learning-oriented acquisitions [35].

Despite children being included in some stages of the design process, robots designed to be used by children are still very much in the hands of adults. So far, the literature does not report any robot that has been designed, developed, and fabricated following the voices and desires of children. In this work, we address this design space.

2.2 Design Process of Robots

Despite the wide range of design approaches for social robots, users are not systematically included in all design stages. In the majority, users collaborate only during the evaluation stage, rarely prevailing for the entire design process [36]. Including users in the design process aligns with critical design principles intended to engage users into thinking, exploring ideas, and challenging assumptions, leading to user empowerment [37–40].

However, critical design research is scarce in human-robot interaction (HRI) and this work is one of the first to dedicate the entire design process of a robot to children by considering their ideas and views in all design stages. Additionally, most of the aforementioned methods primarily rely on professionals, such as actors [41] and dancers [42], or include adult user-populations during the design process. This leaves children with fewer opportunities to participate in the design process of a robot that is actually meant for them [10].

Our work lies on human-centered design practices for a full design process of the social robot YOLO, by systematically and directly involving children in all design stages through participatory design methods. This methodology gives children voice during the design, which is aligning with critical design principles [39].

2.3 Participatory Design with and for Children

Participatory design (PD) is a method from human-centered design (HCD) that empowers users during a design process [6, 43, 44], leading to meaningful, approachable, and joyful products or experiences [4]. Most participatory design (PD) methods applied with children grew out of or built on ideas from PD for adults [10]. However, children are a different population with different needs. Particularly, children have different cognitive, motor, emotional, and communication abilities [45, 46], requiring adaptation of PD methods.

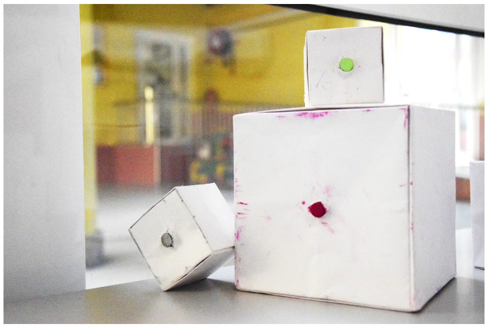

Figure 4: Paper-cubes used during the co-design study with children (Section 4.2). Fabricated with paper and including a built-in drawing mechanism, these cubes enabled: (1) children to have a visual feedback for the created motions, (2) data collection of the drawn trajectories for later implementation in the robot, (3) a constraint for children to represent the movements in a 2D plane and avoiding 3D movements that are impossible to model and replicate in a real robot.

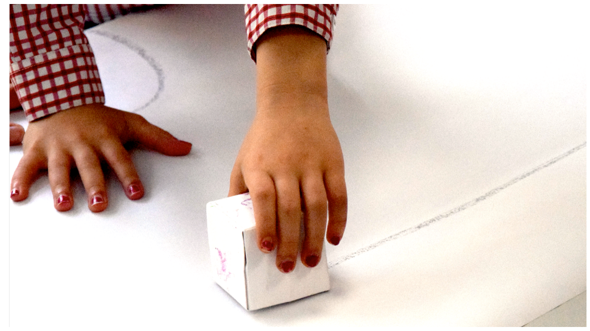

Figure 5: Example of a child expressing movement of a paper-cube by puppeteering it. This was part of the co-design study detailed in Section 4.2.

Children can be included in PD practices under several main roles: user, tester, informant, design partner, co-researcher, and protagonist. We detail these roles below.

- *Children as users* use commercially available technology that has already been developed and distributed for commercial or research [9].
- *Children as testers* help to shape the technology but have no involvement in the design stages [9].
- *Children as informants* impact the design of technology from the beginning of design process [9].
- *Children as partners* equal stakeholders during the design process and have an enormous impact on the design and development of technologies [9].
- *Children as co-researchers* help sharing, gathering, and analyzing data from their practice during robot usage [47].
- *Children as protagonists* carry out a complete design process in which process and product reflection is a central component [48].

In our work, children were involved in different roles when designing the robot for creativity, depending on the design stage. Children took the role of design partners in the early stages of the robot conception and design, as informants and testers during design improvements, and as users when acting as participants in the validation study of the creativity intervention.

3 DESIGN SPACE: A ROBOT FOR CREATIVITY

Creativity is an increasingly important skill for children to have in order to thrive in adult life. Creativity is defined as the "interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful."[49] However, creativity has been shown to decrease in middle school age-years [50]. Research showed that creativity is an ability that can be nurtured if stimulated [51]. Despite this, classrooms generally do not appear to be creativity-fostering places, due to existing biases of traditional education practices [52–54].

Our design challenge concerns using social robots as easy-to-use-toys to be incorporated into children's spaces, such as schools, with the overarching goal of creativity development through play.

3.1 Design Principles

We identified a set of principles that guided the design of YOLO.

- **Design Principle 1: Low Floor, Wide Walls** — Technology is considered to have "low floor and wide walls" when novices find it easy to get started without require learning an entirely new skill set (low floor), and when it supports the exploration of a wide variety of projects (wide walls) [55]. This can be achieved by designing a few and specific behaviors for the robot that promote quick understanding and engagement.
- **Design Principle 2: Creativity Provocation** — Divergent and convergent thinking are two essential forms of creative thought [56]. Using robots to provoke higher levels of creativity requires implementing validated techniques or programs that favor these creative modes.
- **Design Principle 3: Open-ended Play** — "Play is the work of children" [57], as it constitutes their central daily activity used to learn, explore, and connect with the world. Open-ended play environments are specifically supportive of creativity as they are contexts that enable the emergence of fantasy, imagination, and make-believe [58, 59].
- **Design Principle 4: Abstract Form** — When expectations of social robot capabilities are not met, they tend to feel the robot let them down [60, 61]. Disappointment is especially evident when interacting with anthropomorphic robots whose physical appearance does not match their social capabilities [62]. Designing for abstraction means the physical appearance of the robot does not compromise its social abilities which are instead discovered during interaction.

Building on these four principles, the robot was designed as follows: To create a low floor, we designed a robot with a limited number of features, which are simple and specific, and that enable children without any previous experience to create a story. To create wide walls, the robot behaviors were designed as non-directional,

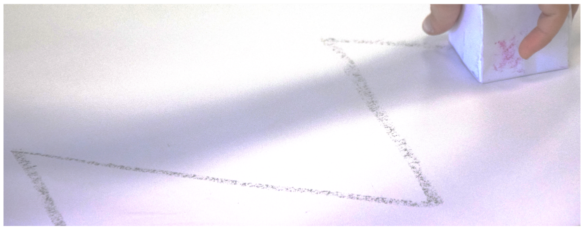

Figure 6: Example of a sketch of a child collected from puppeteering a paper-cube.

Figure 7: Manipulation of a robot prototype for the study of the size of the robot and children's grasping behavior. The robot is covered with red clay to collect data about where and how children hold the robot. This was part of the study of the robot physical embodiment described in Section 4.3.

allowing for the creation of any story content. To provoke creativity, we focused on two techniques that allow for the stimulation of divergent and convergent thinking, which are used by the robot at specific stages of the storytelling; the first technique called "Mirroring" enables the elaboration of a given story idea (convergent thinking) and the other technique, called "Contrasting", moves towards a plot twist (divergent thinking). Open-ended play was supported as children were allowed to create a story about any theme they desired without time limits. To avoid disappointment, the robot was designed with physical affordances that would map its actual capabilities, and without anthropomorphic features.

4 CHILD-CENTERED ROBOT DESIGN

Our design approach is based on the Double-Diamond Design Process Model [4, 8], which maps HCD onto four stages: Discover, Define, Develop, and Deliver. Table 1 shows how children's design roles map onto the established Double-Diamond Design Process Model, and how it relates to the various research activities undertaken as part of this project.

4.1 Discovery with Experts, Theory, and Observation

The first stage of the Double-Diamond Design Process is "Discover", where basic insights about the problem are collected. In our work, the goal of this stage was to investigate how creativity unfolds and what practices can be applied to stimulate it. We used a three-fold approach, which included interviews with creativity education experts, an extensive literature review of theories of creativity, and direct observation of children during playtime. At this stage, children were included as informants.

Expert Interviews and Observations — We conducted semi-structured interviews and direct observation of two creativity education experts that provide dance and theatre improvisation classes to children. Our goal was to understand the methods they use to stimulate creativity during these activities. We discovered that creativity occurs through structured but open-ended activities framed with playfulness [63]. One aspect that was considered common in every creative activity was the emergence of stories that framed the creations with children. The major outcome from this stage was to choose a storytelling activity as the creative context for the robot.

Literature Review — We conducted a systematic review of validated techniques for creativity training with children [64]. This systematic review included a survey of 2247 scientific articles from 1961 to 2018, filtered down to a full analysis of 49 papers using the PRISMA method [65]. Creativity training programs in the literature were as diverse as using physical exercises related with relaxation [66], improvisation [67], pretend play [68], computer-environments [69], and robots [70]. The most influential finding from this stage was the choice of two techniques to be implemented in the robot aimed at stimulating children's creativity during storytelling, for which the chosen techniques were "Contrasting" and "Mirroring" [71]. Both of these techniques relate to idea generation, a core aspect of story creation. While the Contrast technique stimulates divergent thinking, the Mirror technique is responsible for the development of convergent thinking. Both are required to establish the emergence of creativity [72], rather than the more basic act of unregulated self-expression [56].

Observation — We conducted a field study in a school setting using direct observation with video recordings for post-observation, to understand how small groups of children create ideas together in a storytelling context. A sample of 13 children (4 female, 7-10 yo) organized in four groups (three groups of 3 children and one group of 4) participated in this study. Cube-toys were chosen as story characters due to their abstractness and to ensure uniformity in the children's experience (see Figure 2). We observed each group for about 30min, with a total observation time in the school of 2h [73].

This study provided three outcomes for the design process. The first outcome concerns the unstructured nature of storytelling play in which children oscillated between highly creative moments of divergent thinking showing thunderstorms of ideas, to convergent thinking translated by meaning-making moments where they chose which ideas were kept in their story. This supported the choice of the Contrasting and Mirroring techniques for the robot, which were initially chosen during the literature review. The second outcome concerns the difficulty of sharing the cube-toys between them during the story creation. Therefore, the number of robots and children should be even to facilitate dynamics between groups of children, informing the need to build more than one robot for group interactions. The third outcome concerns children using personality attributes in the cube-toys to create new narratives in their story.

Figure 8: Children play with the robot part of the validation of social behaviors for storytelling described in Section 4.4.

This opened a design opportunity to use personality as the basis for the robot's social behavior to provoke more story-lines when children play with the robot. Creativity and personality are also known to be interconnected variables when facing a creative situation [74, 75].

4.2 Definition through Body-Storming, Acting, and Drawing

The second stage of the Double-Diamond Design Process is "Define", which focuses on specifying details of the design requirements. In our work, the goal of this stage was to translate the high-level findings from the discovery stage into specific requirements for the development of the first robot prototype. We had children as partners in the design process, adapting PD methods such as body-storming, puppeteering, and sketching for children as co-designers. At this stage, children were included as design partners.

Co-design with Children — A study was conducted in a school with 44 children (25 female, 6-9 yo) participating in the design of the robot's social behaviors. Based on the previous phrase, we focused on personality traits within story-line creation. Children performed the activity in groups of 3–5, with each session lasting 1 hour and the total time of all sessions being 13 hours [76].

During the co-design study, children played the role of co-designers by designing motion and attributing color for social expressive robot behavior. We used body-storming to prime children toward understanding personality traits. Body-storming is a form of PD to enact experiential awareness [77]. The goal of body-storming was to verify (and in some cases teach) the meaning of the different personality traits that they would represent in the robot in the following stage. Figure 3 shows children in our study engaged in bodystorming different personality types they would later imbue in the robot.

The next stage was to use puppeteering and sketching to develop and elaborate on the social behavior of the robot. We built a paper cube with a built-in drawing mechanism and asked children to act out how this cube would behave according to the personality they were creating (see Figure 4). This mechanism enabled children to represent the movements of the robot by drawing them in large paper sheets of paper (see Figure 6). We collected the resulting sketches, in addition to video and audio recordings, to support the analysis of the results (see Figure 5). We discovered that children create consistent patterns of movements according to different personality types [76]. The major outcome of this study was the generation of specific motion and color patterns, derived from children's interpretation of personalities, to implement in the social behavior of the robot.

4.3 Development through Iterative Prototyping

The third stage of the Double-Diamond Design Process is "Develop", the iterative development of prototypes. In our work, the goal of this stage was to develop both the artificial intelligence (AI) software and the physical embodiment of the robot. At this stage, children were included as testers of the robot.

Refinement of the Robot software — We conducted a study in a Science Museum for children to test the first iteration of interactive behaviors, using a low-fidelity mechanically actuated robot prototypes (see Figure 9-3,4) for children to play with. The total time of the study was 4 hours and a total of 20 children (7–9 yo) played with the robot freely. The robot acted autonomously, displaying a set of behaviors inspired by the co-design study, including colored lights and movements. We relied on Co-discovery and Active Intervention methods to elicit feedback from children [78]. During Co-discovery, children consult each other to understand how the robot works. In our study, children were organized into small groups and were prompted to tell each other how they were playing with the robot.

During Active Intervention the researcher asked questions about the storytelling task and also about desired behaviors that children would like to see in the robot. In addition to these techniques, we used direct observation of children freely playing with the robot to gather additional design requirements. The major outcome of this study was the selection and refinement of behaviors for the robot. For example, colors and motion were a major drive in storytelling. This result led us to explore richer ways to use these modalities by coupling light brightness and motion speed for behavior combination. We removed of some features in the robot that did not support interaction towards storytelling and creation, such as sounds that children paid little attention to compared to other features. The software for YOLO with accompanying tutorials and an API can be found in open-access in Alves-Oliveira et al. (2020) [79].

Refinement of the robot hardware — We conducted a laboratory study with 3D printed non-actuated prototypes of the robot to gather design requirements for the physical shape and size of the robot. We covered the robots' shell with clay to get data about where children place their hands to hold and manipulate the robot (see Figure 7). We used direct observation to discover the best suitable size for the robot, and to study how children grabbed the robot to inform ergonomic modifications in the shell (see Figure 9-5). A total of 3 children (1 female, 7 yo) participated by individually playing with different prototypes of the robot in sessions of 30 minutes.

Figure 9: Iterative prototypes of the robot designed using the process described in this paper. From left to right: 1. Early sketches, 2. Paper prototype to explore scale and mechanism, 3. First actuated prototype used in the "Develop" stage; 4. Second actuated prototype used in the "Develop" stage, 5. Three different passive robot stand-ins for scale and grasp studies; 6. Final version of the robot.

The measure of analysis used consisted of the number of instances of grabbing behavior during play. Therefore, $n = 40$ instances were analyzed, revealing that: (1) children had difficulties in grasping the large-sized robot because the shell was too large, but grasped the medium-sized robot comfortably; (2) children did not treat the small-sized robot as a character during play, possibly because its small shell did not evoke agency; (3) children did not have orientation commitment when manipulating this abstract robot as they did not attribute a fixed "front" or "back" side to it; (4) children consistently used the same area on the robot for manipulating it, suggesting an ideal design space for grabbing;. Data collection ceased at an early stage due to saturation, which occurs when data keeps showing the same results no matter how many participants are recruited [80, 81]. The major outcome of this study was the commitment to a medium-sized robot with a concavity for grasping. This lead to mechanical decisions of accommodating smaller sensors and actuators that fit the reduced size model. The full guide to build YOLO with accompanying tutorials can be found in open-access in Alves-Oliveira et al. (2019) [82].

4.4 Delivery through Testing

The fourth and final stage of the Double-Diamond Design Process is "Deliver", where a more developed prototype is taken through testing and further refinement. We view this stage as the "Evaluation" stage as we implemented the final prototype of the robot and conducted an experimental study. At this state, children were included as users of YOLO.

The aim of our study was to test the efficacy of the robot in stimulating creativity of children. For this, we instructed children to create a story with the robot, using it as a character for their stories (see Figure 1). A total of 62 children (45 male) aged between 7–10 years old participated in this study. The stories created by the children with the robot were compared against the condition of creating a story with the same robot but without displaying any behaviors, and a robot turned off (see Figure 8). We analyzed the stories created by the children using the recording of their voices. Involved coders evaluated relevant variables in creativity research, such as originality, fluency, flexibility, and elaboration. According to literature, when these variables are present in a creative process, the creativity is deemed high [83–85]. Results showed that when children played with the full version of the robot, their stories were more original. More details about this study can be found in Alves-Oliveira et al. (2020) [86]. Note that the paper [86] described the experimental study of children using the robot to create stories, whereas the work presented in this paper describes the design study of the conception, fabrication, and development of the robot.

5 GUIDELINES FOR CHILD-ROBOT DESIGN

We described a two-year-long process that adapted participatory design methods and techniques to involve children in the design process of a social robot. Throughout this work, we identified several design principles that can support the inclusion of children in the social robotic design process.

- **Playfulness, a central mode of communication for children, should be at the core of all design activities.** Play, especially social play, is a key part of child development [87]. Play is defined as a minimally-scripted, open-ended exploration where children are absorbed in the spontaneity of the experience [88]. According to their developmental stage, children engage in different types of play [89] such as physical, intellectual, socio- and emotional- play [90], symbolic and pretend play, including playing with objects and games with rules [91]. In our work, we have imbued all design activities with playful elements to encourage children's expression during the design process of the robot. We relied on playful activities such as acting, sketching, body-storming, and traditional games, to ground the activities that invite children to the design.
- **Toys and craft materials are used by children daily and should be used as tools in the design process.** During childhood, children manipulate objects such as toys to explore and make sense of the world around them [92]. Toys are tools that are approachable and safe to play with, fostering the development of children. Froebel's gifts[93] and Montessori's view on "education of the senses" [94] are examples of how manipulatives can be used to empower children's growth and development. In our

work, we have incorporated toys and materials that are part of a child’s world in all design activities during the robot design and creation. To this end, we opted for paper, crayons, and cards, as the tools that children relied on for the robot design.

- **Child spaces, such as playgrounds, should be the stage on which the design process unfolds.** “Playscapes” are environments that are natural and in which children find joy and safety to play [95]. Research on playground designs has brought to light qualities that lead to the most playful behaviors in children [96]. Effective playspaces support a range of social scales, allowing for solitary and social play; effective playgrounds embrace emotional requirements, such as emotional relief spaces, including privacy and break away points for quiet play [97]. In our work, we have used interior school playgrounds as they evoke playfulness and put our children co-designers in the right mindset for creative exploration. Our work is based on design-research for which we have relied on theoretically-inspired methods applied to a local design problem that has the potential to impact innovations within the global field of design in HRI [98].
- **Using child-appropriate protocols and materials.** Consider a narrative of briefing and debriefing that children can understand to explain the goal of the research. One example for a briefing protocol is the CHECk Tool [99] commonly used during PD sessions with children [100]. This will enable ethical and informed participation of children, empowering them to decide if they want to enroll in the study. Consider data collection methods that are child-friendly, such as the Fun Toolkit that uses a Smilyometer instead of Likert scales [101]. before jumping into the actual activity add an ice-breaking activity with children that can be as simple as sharing hobbies or implementing other techniques, such as Vignettes [102]; this will result in a more relaxed environment with children being more expressive and honest in their opinions towards the technology being tested [103].
- **Designing with children requires a multidisciplinary team.** Experts from a variety of backgrounds are a requisite when working with children. For example, when performing a study with children in a school, an expert in children’s dynamics (such as a psychologist that is trained to interact with children in study contexts) is required, as well as an expert in robotics (such as an engineer that can intervene when a problem with the robot arises). Multidisciplinary teamwork enables focus on different aspects during a study. In teams made up of experts in different backgrounds, however, special care needs to be given to develop a common language to support mutual understanding during different design stages. Team members should be trained together in the lab before heading to a study with children. should meet regularly to provide updates about design stages and make sure that their individual tasks converge toward the intended project goal.
- **Prepare to spend time on legal and ethical policies that concern child studies.** In particular, note that these policies are very localized and thus differ per institutions (e.g., school district, university, specific school policies). Safety standards require that the methods and materials employed in studies with children are certified or are adapted for the child’s developmental stage. Privacy and confidentiality require the adoption of alternative methods for data collection that protect a child’s identity. All of this can cause restrictions on the study conducted and may therefore require exploring alternatives to originally conceived methods (e.g., using direct observation instead of video recordings). Having a long preparation time, and being open to change, is key to conducting design studies with children.
- **Conduct pre- and post-activities with your study partners, such as schools and museums.** Visit the place where the study will be performed beforehand to understand the resources you have available, as this might define the conditions for your study. This includes understanding the physical (e.g., spaces in the school that you can use to conduct the sessions, location of power outlets, etc) and administrative conditions (e.g., understanding who you will be coordinating with to have children coming in an organized way to the sessions). Consider performing clarification sessions with teachers and parents before the study begins as a strategy to have the institution on board during your study and parents signing consent forms in an informed way. At the end of the study thank the school for the time, space, and coordination that enabled the study to be performed. This can be accomplished by performing a debriefing session about preliminary results at the end of the study, or by sending materials of interest to the school such as articles that describe your results. This is not only a way to thank your partners, but also assures a good connection to institutions and provide a return place in case additional sessions are needed.

6 CONCLUSION

This work shows that designing and testing technologies with children is important to develop robots that accommodate their needs and that are understandable for them. Throughout this work, we identified design guidelines that promote the successful inclusion of children in the design of robots: *object choice, playfulness, child spaces*, and *child policies*. The relied on design principles from constructionism theory and creativity research, such as *low floor, wide walls*, *creativity provocation behavior*, *open-ended play*, and *abstract form* to lead the design for this robot. We hope that the detailed description of a multi-stage design process can provide specific methods and techniques, as well as overarching principles, for future designers of social robots for children.

Despite the richness of this design process, our work comes with limitations that we would like to acknowledge. A major limitation is that we have not compared our child-centered design process to other processes of robot design. For future work, it would be interesting to compare different approaches in robot design, accounting for different levels of user engagement.

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Guide to build YOLO, a creativity-stimulating robot for children

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ABSTRACT

YOLO is a non-anthropomorphic social robot designed to stimulate creativity in children. This robot was envisioned to be used by children during free-play where they use the robot as a character for the stories they create. During play, YOLO makes use of creativity techniques that promote the creation of new story-lines. Therefore, the robot serves as a tool that has the potential to stimulate creativity in children during the interaction. Particularly, YOLO can stimulate divergent and convergent thinking for story creations. Additionally, YOLO can have different personalities, providing it with socially intelligent and engaging behaviors. This work provides open-source and open-access of YOLO's hardware. The design of the robot was guided by psychological theories and models on creativity, design research including user-centered design practices with children, and informed by expert working in the field of creativity. Specifically, we relied on established theories of personality to inform the social behavior of the robot, and on theories of creativity to design creativity stimulating behaviors. Our design decisions were then based on design fieldwork with children. The end product is a robot that communicates using non-verbal expressive modalities (lights and movements) equipped with sensors that detect the playful behaviors of children. YOLO has the potential to be used as a research tool for academic studies, and as a toy for the community to engage in personal fabrication. The overall benefit of this proposed hardware is that it is open-source, less expensive than existing ones, and one that children can build by themselves under expert supervision.

Specifications table.

Hardware name	YOLO – Your Own Living Object
Subject area	Educational Tools and Open Source Alternatives to Existing Infrastructure
Hardware type	Other: Creativity Support Tools
Open source license	CC-By Attribution 4.0 International
Cost of hardware	$150–200
Source file repository	https://osf.io/kwrft/

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1. YOLO – Your Own Living Object

Children are avid explorers, using objects to play while learning about how the world works. [59,84,75]. In particular, the usage of toys during play have shown to be related to healthy cognitive development [73]. A new generation of technological objects is joining the more traditional set of toys, including smart-phones, tablets, virtual and augmented reality devices, and social robots. The emergence of technologies for children led to changes in play-time, deviating from traditional sand-boxes and parks to digital and interactive devices. Research shows that children are willing to use and interact with technology [8,44,62] and that technology can have positive benefits in children's learning [33] and creative levels [61]. Additionally, technology has been driving developed societies towards more "creative economies" where the value of innovation, problem-solving, and collaboration, is favored over standardized knowledge acquisition and repetitive tasks [24,60,45,17].

In our work, we aim to contribute to the development of a social robot that will benefit children's creativity during playtime. Children play with this robot while still maintaining traditional play landmarks, such as physical, free, and outdoor play. The specific use-case scenario consists of a storytelling activity in which children use the robot as a character for their stories. It is in the *interaction* with the robot that creativity is intended to be stimulated, similarly to what was developed with other toys [77,83]. This makes YOLO part of a new generation of technological toys that has the potential to boost creative abilities. During the process of play, the robot provides stimuli for children to develop new story-lines for the stories they create. The robot does so by using techniques of creativity training [3]. Particularly, it stimulates two core elements of the creative thought: divergent and convergent thinking [26,22,50], two modes of creative thinking that usually are naturally stimulated through play [39]. This robot is called YOLO, short for Your Own Living Object (see Figs. 1 and 2).

2. Related work

In this section, we contextualize the development of YOLO within the general field of Human-Robot Interaction (HRI) and Child-Robot Interaction (cHRI). We frame our design decisions based on design research including user-centered design techniques, and theories about child development, personality, and creativity.

2.1. Human-robot interaction

HRI is a field of research dedicated to the design and evaluation of robotic systems that interact with humans [30]. These robots have been designed with the ability to "communicate and interact with us, understand and even relate to us, in a personal way" [15]. They have been designed with different embodiments, using a rich taxonomy of expressive behaviors [27], classified according to the environment in which they operate, and to the intended application field [10]. Additionally, their interaction modalities range from emotional expression [55] (including empathy [54], body gestures [69,70], and expressive lights [7]) to color, motion, and sound [40]. High successful interactions with humans tend to occur when the interactive and expressive modalities of robots match their physical embodiment [48]. A robot's embodiment can also range from a human-like appearance [36,43] to non-humanlike shapes [16,85,19]. When a mismatch is perceived between the physical appearance of a human-like robot and its behavior, feelings of eeriness and revulsion may arise, denoting the so-called Uncanny Valley Effect that robot designers want to avoid [48]. To counter this effect, we chose to develop a non-anthropomorphic robot using non-verbal elements, such as colors and movement, to communicate with children.

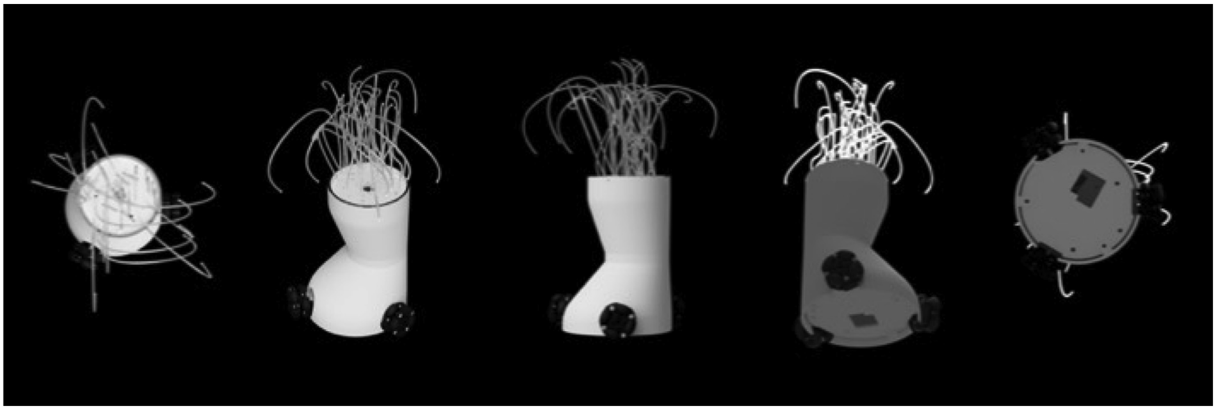

Fig. 1. Perspective views of YOLO from left to right: top, top-side, side, bottom-side, and bottom.

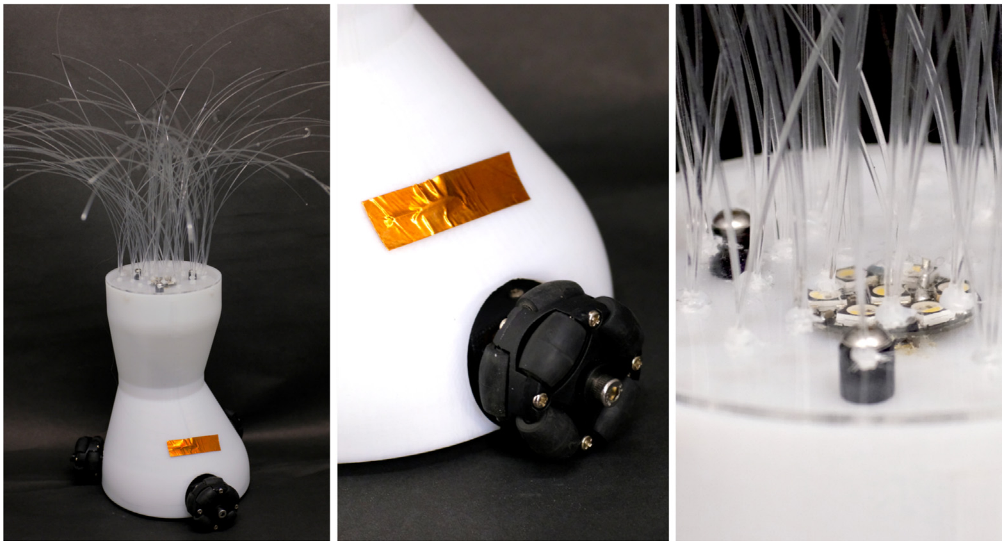

Fig. 2. Detailed views on YOLO robot.

2.2. Child-robot interaction

Our work focuses on playful robotic technology dedicated to children. A wide range of research about technologies for children, especially social robots, has been developed, with associated benefits for education [9] and social play [79,18]. When robots are skillfully used by the teachers and aligned with the students' educational needs [11], such benefits include positive achievements, as an increase in motivation for learning and improvement in collaborative learning [76]. Another major benefit concerns the support of multiple paces and learning styles through play [80], specifically when robots are applied to foster creative thinking and creative expression [63]. The combination of play and learning denotes the potential of robots in making scientific domains of knowledge – such as maths and geometry – approachable for children [64]. This notion aligns with the culture of Digital Manipulatives, for which computers and robots are used as tools to learn about a variety of school topics. Successful examples of social robots that engage children and increase learning acquisitions are the LOGO Turtle [56,57], Curlybot [28], KIBO [25], and Shybo [42]. These novel learning formats have been supported by emerging theoretical frameworks, such as the Digital Play Framework, that intend to guide future design directions about technological objects for children [13].

Social robots bring new opportunities for designers to rethink areas of change concerned with how children relate, learn, and play [1]. However, most robots developed for children are off-the-shelf robotic platforms (such as SoftBank Robotics' NAO and Pepper, or MyKeepon by BeatBots), oftentimes constrained in their expressiveness given the task at hand. In our work, we have designed and fabricated a social robot including children at all design stages [3], to ensure its specificity for creativity stimulation during play.

2.3. Play, create, develop

Creativity is recognized as one of the most sought-after abilities [23]. The economy of developed societies is changing, taking the prospect of a creative economy rather than following with the old industrial economy mindset. The standardized knowledge that before was valued is now being replaced by creative and innovative values [65]. However, in contrast with this change, a decline in creative abilities during the middle childhood years seem to occur, a phenomenon called "creative crisis" [37]. Research has shown that everyone has the potential to be creative, as creativity is a skill that can be developed if nurtured [71]. With our work, we aim to develop a new technological toy to stimulate children's creativity.

According to Piaget's Stages of Development, during middle school age-years, children are in the Concrete Operational Stage, characterized by logic and operational thinking, being able to reason about objects and the relations among them, but having difficulty entertaining hypothetical statements or propositions [58]. Toys are important during the Concrete Operational Stage since the manipulation of objects has the potential to foster children's development and growth [51]. Play is a core activity in children's lives, where objects are manipulated and meanings are explored (e.g., during imaginary play in which a stick can be imagined as a horse) [58,84,51], being the leading source of growth [84] and learning [38,47]. Playful activities are a way to stimulate creativity by fostering the development of cognitive and affective processes [67] that enable formal thinkers to structure solutions for complex challenges [52]. In fact, if creativity is stimulated during play in childhood, it has the potential to be developed into mature creativity in adulthood [6,68]. Pretend play, in particular, is associated with divergent thinking, a major indicator of creativity [73].

2.4. Robot design

YOLO was designed using formative research and feasibility studies. Formative research consists of an exploratory research methodology whose goal is to guide a design process, allowing ongoing intermediate assessments [29]. By identifying and solving concrete usability problems throughout the entire process design, current systems can be improved or new ones are developed [81,82]. Feasibility studies consist of are pieces of research performed before the main study, used to estimate crucial parameters that are needed to design the main study [4]. These intermediary studies which will help to prepare for full-scale and large research intervention, allowing for low-cost improvements before experimentally testing the effectiveness of an interventions or product [14]. Additionally, we followed the Double-Diamond Design Process Model to design YOLO, an established theory in the field of design research [21,53].

Contextual design was used by involving children at different design stages of the robot [3]. The importance of contextual design lies in the fact that it validates the already embodied system where the robot will exist in, capturing the child's world as the floor for design decisions [32,31]. Data gathered during fieldwork was the base criterion for deciding what needs to be addressed, what the robot should do, and how it should be structured within the reality of children [12]. Additionally, we took into account the Big Five Model of Personality to inform the design of the social behaviors for the robot [20]. Finally, the robot was aimed to stimulate creativity during play. Therefore, the creativity-stimulating behavior of YOLO was based on two established creativity techniques for idea generation, an important stage in story creation. These techniques are called "contrast" and "mirror" [74]. While the Contrast technique stimulates divergent thinking, the Mirror technique is responsible for the development of convergent thinking. Both modes of thinking are required to establish the emergence of creativity [41]. Therefore, YOLO's behavior is not only loaded with social behaviors (derived from personality theories) but also with behaviors that can lead to creativity stimulation in children.

3. Interaction elements

To sustain playful and creative interactions with children, YOLO makes use of implicit interaction modalities, such as movements and lights, to communicate with children [35]. YOLO's interactive elements are described below.

3.1. Lights and movement as interaction modalities

Lights and movement were chosen as the main interaction modalities between the robot and children as this combination was recognized as one of the most efficient nonverbal multi-modal communication for non-anthropomorphic robots [40]. YOLO interacts with children by making use of lights that display different colors creating different emotional expressions by using different scales of brightness levels that create a so-called "blinking behavior". For example, when the robot exhibits an introvert personality, it would use less light-blinking behaviors with smooth transitions between them; when exhibiting an extrovert personality the light-blinking behavior would happen with more frequency and at faster speeds of transition. Additionally, movement is used for interaction with YOLO performing different navigation patterns at varying speeds. In this sense, the robot senses how children move it (the robot can recognize the manipulation patterns of children while grabbing it), and reacts to these behaviors. For example, if children perform angular movements patterns with the robot (pretending, e.g., that the robot is avoiding obstacles, similarly to what children do when they play with car toys), the robot detects these and can react to them either by imitating them or by doing a different movement. In this case, the robot is reacting to a movement previously performed by children, in what we called a *reactive behavior*. On the other hand, the robot can initiate an autonomous behavior to stimulate new ideas during play time, in what we called *proactive behavior*, which means that the robot, without being previously manipulated by children, can start moving around to call their attention for playing.

3.2. Abstract shape as imagination trigger

YOLO has a minimal abstract body shape as an invitation to children's imagination. Literature states that conceiving states of fantasy in which reality constraints have been dropped serve as a technique to increase idea generation [74]. Therefore, by designing an embodiment that does not resemble previously known objects, YOLO can serve as any character that children wish for their stories, increasing idea generation (which is part of the divergent thinking in creative thought). The abstractness of the robot is envisioned to amplify imagination possibilities for children's stories, inciting them into creating a wide range of story-lines that contribute to their creative thinking.

3.3. Touch for shared control

Children are usually in full control of their toys. However, this is not the case when they interact with autonomous robots, as interactive technology performs actions that are not controllable by children due to their autonomous nature. During an interaction, this can lead to positive effects, such as engagement due to novelty, but can also create frustration and sometimes even fear in children, possibly leading to interaction breakdowns with robots [72]. To address this aspect, YOLO has a shared control option that gives control over the interaction back control to children, similarly to what occurs during interactions with their traditional toys. This was made possible by using capacitive touch sensors in the robot's shell. When children touch the robot, the capacitive touch sensor is activated and the robot refrains from performing any autonomous behavior. During this deactivated time, children can play with it as they do with traditional toys. When children release the robot, which means that the capacitive sensor does not recognize touch, the robot returns to its fully autonomous mode. This shared control enables children to have the control they are used to with their traditional toys at certain levels of the interaction, and at the same time enables the robot to perform autonomously.

4. Technical elements

In this section, we detail YOLO's technical elements related to its hardware design.

4.1. Small-scale and light-weight design

YOLO is a 167 × 120 mm robot with three omni-wheels that enable navigation and manipulation in any direction (see Fig. 3). It was designed to be a small-scale and light-weight robot meant for children's hands' size and easy manipulation. With most robots, the space required by electronic circuits, wires, and power, make small-size and light-weight designs hard to achieve. In fact, most off-the-shelf robots for children are heavy to hold, e.g., the NAO robot weights 5.4 kg. In its final version, YOLO has a weight of approximately 0.5 kg, the equivalent of a basketball, and its half-hourglass shape enables an easy grabbing for children's hand size (see Figs. 2 and 3).

4.2. Child-proof design

YOLO's shell was fabricated using 3D printing material, with options for laser cutting. The robot's interior components (such as screws and standoffs) are made of nylon to avoid shorts between electrical boards. The circuitry and electronic boards were assembled in a compact and robust layered design in order to be safely manipulated by children (see Fig. 4). These materials and assembly processes make YOLO child-proof, accommodating for unrestricted and uncertain manipulations of the robot during play.

4.3. Grab-and-go play

YOLO was designed as a standalone and portable robot for a playful grab-and-go mindset. To enable portability, the robot has a robust internal power system, providing energy to all internal components. Compact power designs for robots are hard to achieve due to the large size of commercially-available batteries, commonly presenting non-ergonomic shapes. In fact, most robots for children are mostly stationary and dependent on power outlets to function, e.g., MyKeepon is a small and light weighted robot for children, however, it is a power outlet dependent robot. YOLO's portability enables free play both indoors and outdoors, not constraining it to pre-determined spaces. This is similar to what happens when children play with their traditional toys.

5. Design files

YOLO can be build using the design files included in Table 1 and represented in Fig. 5. The design files are in STL format and ready to be 3D printed. Some of these files can be converted to a DXF format, adding a laser cutting option for faster and cheaper opportunities to fabricate YOLO. If opting to laser cut some of the components, note that the thickness of the laser

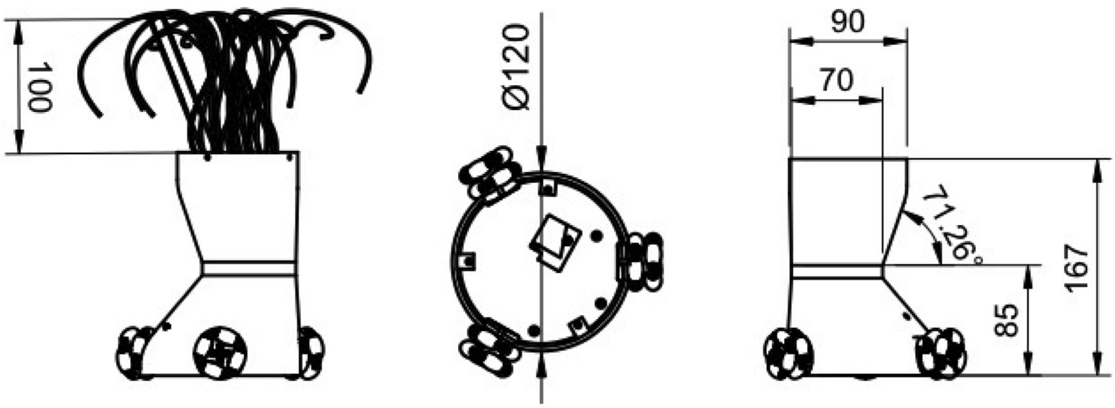

Fig. 3. YOLO's drawing with main dimensions in mm.

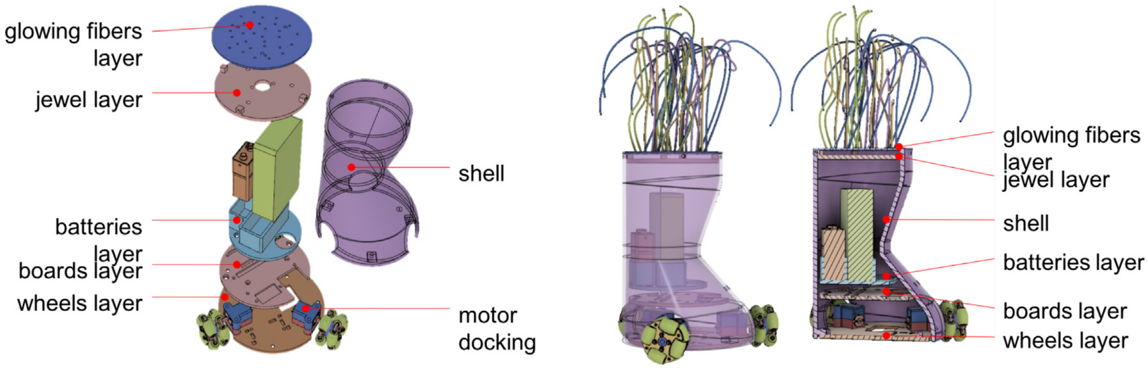

Fig. 4. YOLO's exploded view (on the left) and section analysis with component coloring (on the right).

Table 1
Design files to build YOLO.

Design file name	File type	License	Location of the file
Shell	CAD file in STL format	CC BY 4.0	https://osf.io/xdgf5/
Batteries layer	CAD file in STL format	CC BY 4.0	https://osf.io/3dgyb/
Boards layer	CAD file in STL format	CC BY 4.0	https://osf.io/4gj65/
Wheels layer	CAD file in STL format	CC BY 4.0	https://osf.io/hyb56/
Glowing fibers layer	CAD file in STL format	CC BY 4.0	https://osf.io/bqg4f/
Washer	CAD file in STL format	CC BY 4.0	https://osf.io/5pdwj/
Motor docking (1)	CAD file in STL format	CC BY 4.0	https://osf.io/crz7j/
Motor docking (2)	CAD file in STL format	CC BY 4.0	https://osf.io/eruac/

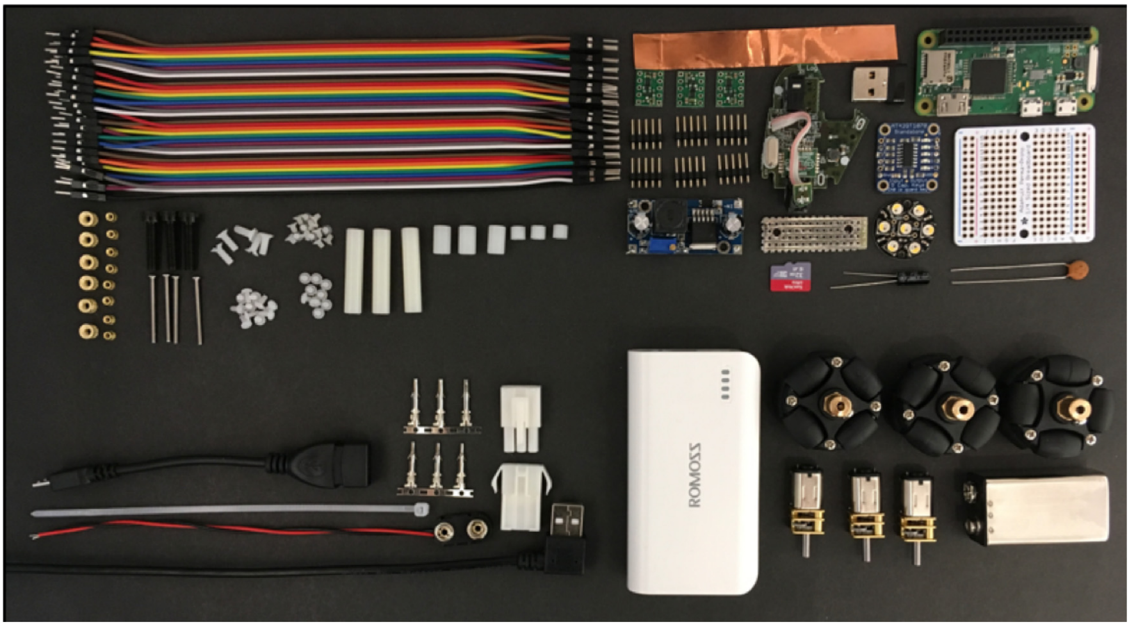

Fig. 5. YOLO parts lineup.

cutting material should correspond to the CAD model dimensions. We suggest choosing a material for the laser cutter work that protects electronic boards, such as acrylic. Below is the summary of the design files presented in Table 1:

- ***Shell*** – File with the cover of the robot. This is the largest 3D printing file and requires a 3D printer capable of operating at large dimensions – at least 120 × 200 × 200 mm of printing capability. Consider a vertical bottom-up position for printing the shell. Support material should be added on the faces of the three tabs. This design file does not present a laser cutting option as it is made of 3D organic shapes not ideal for laser cutting work.

- ***Batteries***, *boards*, and *wheels layers* – These design files are composed of three circular platforms that should be placed on the interior of the shell to hold all the electronic components in place (see Fig. 4). Consider printing the layers horizontally. Support material is needed only on the face of the counter-bore holes of the larger platform. The laser cutting option is valid for this design file.
- ***Jewel layer*** – This file contains the design that serves to nest the LED jewel that will be attached from the top of the shell (see Fig. 4). Consider printing the LED nest horizontally with support material. This file does not support a laser cutting option due to its 3D design requirement.
- ***Glowing fibers layer*** – This design file contains the plate where the optical fibers should be glued (see Fig. 4). Consider printing the LED nest horizontally with support material. The laser cutting option is valid for this design file.
- ***Washer*** – Washers should be placed between the "Jewel layer" and the "glowing fibers layer" to secure this connection (see Fig. 4). YOLO uses three washers to support this connection, so consider printing 3 parts. The laser cutting option is valid for this design file.
- ***Motor docking (1) and (2)*** – Composed of two files that together provide docking for the motors. Support material is not needed for 3D printing. The laser cutting option is valid for "Motor docking (2)".

6. Bill of materials

The total estimated expenses for building YOLO is of approximately $200. Although this cost might strike as expensive for a home-made robot, the total estimate price includes purchases of items that come in large packs, such as battery clips and wire zip ties, or that come with extra material quantities, as wires and screws. A concrete example is the battery clips that come in packs of 10, while YOLO requires only 1; wires have an extension of 25ft and YOLO requires short extensions due to its compact design. Therefore, the total estimated price can be reduced if YOLO is built in a laboratory or a maker space that already has some of the tools and materials for building and assembling. A description of the total bill of materials is presented in Tables 2–5.

7. Assembly

Instructions for the robot's assembly are provided below.

7.1. Assembly preparation

The assembly requires the following tools: hacksaw, utility knife, screwdriver set, calipers, scissors, soldering kit (including solder spool, soldering station, wire stripper, diagonal cutters, solder wick for solder removal, soldering vise with a magnifying glass, and a panavise), and glue. 3D print and laser cut the required materials in Table 2 and have ready the components in Tables 3–5 and Fig. 5. Before assembly, configure the voltage transformer with an input of 5.0 V and step down the buck converter output for 1.5 V. Additionally, follow the steps described below:

1. **Hack mouse sensor**
   (a) Hack a mouse sensor that will serve as in-built system for motion detection of the robot.

Table 2
Bill of electronic components of YOLO.

#x270E;	Designator	Component	Quantity	Cost per unit in USD	Total cost in USD	Supplier
1	Raspberry Pi	Raspberry-pi w zero	1	10.00	10.00	Adafruit
2	Touch sensor	Standalone 5-pad capacitive touch sensor breakout AT42QT1070	1	7.50	7.50	Adafruit
3	Jewel	NeoPixel jewel 7 × 5050 RGBW LED w/ integrated drivers natural white ~4500 K	1	6.95	6.95	Adafruit
4	Voltage converter	LM2596 DC-DC buck converter step down module power supply output 1.23 V–30 V	1	14.95	14.95	Amazon
5	Optical sensor	Logitech wireless mouse M170	1	9.00	9.00	Amazon
6	Motor driver	DRV8838 single brushed DC motor driver	3	2.99	8.97	Pololu
7	Motor	Micro metal gearmotor HP 6 V	3	15.95	47.85	Pololu
8	Protoboard	Adafruit perma-proto quarter-sized breadboard PCB	1	2.50	2.50	Adafruit
9	Power distribution board	Universal glass fiber PCB board	1	3.80	3.80	DX
10	Ceramic capacitor	Ceramic capacitor disc 0.047 μF 25 V +80% to −20%	1	0.25	0.25	Jameco Electronics
11	Electrolytic capacitor	10 μF 50 V electrolytic capacitors	1	1.95	1.95	Adafruit

Table 3
Bill of power and connection components of YOLO.

#x270E;	Designator	Component	Quantity	Cost per unit in USD	Total cost in USD	Supplier
12	Wires	Hook-up wire spool set 22AWG solid core 6 × 25 ft	1	15.95	15.95	Adafruit
13	Omni wheels	38 mm by 3 mm omni wheels	3	6.40	19.20	Aliexpress
14	Power bank	USB battery pack 4000 mAh, 5 V, 1A	1	24.95	24.95	Adafruit
15	9 V battery	EBL advanced 9 V 1200 mAh lithium batteries	1	5.50	5.50	Amazon
16	SD card	SanDisk ultra 32 GB micro SDHC UHS-I card with adapter	1	12.96	12.96	Amazon
17	Router	TP-Link N300 wireless wi-fi router 2 × 5dBi high power antennas up rightarrow 300Mbps	1	19.99	19.99	Amazon
18	Glowing fibers	CHINLY roll PMMA plastic	1	8.44	8.44	Amazon
19	Copper tape	Copper foil tape with conductive adhesive	1	5.95	5.95	Adafruit
20	Battery clip	Cable connection 9 V plastic battery clip connector buckle	1	0.40	0.40	Amazon
21	Female USB to micro USB	USB A female to micro USB B 5 pin male adapter cable	1	2.50	2.50	Amazon
22	Micro USB	Micro USB plug rightarrow 5.5/2.1 mm DC barrel jack adapter	1	1.95	1.95	Adafruit
23	90° USB	USB to right angle mini USB with 90°	1	6.99	6.99	Amazon

Table 4
Bill of fasteners for YOLO.

#x270E;	Designator	Component	Quantity	Cost per unit in USD	Total cost in USD	Supplier
24	M2 brass inserts	Heat-set inserts for plastics; M2 × 0.4 mm thread; 2.9 mm length	28	0.10	10.44	McMaster
25	M3 brass inserts	Heat-set inserts for plastics; M3 × 0.5 mm thread; 3.8 mm length	3	0.12	12.30	McMaster
26	Hex standoff	Nylon 6/6 plastic hex standoff 3/16″; 3/16″ long; 2–56 female thread	2	1.47	2.94	McMaster
27	Small round standoff	Nylon 6/6 female threaded round standoff 1/4″ OD; 13/32″ length; 4–40 thread	2	1.40	2.80	McMaster
28	Big round standoff	Nylon 6/6 female threaded round standoff1/4″ OD; 1–1/4″ length; 4 – 40 thread	3	2.00	6.00	McMaster
29	M2 pan head screw	Nylon pan head phillips screws M2 × 0.40 mm thread 5 mm	18	0.90	4.98	McMaster
30	M3 pan head screw	Nylon pan head phillips screws M3 × 0.50 mm thread 16 mm	3	0.23	7.82	McMaster
31	Long screw	Passivated 18–8 stainless steel pan head phillips screw 1–72 thread 1″ long	6	1.33	11.09	McMaster
32	Socket head screw	Black-oxide alloy steel socket head screw M4 × 0.7 mm thread 18 mm long	3	0.34	11.31	McMaster
33	Small flat head screw	Nylon slotted flat head screws; 100° countersink; 2–56 thread; 1/8″ long	4	0.25	6.13	McMaster
34	Big flat head screw	Nylon slotted flat head screws 100° countersink; 4–40 thread; 5/16″ long	13	0.73	5.59	McMaster

Table 5
Bill of structural components of YOLO.

#x270E;	Designator	Component	Quantity	Cost per unit in USD	Total cost in USD	Supplier
35	Shell	3D printed design in PLA	1	19.28	19.28	FF3DM
36	Circular layers	3D printed design in PLA	1	68.44	68.44	FF3DM
37	Motor docking	3D printed design in PLA	6	2.00	12.00	FF3DM
38	Washer	3D printed design in PLA	3	1.00	3.00	FF3DM
39	Glowing fibers layer	Laser cut design in clear acrylic with 1.50 mm of material thickness	1	13.54	13.54	Sculteo

(b) Tutorial video on how to hack a mouse:https://youtu.be/Jz-cXqAwu4o

2. **Place brass inserts**
   (a) Place the brass inserts in the dedicated places using a soldering iron (Fig. 7, steps 1–3).
   (b) Tutorial video on heating brass inserts:https://youtu.be/HB2Q_Wywl1s
3. **Cut circboard**
   (a) Cut a circboard and drill two 2.10 clearance holes for attachment.

Fig. 6. Close-ups on YOLO's inside.

   (b) Tutorial video for cutting a circboard: https://youtu.be/ummbqeoAhJY
4. **Cut glowing fibers**
   (a) Cut the glowing fibers and attach them to the glowing fibers layer by using a hot glue gun or other effective glue. The length of the glowing fibers size can be selected by personal preference. We used lengths between 140 and 170 mm.
   (b) Tutorial video on cutting glowing fibers:https://youtu.be/7TzWtuXsoN8

When these steps are finalized, start the assembly flow of YOLO described in Section 7.2.

7.2. Assembly flow

A step-by-step assembly flow with an action Diagram [2] is present in Fig. 7. Follow each step and complement the assembly flow with the wiring instructions on Fig. 8. An exploded view of YOLO that supports the understanding of the final robot configuration is present in Fig. 4, with close-up views on Fig. 6. When the robot is fully assembled, attach a batch of copper tape to the shell of the robot to connect the wire that comes from the capacitive touch sensor. This will enable the robot to respond to touch.

7.3. Assembly safeguards

Assembling YOLO is a process that involves interacting with mechanical tools and machinery for which safety guards are required. To the best of our knowledge, no safety guidelines for personal fabrication have been formally established, and misuses have been considered users' responsibility [49]. As such, we strongly advise YOLO makers to follow our recommended safeguards.

It is advisable to assemble the robot under expert adult supervision at all times. Additionally, assembling this robot requires knowledge over some mechanical engineering procedures, such as soldering. We recommend a tutorial about soldering by Mitch Altman, Andie Nordgren, and Jeff Keyzer, "Soldering is Easy". We advise to train the art of soldering using a training board, and only after mastering this art, start soldering YOLO. The physical presence of an expert person during soldering, wiring, and 3D printing or laser cutting is recommended.

8. Operation instructions

To operate YOLO, consider the schematics present in 9. YOLO can display different social behaviors. Therefore, it can be used as a creativity-stimulating robot for children's playtime (for this, consider downloading an available version of the software with pre-sets that we have developed available at this link. In this case, YOLO will be interacting with children in a playful way, while seeking to stimulate their creativity. Another way is to develop a software to operate YOLO. This can be performed by any person with some knowledge of programming. In this case, YOLO's software can be developed and personalized according to the needs and goals of the developers. To develop software for YOLO consider a Python script-based language and Raspberry-Pi's specifications and the API created and available at this link : https://github.com/patricialvesoliveira/YOLO-Software.

To start operating YOLO, combine the materials required to initialize the robot present in Table 6 with the operating instructions in Fig. 9. It is important to note that the performance of the robot is dependent on battery life, router range, and strong wiring connections. Regarding the battery, the average life is between 5 and 7 h. This average can fluctuate depending on the playing behavior of children, i.e., if children interact more with YOLO, the battery life will decrease as

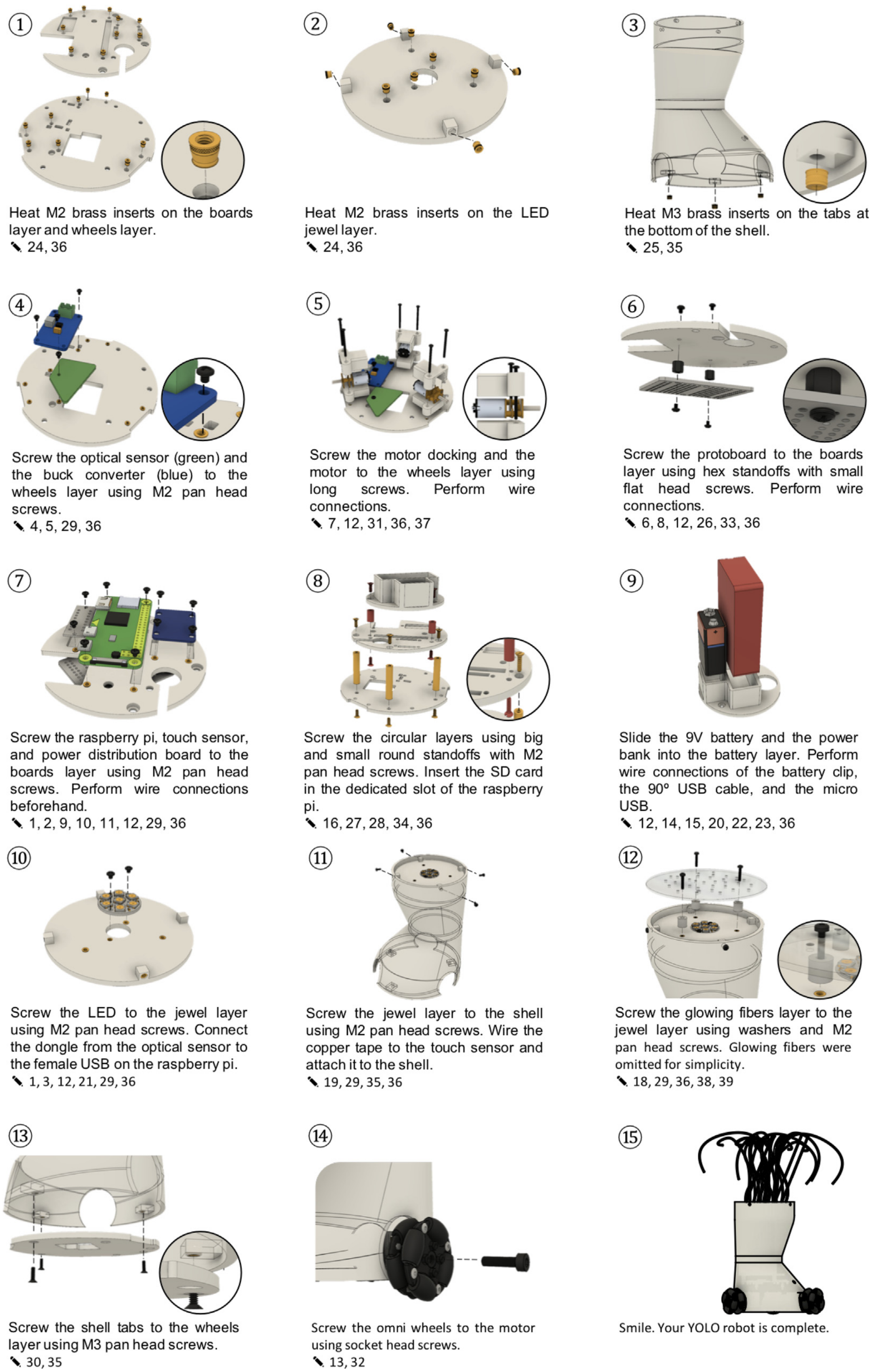

Fig. 7. YOLO's assembly flow. Numbering accompanied by the symbol #x270E; correspond to materials on Tables 2–5.

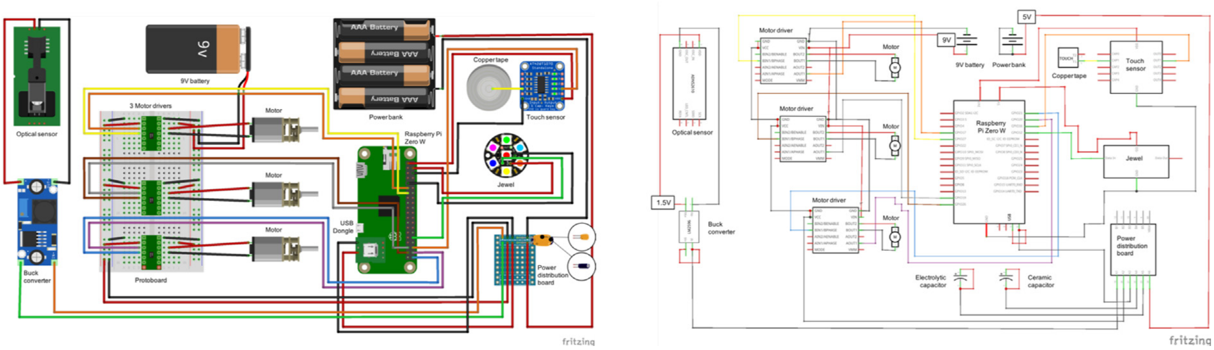

Fig. 8. Wiring schematics of YOLO with visual components (on the left) and circuit schema (on the right).

the robot is prompt to perform more behaviors. If one or more omni-wheels start to not move, substitute the 9 V battery, as there might be a power shortage. For full performance, YOLO's batteries need to be properly charged. Therefore, if the robot is non-responsive, recharge the power bank and try again when it is full. If YOLO continues non-responsive, check the wiring connections as they might need extra soldering as the unrestricted movements during children's play can weaken the connections. As the router range is wide, children can play with YOLO both indoors and outdoors. If YOLO starts being non-responsive, consider a smaller distance between the robot and the router.

Operation safeguards

YOLO is a robot made for children. Due to its target group and playful application nature, there are no major hazards when operating and playing with it. However, like any other technological toy, children should be supervised by an adult at all times. Additionally, a responsible adult should be in charge of initializing YOLO.

9. Validation and characterization

The field of HRI is characterized by multidisciplinarity, for which the open access to research tools, such as robots' hardware and software, is crucial [34]. YOLO presents as a low-purchase and low-maintenance cost robot, that can be used as a tool for research studies with children. The open source hardware of YOLO thus provides opportunities for researchers with and without engineering background to build this robot and further use it targeting their own research goals, without depending upon complex robotic platforms. To demonstrate how this robot can be applied to academia, researchers can use it as a platform to explore the design of behaviors for a robot aimed at interacting with children. Another example is the usage of this robot by the social and cognitive sciences field as a controllable and programmable tool, to study the developmental aspects of children when interacting with robots. Predominantly, the scientific community relies on the usage of off-the-shelf robots as their research platforms when performing studies. Nonetheless, off-the-shelf robotics platforms are generally expensive (with purchase prices ranging from $5.000 to $20.000, or more) and associated with high maintenance costs. In addition, the majority of these robots require special transportation services to be used during field studies, due to their robust size and heavyweight, placing additional costs for academic laboratories. YOLO offers a less expensive yet interesting solution for research.

In the scope of this work, we have used YOLO as a research tool for STEAM activities aimed at promoting robotics knowledge among young children and adults. We have conducted two use-cases with YOLO in the scope of this work. In the first use-case, we performed live demos of YOLO with the robot operating autonomously at the Sciencenter, a science museum for children in Ithaca, NY, USA. During the time YOLO was in the museum, children approached the robot and were invited by the principal researcher to create stories with the robot. Children created short stories alone, together with other children, or with the help of their parents. To help guide the process of story creation, we provided the first story-line in which the robot "was asleep and dreaming" and asked children to tell the story of the robot's dream. Therefore, when children interacted with it, they started creating story-lines, such as "the robot is dreaming that it goes to school". These narrations would change according to the robot's behavior and to the will of children. The second use-case was to present YOLO at the RAW Exhibition organized by the Medium Design Collective, to showcase the process of creation of different technologies

Table 6
Materials and their usages required to initialize YOLO.

Material	Usage
YOLO robot	Artifact that will be operated.
Router	To connect the Raspberry Pi and to the software program via wi-fi.
Computer/laptop	To initialize YOLO's software program.

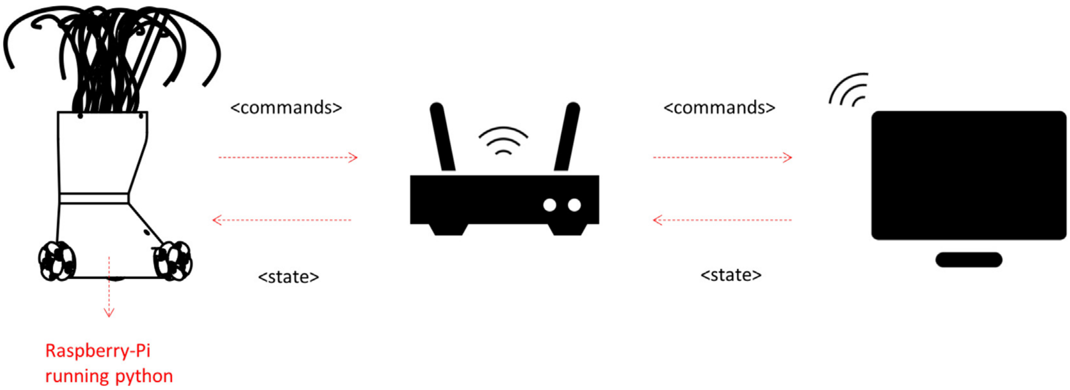

Fig. 9. Operating instructions for YOLO.

Fig. 10. YOLO exhibited in STEAM activities for children (on the left) and adults (on the right).

and art installations. In this case, we demonstrated the design process of this robot, from prototype to its final shape and behaviors. This enabled adults to engage in conversations about the robot's working and the design decisions made during its fabrication process. During these activities, YOLO interacted with more than 50 children and a hundred adults (see Fig. 10).

10. Conclusion

Open-access and open-source tools provide opportunities for lay people to engage in personal fabrication where knowledge is shared while building a robot or other technological device [78,66,46]. In this work, we provided a guide for building a social robot called YOLO, aimed at being a toy for children's playtimes. The open-access initiative is aligned with the strategic plan for the Open Educational Movement, whose goal is to provide equal access to knowledge and educational opportunities across the world, increasing the educational resources for children [5].

During the process of building YOLO concepts related to mechanical engineering such as soldering, performing wire connections, etc are learned. The acquired knowledge can be applied to other curricular domains, making YOLO an object to think-and-learn-with [56]. Additionally, the hands-on experience of building YOLO trains children's dexterity, an important ability acquired through physical play. YOLO can be used in a wide range of application contexts, such as in school and at home.

Declaration of interest

None.

Human rights

The work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; informed consent was obtained for experimentation with human subjects. The privacy rights of human subjects were always considered.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ohx.2019.e00074.

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Original software publication

Software architecture for YOLO, a creativity-stimulating robot

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ABSTRACT

YOLO is a social robot designed and developed to stimulate creativity in children through storytelling activities. Children use it as a character in their stories. This article details the artificial intelligence software developed for YOLO. The implemented software schedules through several Creativity Behaviors to find the ones that stimulate creativity more effectively. YOLO can choose between convergent and divergent thinking techniques, two important processes of creative thought. These techniques were developed based on the psychological theories of creativity development and on research from creativity experts who work with children. Besides promoting creativity, this software allows the creation of Social Behaviors that enable the robot to behave as a believable character. We built 3 main social behavior parameters: Exuberant, Aloof, and Harmonious. These behaviors are meant to ease immersive play and the process of character creation. The 3 social behaviors were based on psychological theories of personality and developed using children's input during co-design studies. Overall, this work presents the design, development, and usage of social robots that might nurture intrinsic human abilities, such as the ability to be creative.

Code metadata

Current code version	v0.4
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX_2019_242
Legal Code License	CC Attribution 4.0 International
Code versioning system used	git
Software code languages, tools, and services used	Python
Compilation requirements, operating environments & dependencies	Raspbian Stretch Lite OS
If available Link to developer documentation/manual	https://github.com/patricialvesoliveira/YOLO-Software/wiki
Support email for questions	Samuel Gomes: samuel.gomes@tecnico.ulisboa.pt and Patrícia Alves-Oliveira: patricia_alves_oliveira@iscte-iul.pt

Software metadata

Current software version	v0.4
Permanent link to executables of this version	https://github.com/patricialvesoliveira/YOLO-Software
Legal Software License	CC Attribution 4.0 International
Computing platform / Operating System	Linux (Raspbian Stretch Lite OS)
Installation requirements & dependencies	Raspbian Stretch Lite OS
If available link to user manual	https://github.com/patricialvesoliveira/YOLO-Software/wiki
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Fig. 1. YOLO, a social robot that can boost creativity in children.

1. Introduction

Creativity is one of the most sought-after skills, with recognized benefits in education, mental health, and professional success [1,2]. It is associated with states of joy, play, efficiency, and pleasure [3,4]. When stimulated in childhood, it promotes overall development with specific benefits in learning and adaptation. [5]. Creativity has been stimulated through the use of different intervention programs with promising effectiveness levels, demonstrating the potential to develop creativity with proper training [6,7]. However, most of these interventions developed for children lack elements of joy and fun. Instead, they are considered similar to test-like exercises that can hinder their creative expression. The fast pace of technology development enabled the design of new tools for exploring the context of creativity stimulation [8] (e.g., the CUBUS virtual environment for storytelling with emotionally evocative characters [9]).

In our work, we aim to expand the range of technologies used for creativity stimulation by incorporating social robots to catalyze this ability. With this in mind, we designed and developed YOLO (Your Own Living Object), an original social robot to be used as a toy during children's play times (see Fig. 1). YOLO belongs to a new generation of technological toys meant to stimulate creative abilities in children. This robot is envisioned as a character children use during storytelling. By having a small-size and a light-weight design, YOLO can be manipulated by children as if it was a traditional toy (similarly to what they do with dolls or toy cars). The added-value of this robot is that it can increase the creative thought process of children during story creation by providing novel ideas for storylines. Because YOLO is a non-anthropomorphic robot, it interacts with children using alternative but effective interactive modalities. These comprise variable motion and illumination profiles. In this paper, we detail the software behind YOLO. The software is composed of Creativity and Social Behaviors whose design was grounded on creativity research [10], the Big Five personality model [11], and co-design sessions with children [12]. We release the robot's software[1] along with its installation guide[2] in open access. This software should be exclusively installed on YOLO hardware [13].

2. Background and problems

2.1. Creativity research

As societies develop into creativity-based economies, innovative and creative problem solving and the ability to collaborate are becoming must-have skills [1,14]. However, around the age of 7–9 years old there is a decline in children's creativity abilities known as the "creative crisis" [15]. Research has shown that everyone has the potential to be creative and that creativity can be nurtured if stimulated [16,17]. In our work, we aim to contribute to the increase in children's creativity by using a social robot. It therefore becomes imperative to stimulate this ability at a young age. In particular, emphasizing the school environment where children spend most of their time. While some schools already feature activities (e.g., storytelling) to support the promotion of children's creative thinking [18], current activities can be challenging to integrate into traditional classroom formats as they need preparation time and are not formally included in the school curriculum [19]. Technologies – such as social robots – appear as a more effective tool to apply in these contexts.

2.2. Robots for creativity

Robots have been programmed with a deep variety of socially intelligent behaviors and affective states; thus, allowing them to be perceived as social actors [20,21]. Additionally, due to their physical and interactive nature, they become a technology that can uniquely impact creativity stimulation. Ali, Moroso, and Breazel [22] demonstrated that a robot displaying creative behaviors positively influenced the creativity of children. The authors found that children who interacted with a creative robot generated more ideas, explored more themes, and were more original, than children who interacted with a non-creative robot [22]. Additionally, Gordon et al. [23] demonstrated that children become more curious, an important creativity trait, when interacting with a curious robot. The authors found that these children posed more questions and become avid explores, compared to children who interacted with a non-curious robot [23].

3. Software framework

3.1. Software architecture

The architecture of our software includes several modules that manipulate data at different levels of abstraction from the low-level sensors and actuators to high-level behaviors. Fig. 2 shows the scheme of these modules and how they interact. Each module is explained in the next sections.

3.2. Control

This module has two main functions: first, it extracts data associated with the robots' sensors and translates into a programmable format. Second, it instructs the actuators what to do based on the software calls.

[1] Download YOLO Software: https://github.com/patricialvesoliveira/YOLO-Software.

[2] Link to YOLO Software installation guide: https://github.com/patricialvesoliveira/YOLO-Software/wiki.

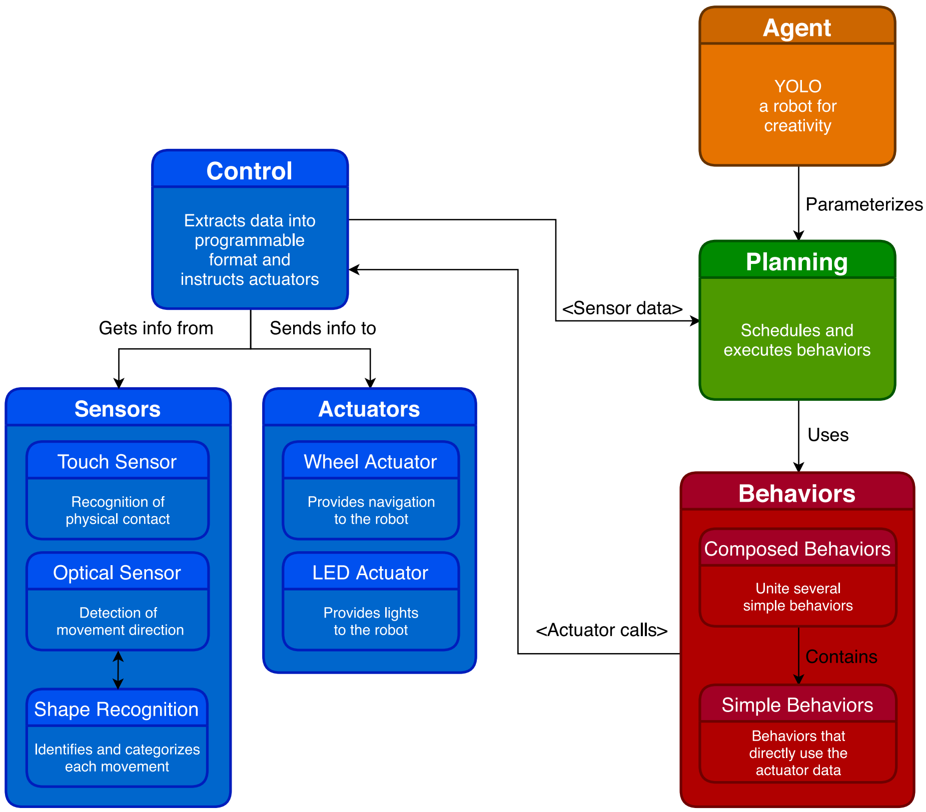

Fig. 2. Architecture of the modules that compose YOLO software.

The *touch sensor* of YOLO indicates to the robot that physical contact was established, and the *optical sensor* observes the differences in position to detect the direction of movement. The sensors are updated at each moment. The *shape recognizer* dynamically identifies and characterizes each movement using Machine Learning (ML). The pre-trained K nearest neighbor (KNN) algorithm determines a shape using the robot motion sensors which capture coordinates in 3 s intervals [24]. Fig. 3 depicts the ML workflow. We trained the model by collecting raw coordinates and converting these coordinates into a feature vector using the convex hull algorithm [25].[3] Every time a movement is detected, KNN is used to determine the closest matching shape from the training data. Simulations with a computer mouse showed us that with $n = 3$, KNN provided high accuracy (94%). Therefore, we used this parameterization. The current ML model was trained with the physical robot and can recognize with an 80% success rate the following shapes: circle, rectangles, loops, curls, spikes, and a straight line (see Fig. 4).

YOLO actuators include the *Wheel Actuator* and *LED Actuator*. While *Wheel Actuator* receives direction and speed values and moves the wheels' motors accordingly, *LED Actuator* receives a color and brightness level and displays it in the robot's LEDs.

3.3. Behaviors

The *Behaviors* module coordinates the simultaneous execution of different actuators based on given parameters. The intended behavior arises from the simultaneous execution of different actuators. To simplify the development process, we divided behaviors into more concrete *Simple Behaviors*, which directly use the actuator data and *Composed Behaviors*, which unite several simple behaviors. *Simple behaviors* directly call the *Control* module. These behaviors consist of assigning different light behaviors (different colors, animations, and brightness) to different movement configurations (different movement patterns at varying speed).[4] *Composed behaviors* can be used to define the social behaviors which YOLO exhibits, such as Exuberant, Aloof, and Harmonious.[5]

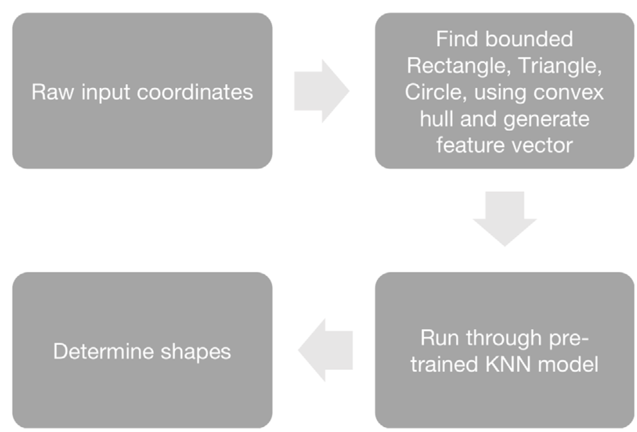

Fig. 3. Workflow of the ML algorithm for shape recognition used by YOLO.

[3] More details about our shape recognizer algorithm are present at this link: https://github.com/patricialvesoliveira/YOLO-Software/wiki/Algorithm.

[4] Examples of simple behaviors are included with the software documentation: https://github.com/patricialvesoliveira/YOLO-Software/wiki/SimpleBehavior-Hierarchy.

[5] Composed behaviors are further explained at the software documentation: https://github.com/patricialvesoliveira/YOLO-Software/wiki/ComposedBehavior.

Table 1
Software functionalities considering the sensors used, the input collected, the actuators in place, and the output provided.

Sensor	Input	Actuator	Output
Touch sensor	Ability to recognize when the robot is being touched.	LED lights	The robot displays white lights while being touched, refrains from performing any behavior. When not sensing touch, the robot displays colors associated with its different social behaviors.
Optical sensor	Recognition of the direction of the play patterns of children while manipulating the robot.	Omni wheels	Imitating the collected movement patterns.
Time	Stage of the storytelling that children are currently engaged in.	Omni wheels and LED lights	The robot performs a creativity technique according to the storytelling arc.

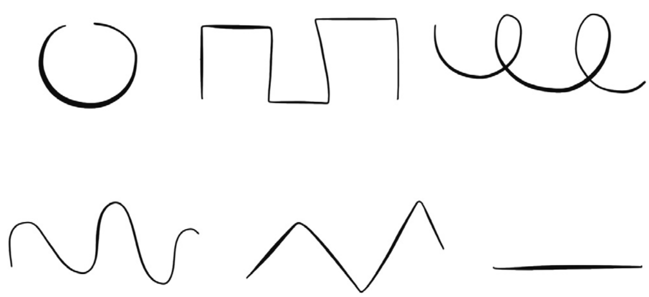

Fig. 4. The lines illustrate the movement shapes performed by YOLO that are recognized by our algorithm. Illustrated shapes are: circle, rects, loops, curls, spikes, and straight line.

3.4. Planning

The *Planning* module schedules the behaviors in each moment of the interaction, executing specific ones based on the current interaction state. In order to trigger new interaction states, *Planning* module uses the data extracted from the sensors which the *Control* module provides. A flowchart illustrating the schedule provided by the *Planning* module is depicted in Fig. 5.

4. Software functionalities

A primary function of this software is to serve as an Application Programming Interface (API) that enables any user the opportunity to design personalized behaviors for YOLO, consequently providing the possibility to generate new behaviors and interaction modes.[6] The robot can receive information from the environment (input) and express different interactive behaviors (output). Table 1 lists pre-sets that were developed for YOLO to act as a social robot that can stimulate creativity in children.

Since each aspect of the robot is controllable and parameterizable, behaviors can be tweaked, created and mixed. To demonstrate the API functionality, we conducted testing sessions in which we asked two participants unfamiliar with YOLO software to create different behaviors for the robot. One of the participants had a background in Computer Science and the other in Psychology. The participants were instructed to choose beloved characters from animation movies and to create a behavior for the robot that would resemble the behavior of those characters. The examples created by the participants were Mickey, Barbie, Bugs Bunny, and Genie from Aladdin.[7]

4.1. Implementation

In our work, we developed a software that gives life to the social robot YOLO, whose interaction is meant to display Creativity and Social Behaviors.

4.2. Creativity behavior

In our specific application scenario, YOLO acts as a character that can trigger new directions in children's stories that otherwise would not emerge. During story creation, a combination of divergent (i.e., broad gathering of multiple ideas) and convergent thinking (i.e., narrowing down possibilities to create a coherent story plot) is required [26–28]. We have chosen two techniques that are often used to stimulate creativity, named "mirroring" and "contrasting" [10] (see Fig. 6)[8]:

- **Contrasting —** This technique is used to stimulate divergent thinking [29]. In the Contrast technique, YOLO provides stimuli unrelated to the storyline that children are exploring at the moment, producing an opportunity to explore new directions in the plot. This leads to heightened action and interesting plot twists in the stories of children.
- **Mirroring —** This technique is used to stimulate convergent thinking [30]. When using the Mirror technique, YOLO provides stimuli that are connected with the storyline that children are exploring, leading to the elaboration and convergence of story ideas. This leads to the emergence of interesting details about a character, a scenario, or an action in the story.

4.3. Storytelling arc

Successful and satisfying stories follow a storytelling arc [31,32]. According to the Theory of Dramatic Structure, each story has five acts: exposition, raising action, climax, falling action, and dénouement [31,32]. These five acts can be modified and adapted to the dramatic structure of short stories, fables, or fairy-tales. In our software, we considered a short-story format similar to what is used in children's stories [33]. Therefore, we divide the narrative of a story in the following phases:

- **Rising action —** Characters are introduced, a context is given to the story, and the story builds. During this stage, YOLO stimulates convergent thinking by using the mirror creativity technique (see Section 4.2);
- **Climax —** The story reaches the point of greatest tension. During this stage, YOLO stimulates divergent thinking by applying the contrast creativity technique (see Section 4.2);

[6] A guide the API is provided with the software documentation: https://github.com/patricialvesoliveira/YOLO-Software/wiki/API-Documentation.

[7] Examples created by the participants using the API: https://github.com/patricialvesoliveira/YOLO-Software/wiki/Examples.

[8] Parameterization specifications for the creativity behaviors of YOLO can be found here: https://github.com/patricialvesoliveira/YOLO-Software/wiki/CreativityProfile.

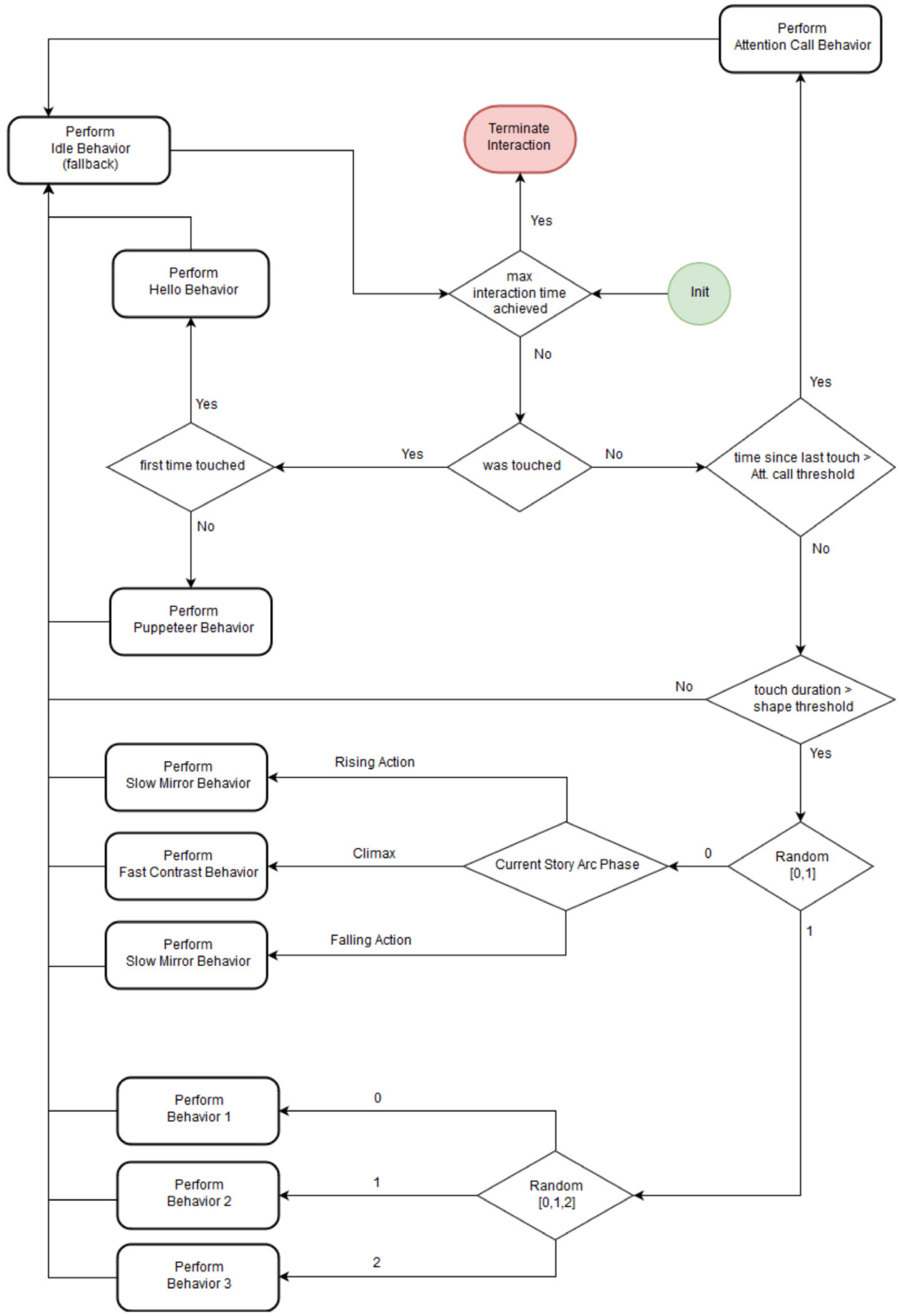

Fig. 5. State machine diagram representing the schedule of the procedures executed in the *Planning* module.

- **Falling action —** The story shifts to an action that happens because of the climax, which means that the conflict is resolved and the story reaches its end. During this stage, YOLO stimulates convergent thinking by using the mirror creativity technique (see Section 4.2).

4.4. Social behavior

YOLO expresses different social profiles to exhibit social behaviors. The profiles are named *Exuberant*, *Aloof*, and *Harmonious*.[9] These social behaviors appear as pre-sets when YOLO is turned on and can be used interchangeably, making the robot a flexible character in the children's stories. The three different social modes for YOLO are explained below:

- **Exuberant —** YOLO reacts to every social interaction in an "enthusiastic" manner. Movements are fast and have a high amplitude. It displays vibrant purple and red colors with high brightness levels. As Exuberant, YOLO is proactive and seeks out social interaction. This is a vibrant, frenetic, and daring social profile;
- **Aloof —** YOLO is less "socially reactive" and is a "shy robot". In this mode, the robot exhibits low amplitude, slow movements and displays cold colors such as green and blue with low brightness levels. As Aloof, YOLO is not proactive; does

[9] Parameterization specifications for all the social behaviors of YOLO can be found here: https://github.com/patricialvesoliveira/YOLO-Software/wiki/SocialProfile.

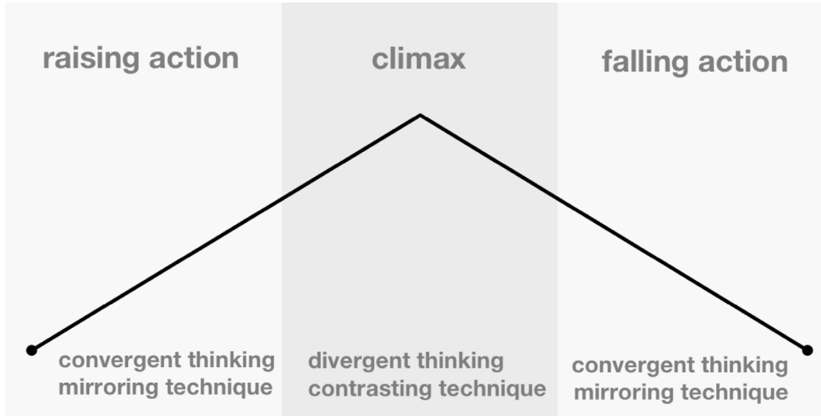

Fig. 6. Storytelling arcs associated with creativity techniques: convergent thinking is stimulated during rising and falling action phases by using the mirror technique; divergent thinking is stimulated during climax by using the contrast technique.

not seek interactions. This profile could also be described as loner, contemplative, or reclusive;

- **Harmonious —** YOLO acts in a moderated fashion, presenting behaviors that are in-between the extreme versions of Exuberant and Aloof. As Harmonious, YOLO exhibits medium speed, movements with medium amplitude, and displays warm colors such as yellow and orange at medium brightness levels. This is a balanced and moderate profile.

4.5. Child–robot interaction design

Children use YOLO as a character in their stories, moving it around while creating story-lines. The robot, being an active character, provides ideas for new narratives. It does so by using two techniques aimed at stimulating divergent and convergent thinking, ''Mirroring'' and ''Contrasting'', respectively. The robot decides which technique to use according to the story arc in which children are involved (see Fig. 6). Each story arc is associated with fixed timing, e.g., Raising Action starts at time 0 and goes until time 5. The timings were defined given knowledge collected from previous studies where children created stories with the same robot with the purpose of establishing a mean time for each story arc. Additionally, YOLO can be puppeteered by children mimicking a traditional toy. The puppeteer mode is activated when YOLO detects children's physical contact. Therefore, while children are physically touching the robot, i.e., playing, the robot refrains from performing any movement. This mode enables children to be in full control of YOLO, thus, maintaining traditional play formats.

5. Illustrative example

To validate the effectiveness of our software, we have tested it with children in a storytelling activity. The instruction provided information that they should use the robot as a character for the story they created. In the box below, we transcribed part of an interaction case during a study session between a child and YOLO (see complementary Fig. 7). In this example, it is visible how the robot makes use of its interaction profiles to stimulate convergent and divergent thinking and how this relates to the different stages of the storytelling.

The child is on the floor playing with YOLO.
Child: *"This is a football field and YOLO is from the Juventus team, so we are going to win!"*
The child manipulates YOLO in the imaginary football field, imitating the robot running after an imaginary ball and deviating from imaginary team adversaries. Because YOLO is still in the first part of the storytelling arc, i.e., in the Raising Action stage, the robot will stimulate convergent thinking abilities. Therefore, the robot imitates the last movement that the child performed. The child looks at the robot while it is moving.
Child: *"Yes! Go for it, Ronaldo, score!* (Ronaldo is the name of a Portuguese football player).
The child imitates scoring a goal and then grabs YOLO and celebrates.
Child: *"Ok Ronaldo, but we have to continue doing well. These other guys are good too.*
The child continues manipulating YOLO through the adversaries. At this point in time, YOLO entered the next storytelling arc which is the Climax. During climax, divergent thinking is stimulated so the robot will perform a movement that is different from the last movement that the child has performed. The child manipulates the robot straight ahead towards the soccer goal but the robot goes the opposite direction.
Child: *"What happened? Oh no, the other guys hit you in the knee. Assistance is needed here!"*
The game continues.

6. Conclusions and impact

As societies develop increasingly higher levels of sophistication, social robots can play a crucial role in the development of human creativity. Related research has indicated that social robots impact the play behaviors in children, pulling them towards traditional play formats such as physical, unstructured, and unrestrained play, benefiting multiple aspects of growth [34].

In this article, we presented the software which allows the YOLO robot to encourage creativity stimulation. This software allows potential developers to create behaviors that make the robot act according to different social behaviors. We also described several tests applying our software in real-world scenarios. These tests revealed the potential of our program, as robots using our software provoke creative narratives in stories which the children created.

Fig. 7. Use-case example of a child using YOLO as a character for the creativity-stimulating storytelling scenario.

The impact of this software is broad. By being an easy-to-use tool, stakeholders such as educators and parents have access to a robot that is easy to prepare (e.g., for Science, Technology, Engineering, Art, and Mathematics (STEAM)-related activities), contrasting with other existing technological tools that can be cumbersome for non-experts to prepare [19]. Additionally, this software serves as a solid platform in academic studies, where researchers can use YOLO's API to study child–robot interaction.

7. Highlights

- **Creativity stimulating robot:** YOLO can stimulate children's creativity during play;
- **Open-access:** Access to the code and the guide to install and execute the software;
- **Scalability and personalization:** API for developers to create new behaviors for YOLO;
- **Application:** YOLO can be used by children's stakeholders and by the research community.

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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