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Citation for the original published paper (version of record):

Obaid, M., Baykal, G., Klrlanglç, G. et al (2023). Collective co-design activities with children for designing classroom robots. ACM International Conference Proceeding Series: 229-237. http://dx.doi.org/10.1145/3628096.3630094

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Collective co-design activities with children for designing classroom robots

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ABSTRACT

In order to design classroom robots that meet children's expectations, it may be useful to involve children in the design process. In this paper, we propose a suite of activities that can be utilized collectively to help in co-designing classroom robots. We outline the details of a combination of activities including building a robot model using a dedicated robot toolkit, a placement activity, a story-telling activity, and an interview. We explore the use of these activities through a study with 31 children (8-15 years old), where we analyzed the data using a framework for the design of social robots extended to cover the classroom situation. Our study showed that the activities could help distinguish some clear group preferences regarding the embodiment of the robot, especially the head, arms, and legs, the role of the robot, and the personality. While we used these activities in a study to illustrate their use for an open-ended design process of a classroom robot, we argue that the proposed suite of activities complement each other and may help robot designers to involve children in the design process in a holistic way. This can allow designers to gain elaborate and in-depth insight from children who do not usually (and necessarily) have domain knowledge in classroom robot technologies, and can promote them to articulate ideas and views about the prospective attributes in terms of physical appearance, contextual behavior, and social interaction.

CCS CONCEPTS

• **Human-centered computing → User centered design**.

KEYWORDS

Robot, Classroom, Prototyping, co-design

AfriCHI 2023, November 27–December 01, 2023, East London, South Africa

ACM ISBN 979-8-4007-0887-9/23/11.
https://doi.org/10.1145/3628096.3630094

ACM Reference Format:
Mohammad Obaid, Gökçe Elif Baykal, Güncel Kırlangıç, Tilbe Göksun, and Asım Evren Yantaç. 2023. Collective co-design activities with children for designing classroom robots. In *4th African Human Computer Interaction Conference (AfriCHI 2023), November 27–December 01, 2023, East London, South Africa.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3628096.3630094

1 OVERVIEW

It is evident that involving children in the design process of advanced technologies is important and allows designers to explore children's preferences at an early stage in the design process [7][10][28]. Developing co-design tools and techniques not only encourages children to take the role of informants or design partners to involve in the decision making process at early phases of design [3], but also empowers them to be able to reflect on the future technologies as protagonists [12]. Advanced robotic technologies are among these future technologies, and will presumably enter children's learning environments such as classrooms in the near future [17]. However, sometimes it is difficult to gain appropriate feedback from low fidelity prototypes (e.g. [6][25]) especially when children do not have the relevant domain knowledge. Previous studies have shown the impact classroom educational robots may have on the performance and learning of children [4][21] [5]. Thus, utilizing a toolkit that makes the prototyping process more concrete and elaborate for children in the design of their classroom education robot will help in realizing their preferences and needs (with a holistic perspective including appearance, behavior, and social interactions) as children and adult designers may have different opinions on the design of robotic agents [33][18].

Although the research community has indeed focused on defining children's design preferences and implications for robotic features including physical and behavioral aspects [33][34][32] [22], many investigations are conducted as laboratory studies using commercially available robots [11]. While co-design of robots with children has not received much attention yet, several researchers have focused on co-design of robots with elderly subjects[16][27][8]. Other research has merely focused on students' and teachers' acceptance of robots in the classroom (e.g., [24]). To the best of our knowledge, very few researchers have looked at establishing a set of co-design activities with children to design an assistant classroom robot holistically including its appearance, behavior or social interactions. Arnold et al. [2], for example, used a co-designing approach to design social robots with children, where they used a technique called "Bags of Stuff." This technique is a general design technique often used with children in inter-generational design teams to design all kinds of technologies [31]. More recently, the work by [1] presented a design process of a robot that aims at simulating creativity in children. In their work, they followed a set of human-centered design methods to design a robot "Yolo", and their results demonstrated an increase in children's creativity during play. Moreover, our previous work has taken a novel trajectory in investigating possible co-design activities with children, that can be used to elicit children's design preferences for classroom robots [18][20][19][13]. However, it remains challenging to analyze and translate children's creative contributions resulting from co-design activities (e.g. stories, paper prototypes, enacted ideas) [30]. Thus, extending on previous work, we foresee that designing classroom robots requires multiple aspects to be considered beyond the form factors such as the personality, roles, types of tasks etc. In this context, previous work lacks in providing a more holistic approach to capture children's design input towards a classroom robot; thus, we took the next steps into tackling this limitation. In the work presented here, we focus on presenting a holistic approach to developing activities that can be used as part of co-design sessions to reveal children's design preferences regarding multiple aspects of a classroom robot.

In relation to aspects to consider when co-designing (classroom) robots, Fong et al. [9] created a taxonomy of design aspects for socially interactive robots, consisting of eight elements: Embodiment, Emotion, Dialogue, Personality, Human-Oriented Perception, User Modeling, Socially Situated Learning, and Intentionality. For the design of classroom robots as a special case of social robots, all these aspects need to be considered. However, a classroom robot is more than a social robot because it needs to function properly within this particular context. Children's design input may possibly only shed light on the first four aspects of the taxonomy presented above, since the latter have a more complex nature and needs further elaboration. However, children may also provide input about some specific aspects of the design related to the particular classroom context, going beyond the general taxonomy.

In this paper, we build on the outlined previous work, with an aim at eliciting a more holistic understanding of children's design input in multiple aspects that explores a classroom robot's **appearance** (or embodiment in the framework by Fong et al.), its **social interactions** (emotion, dialogue, and personality in the framework by Fong et al.) as well as its **contextual behavior**, meaning how it behaves in the classroom, such as its role in relation to the teacher and its tasks. To achieve this, we have carried out a series of studies to investigate a suite of co-design activities to be used with children, consisting of a toolkit [20] focusing mainly on the appearance of the robot, complemented with a placement activity, a storytelling activity, and an interview session. The collective co-design activities can be used in a co-design process to help reveal children's design preferences for a classroom robot and inspire the whole design process.

To our knowledge, no previous research has addressed or provided children's holistic perspectives on classroom robots, recognizing that all aspects are interrelated. Thus, the following are our main contributions to the research community: (1) Utilize a suite of collective co-design activities to encourage children to consider multiple aspects when designing classroom robots. (2) Report on the various design inputs elicited from children as well as our reflections on opportunities and limitations of the collective co-design activities for classroom robots.

2 METHOD

We utilized a set of co-design activities to involve children in the design of classroom robots in various steps. Our goal is to enable children express their preferences via the presented co-design activities. Our focus comes from the fact that "Most people [...] are not in the habit of using or expressing their creativity; their creativity is likely to be latent" [29] (p. 95). Thus, our aim was to allow children to express their preferences, providing an inspiration for designers based on those preferences through creative and participatory techniques. In this section, we first describe the details of the data collection and procedure of the co-design activities. Thereafter, we describe our analysis process of the data gathered.

2.1 Data Collection and Procedure

In this exploratory study, we aimed to understand the extent of the knowledge gained from our co-design activities by asking children to design a classroom robot based on their preferences. Thirty-one children (8-15 years old, M=11, SD=2.3, 16 girls and 15 boys) participated. The majority of the children (25 of 31) did not have any robotics knowledge, while four had little robotics knowledge, and two had attended some robotics classes. Children participated in the sessions individually in the presence of one facilitator and one observer. The studies took place in a quiet room that was used as a classroom for the summer school. The main session was moderated by a facilitator while an observer took notes. Each session was moderated in Turkish as children's native language and was video recorded. The session started by getting informed consent from the child and the parents/caregiver. The data was collected in three co-design activities for using the prototyping toolkit [20]. (1) Embodiment: Designing the physical components of the robot, (2) Placement: Determining the place and the size of the robot within a classroom model, (3) Storytelling: Drawing scenarios for the envisioned classroom robot aiming to collect children's insights with a holistic approach (see Figure 1). The average duration for designing physical robots was 02:35, the average duration for storytelling was 18:38, and the average duration of total study sessions was 21:13. The following outlines the details of the three co-design activities.

2.1.1 Assembling the robot. Research [31] has shown that children often prefer to create their own robot. Therefore, we provided the children with the Robo2Box [20] to create their own robot individually. The facilitator asked the children to build a robot to be used in a classroom, first introducing the element groups in the Robo2Box, namely heads, torsos, legs and arms, and then letting them construct it. Once a child finished building it, they were asked to pick (a) building material(s) for their robot from the set of material specimens (plastic, fabric, etc.).

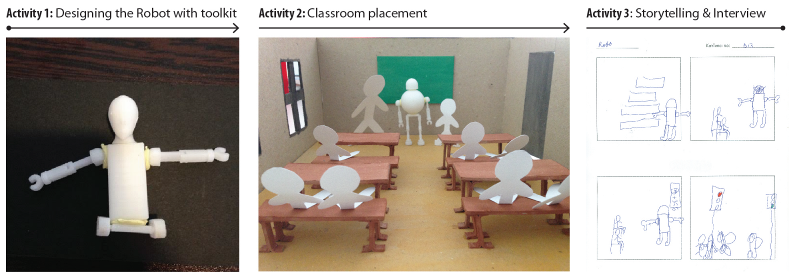

Figure 1: An example of the co-design activities proposed to reveal children's design preferences for classroom robots

Category		Part label	Look: Human	Animal	Machine
Head	1	Human head	x		
	2	Animal head		x	
	3	Rectangular			x
	4	Rectangular with neck	x		x
	5	Spherical			x
Torso	1	Sharp-edged distorted rect.	x		x
	2	Curved-edged distorted rect.	x		
	3	Sharp-edged square		x	x
	4	Curved-edged square		x	
	5	Sharp-edged rect.			x
	6	Spherical square			x
Legs	1	2 fixed human legs	x		
	2	2 fixed animal legs		x	
	3	4 fixed animal legs		x	
	4	2 fixed machine legs			x
	5	4 fixed machine legs			x
	6	2 fixed wheels	x		x
	7	Thrust engine			x
	8	Tracks			x
Arms	1	2 human arms	x		
	2	2 wings		x	
	3	2 machine arms			x

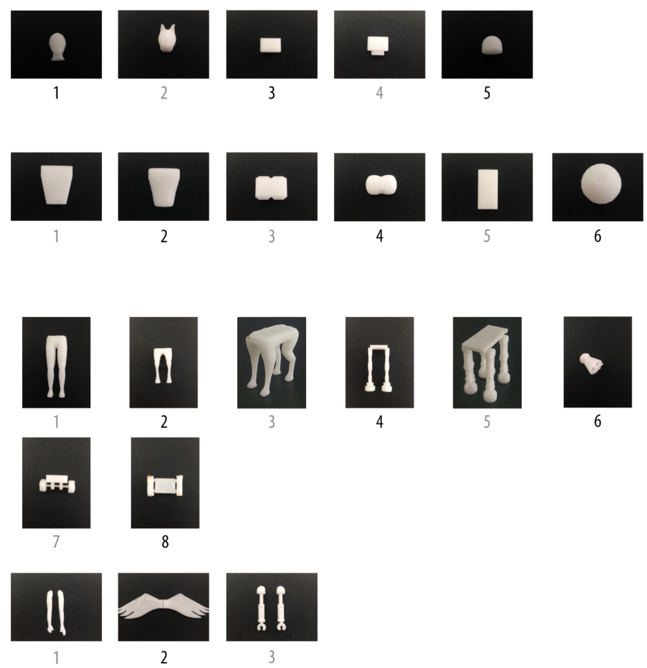

Figure 2: Main codes used to analyze the designs made with the Robo2Box.

2.1.2 Placing the robot in the classroom and discussing its size. Next, the facilitator presented a cardboard classroom model (Figure 1) and asked the child to place their robot in it. The classroom model was rectangular (30 x 30 centimeters) and closed on two sides as the walls of the classroom while the children were able to see inside clearly. It included four student desks, a board on one wall, and two windows on another wall. The model also included one teacher and eight students' models, with seven students sitting at their desks and the teacher and one student placed each side in front of the board, standing. All the objects and people in the model were sized relative to each other, and the reference point in height was the assembly of human heads, curved-edged rectangular torsos and 2-fixed human legs from the toolkit to create an adult's height. The children were also asked to comment on the robot's size in relation to the paper people representing a teacher and students inside, and to specify whether their robots were the same size, bigger or smaller than any of the paper models.

2.1.3 Storytelling and Interview. The final part focused on asking the children to write or draw a story about the robot they had assembled and how it would act in the classroom; a method inspired by Woods et al. [34]. To create the story, the children were presented with a blank sheet of A4 paper with four sequential frames on it, along with colored pencils. They were free to write or draw their stories, and they were not required to fill in all the frames on the paper. Following this, each child participated in a semi-structured interview with the facilitator where they explained their story in their own words. The aim was to encourage them to be able to elaborate on their robot design in terms of the form factors, emotional attributes and communicative features of the robot that they might have not expressed with the toolbox, and to ask some clarification questions if needed, such as, “Does your robot have emotions? If so, how does it show them?”, “Does your robot talk? How? What kind of voice does your robot have?”, “How does your robot behave towards students? More like a friend, like a teacher, or something else?”, and “What tasks does your robot have in the classroom?”. The set of activities aimed to gain insight into their preferences of classroom robots regarding the appearance, social interactions, and contextual behavior.

2.2 Data Analysis

To analyze the data gathered from the three co-design activities, a single coding scheme was created. The codes in Figure 2 (i.e. Head, Legs, and Arms) were used for analyzing the children’s robot designs. Two coders used the coding scheme independently to determine the inter-rater reliability Cohen’s kappa for the data of six children. The inter-coder reliability was sufficiently high (Cohen’s kappa >0.70). Thereupon, coding of the further data was done by a single coder. However, “Head" had to be coded two coders because of a low inter-coder reliability (.31) and then resolved through a discussion.

We also analyzed the placement of the robot by looking at the following preferences: 1 = close to the teacher, 2 = at the side of the classroom, 3 = at the back, 4 = among the students, 5 = next to the door, 6 = on a student’s desk, 7 = moving around, 8 = at the front of the classroom, 9 = in the teacher’s place). The inter-coder reliability for the placement was .82. The codes used for the size of the robot were the following: 1 = smaller than child, 2 = child-sized, 3 = between child and adult, 4 = adult-sized, 5 = larger than adult. Since the coding of the size had a rather low inter-coder reliability (.25), for the remaining 25 children, this characteristic was coded by two coders independently before resolving any conflicts. Finally, analysis of the data from the storytelling activity and the interview was derived from the elements addressed by Fong et al. [9] to understand the robot’s social interactions, emotions, dialogue and personality, as well as some codes to understand the robot’s contextual behavior i.e. its tasks and role. We conducted a thorough analysis of these aspects based on the following characteristics.

For analyzing the **emotions**, we coded whether the child wrote or drew emotions in their stories or during the interviews (0=no emotions, 1=emotions). The inter-coder reliability for emotions was .67. As indicated by Fong et al. [9] we also coded how emotions were expressed (if there were any emotions) (0 = through facial expressions, 1 = body language, 2 = facial expressions and body language). For **dialogue** the coders determined if there were any indications in the stories or during the interviews of how the robot would engage in a dialogue (0 = human-like, 1 = machine-like, 2 = human-machine like, 3 = non-verbal, 4 = unknown). If it had done so, the coders also indicated the kind of voice (0 = human-like, 1 = machine-like, 2 = human-machine like, 3 = no-voice, 4 = unknown). The inter-coder reliability for both codes was 1.0.

For analyzing **personality**, we adopted the Big Five personality characteristics approach described by Syrdal et al. [26], but instead of asking the children to fill out a questionnaire, we coded and analyzed the stories to find out whether any of the characteristics were mentioned: agreeableness (e.g., trustworthy, friendly, nice, pleasant), emotional stability (e.g., stable, adjusted), conscientiousness (e.g. helpful, hard-working, dutiful), openness (e.g., intelligent, imaginative, flexible), extroversion (e.g., warm, sociable, outgoing, confident). For each of those five characteristics we coded whether the characteristic was present (1) or not present (0). Since this was a highly qualitative analysis, the two coders worked together on establishing the results; thus, inter-coder reliability was not measured.

3 RESULTS

The results obtained from each of the design activities will be presented first. Thereafter, we discuss how combining the results from the set of activities can lead to a more complete picture of children’s design ideas for classroom robots.

Embodiment of the robots: Table 1 presents the results of children’s preferences for the separate body parts of a classroom robot. The results showed a higher preference for a human-like head or a human-machine like rectangular head when compared to an animal head or a spherical head. For the torso parts children tended to prefer the sharp-edged and curved-edged distorted rectangular torso, which could be either human-like or human-machine like. Squared, rectangular, or spherical torsos were less popular, which aligns with children’s preference for a human-like form with shoulders broader than its lower torso. Children’s prototypes with Robo2Box also showed a higher tendency to create two fixed machine-like legs and two machine-like arms. In addition to that, they used wings in combination with either machine-like or human arms.

In our study, children showed more tendency to use machine-like legs in contrast with the previous work findings [18] through children’s drawings in which children mainly drew human-like legs. A possible explanation is that children in a previous work found it difficult to imagine machine-like legs, therefore the legs looked rather human-like even though they may not have necessarily been intended as such. This finding indicates that being presented with alternatives for both human and machine-like legs in the toolbox helps children express their preference more clearly.

Placement and the size of the robots in the classroom: In this activity, we aimed to extract children’s preferences about the role and the size of the robot. Thus, we asked children to place their robot in a classroom model and describe their preferences about the robot’s size and location in relation to the teacher and the children. Some children indicated that the robot could be in different places, as follows: Close to the teacher (7), To the side of the classroom (7), At the back of the classroom (6), Moving around in the classroom (4), Next to the door (3), At the front of the classroom (3), In the teacher’s place (2), At the students’ desk (2), and Among the students (1). These results are presented in Table 2.

When it comes to the size of the robot, children’s preferences were rather varied and scattered. Thirteen children expected their robot to be larger than a child but smaller than an adult, six children thought that it would be the size of an adult, and six thought that

Category	Part	#Ch.	Category	Part	#Ch.
Head	No head	1	Arms	No arms	1
	Human head	9		2 human arms	5
	Animal head	3		2 wings	5
	Rectangular	8		2 machine arms	16
	Rectangular with neck	9		Mix of parts	4
	Spherical	0			
	Other part	1			
Legs	No legs	0	Torso	No torso	0
	2 fixed human legs	7		Sharp-edged distorted rect.	10
	2 fixed animal legs	1		Curved-edged distorted rect.	8
	4 fixed animal legs	1		Sharp-edged square	4
	2 fixed machine legs	13		Curved-edged square	4
	4 fixed machine legs	1		Sharp-edged rect.	2
	Thrust engines	4		Spherical square	2
	Tracks	2		Mix of parts	1
	Mix of parts	2			

Table 1: Coding of the body parts - #Ch. is the number of children coded to have a preference towards particular body parts.

Figure 3: Examples of stories made by the children

Position	#Children
Close to the teacher	7
To the side of the classroom	7
At the back of the classroom	6
Moving around in the classroom	4
Next to the door	3
At the front of the classroom	3
In the teacher's place	2
An the students' desk	2
Among the students	1

Table 2: Position of the robot in the classroom

it would be bigger than an adult. Only five children thought that their robot would be child-sized or smaller than a child; while for one child the size remained unclear to the researchers. **Envisioned scenarios for the classroom robots:** After children built the robot and identified the place and the size of the robot, we asked them to create a story about how they envisioned the use of the robot with their drawings. Figure 3 shows examples of the stories that the children created. By creating the story, they elaborated further on the tasks, role, emotions, communication and personality of the robots which we present respectively.

Tasks of the robot: The children mentioned many different tasks for their robot. We analyzed their answers by categorizing thematically and identified eight general types of tasks from most often to most seldom: acting as a servant (31), teaching (18), disciplining and rewarding (6), playing and entertaining (5), providing IT and information services (5), correcting exams and homework (3), and preparing exams and homework (1).

These results showed that children attribute some serving tasks to the robot, such as carrying and getting materials, or cleaning. Furthermore, many children also described multiple tasks that combine those serving tasks with teaching tasks, such as giving lectures. This indicates that children expect the robot to have a wider range of tasks than their teachers. Table 3 shows an overview of the number of children envisioning those general tasks for their robot.

Role of the robot: The stories provided some insight into children's thoughts on the types of roles that the robot could take in the classroom. Fifteen children described their robot as an assistant to the teacher. Five described it as replacing the teacher. Three described the robot as only functioning independently of the teacher. Eight described the robot as both assisting the teacher and acting independently but with the teacher present. In Table 4 we present the combination of the robot's role with its tasks.

Emotions: Either in their stories or during the interviews, nineteen children expressed that their robot would have some emotions.

High Level Task	Examples of Underlying Tasks	#Children
Acting as a servant (SERV)	carry or get materials, clean and tidy	31
Teaching (TEACH)	give lectures, substitute absent teacher	18
Disciplining and rewarding (DISC)	keep order, reward	6
Playing and Entertaining (PLAY)	entertain, sing, play	5
Providing IT and information services (IT)	print, play music, compute	5
Correcting homework and exams (CORR)	-	3
Preparing homework and exams (PREP)	-	1

Table 3: Tasks of the robot

Role	SERV	TEACH	DISC	IT	PLAY	CORR	PREP
Assisting	13	7	4	3	1	2	0
Independent	2	1	1	0	1	0	0
Replacing	3	5	0	1	0	1	1
Independent and assisting	5	4	1	1	2	1	0

Table 4: Role of the robot and tasks it will perform in this role

Eight thought that the robot would communicate emotions through facial expressions only, eight thought that this would be through body language only (which could also include visual indicators on its body), and three thought that it would use both facial expressions and body language. Twelve did not describe any emotions for the classroom robot at all.

Dialogue: The interviews helped us understand children's thoughts about how the robot communicate. Almost all the children expected the classroom robot to use some human-like language to communicate, with only four thinking that the form of communication of the robot would be mainly non-verbal. Seven indicated that the robot should have a human-like talking style but with a machine-like voice, while two indicated that it should have a human-like talking style but with a human-machine like voice. The children thus made a clear distinction between the robot's talking style, which should be human-like, and the robot's voice, which should not necessarily be human-like and could sound more mechanical. The results are shown in Table 5.

Type	Robot's talking-style	Robot voice
Human-like	19	11
Machine-like	4	11
Non-verbal	4	4 (no voice)
Human-machine	1	4
Mix of human and machine	3	1

Table 5: Children's expectations of the talking style and voice of their robot

Personality: When children wrote or talked about their classroom robots they often expressed some personality characteristics. The following are different personality characteristics expressed in the robot stories: Agreeableness (29), Emotional stability (21), Conscientiousness (15), Openness (9), Extraversion (6). The personality characteristics attributed across different roles can be viewed in Figure 4. The results show that children sought emotional stability and agreeableness from a robot when it replaces a teacher and conscientiousness when assisting the teacher, and openness is expected when the robot has independent roles within the classroom.

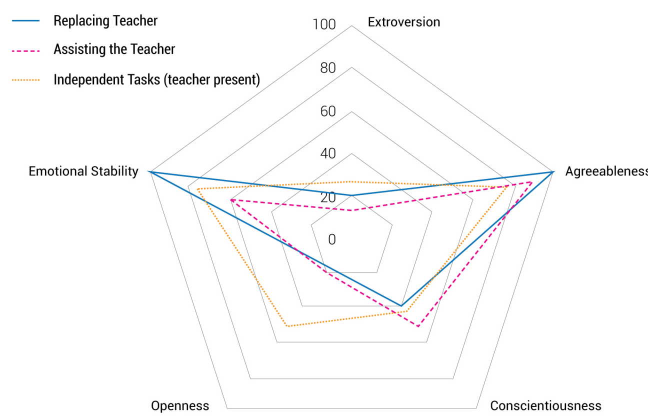

Figure 4: The personality characteristics mentioned in the stories for the different robot roles

4 DISCUSSION AND FUTURE DIRECTIONS

In this paper, we incorporated a prototyping toolkit into a set of co-design activities with children to extract their insight into multiple components of a classroom robot and encourage their involvement in the design process of a future technology. While previous research has only described some results that can be obtained by accumulating data gathered from a single activity, this study aims to provide children with the means to express their design ideas for a classroom robot. We argue that various attributes of classroom robots such as physical appearance, social interactions, contextual behaviors, and role are intertwined and should thus be understood together, and that integrating the prototyping toolkit with several co-design activities helps children to explain and reflect on their ideas in an elaborate and holistic way. The proposed use of the prototyping toolkit in a holistic and iterative design process would be helpful for designers and researchers to gather a variety of information and build links between the different perspectives on Form, Size, Placement, Roles, Tasks, Personality, Dialogue, and Emotions gathered from children's views about classroom robots (see Figure 5). Thus, applying the prototyping toolkit in multiple steps of co-design activities not only helps to gain a broader view about multiple aspects of robots, but also enables us to grasp a deeper understanding of children's opinions. Here, we discuss the main insights gained from our study that utilize and combine multiple co-design activities:

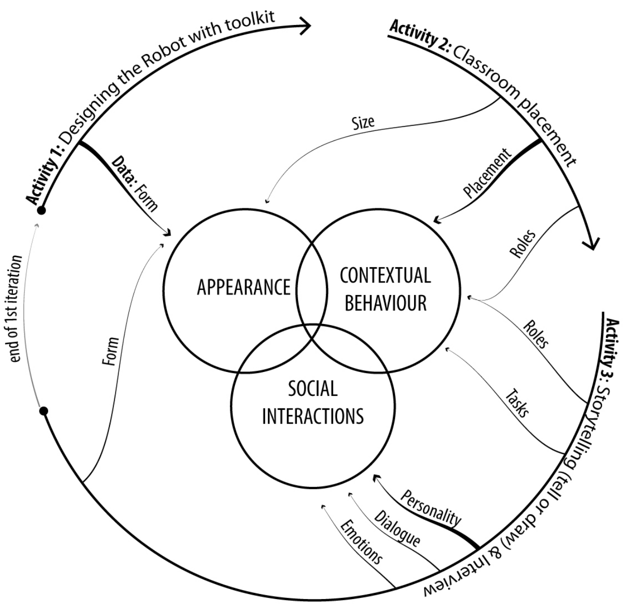

Figure 5: From design activities to knowledge that informs a co-design process.

4.1 Insights gathered from assembling the robot activity:

The results of using the Robo2Box in a co-design activity can help to extract an understanding of children's design preferences around the form factors of the robot, providing identifiable and analytical features that could be coded with a high reliability. Interestingly, unlike the participants in the study by Duckworth et al. [8] who were asked to choose a character for a robotic therapy system, the children did not design robots resembling animals, even though animal forms were also present in the Robo2Box. Our findings indicate that children's preferences for the form factors of a robot design change according to the context of use, which was the classroom in this study. Thus, the variety of the elements provided readily in the toolkit not only help children to translate their ideas into concrete design model, but also help designers to identify children's exact preferences across a variety of possible options. Letting children express their ideas about the type of tasks that a robot in relation to its physical appearance might employ also helps children to reflect on the function that links to the form factors of the classroom robot. In some cases, children changed their form preferences while creating the model (e.g. replacing a humanoid arm with a machine-like arm, because of the idea that a classroom robot should be able to reach out to places where a teacher cannot reach). Moreover, having built a concrete model helps children to warm up with the topic in general and further describe the other attributes of a classroom robot in the next steps of the co-design session.

4.2 Insights gathered from placing the robot activity:

The placement task further helped us to understand how children conceive the robot would be situated in the classroom as to whether it stays close to the teacher, stands a bit to the side, moves around in the classroom, or stands in front of the classroom. However, while the placement task was also meant to be able to discuss the size of the robot, understanding this from the open-ended conversation with the children about the size was challenging, because some of their opinions about the size of the robot changed as their design ideas evolved during the co-design activities, meaning that they did not stick with what they had initially decided. Thus, an additional activity to better understand the size of the robot would be necessary, especially since our study indicated that a classroom robot could be larger than the children themselves. This seems to be very different from the size that children might like for a friend robot [16].

Figure 4 shows the relation between the personality that children envisioned for their robot and its role in the classroom. While extroversion, agreeableness, and conscientiousness were similarly important for each of the roles, the children who thought of the robot as independent of the teacher wrote more about its personality in terms of openness such as it being intelligent, flexible or creative. Furthermore, when children associated a responsible role with a robot in charge of multiple tasks, they were also inclined to mention emotional stability as an essential personality characteristic.

4.3 Insights gathered from the storytelling activity:

The storytelling activity and interviews were useful to gain information on the tasks of a classroom robot. They thought that the robot could help the teacher correct behavior, carry materials, clean the classroom, and protect them. These tasks provided a clear picture of the robot as a servant or assistant to the teacher. The storytelling activity was also useful to elicit children's ideas about the emotions for a robot. However, the children's views leaned towards the idea that the robots do not express emotions through facial expressions or body language. One could argue that the solid nature of the prototyping toolkit offered limited prompts for children to ideate on abstract components such as emotions.

Combining the storytelling activity and the interview helped us verify that the children thought their classroom robot would use speech and have a human-like talking-style. However, during the interviews it became clear that unlike the talking-style, the robot's voice would not necessarily have to be human-like. It could also sound machine-like, which is in contrast to the findings of Okita et al. [35] who found that the children in their study preferred the

Asimo robot to have a human voice. The interview activity was the only way to find this out. An alternative approach would be to let the child perform a play-activity with their robot instead of writing a story.

In summary, the main take-aways derived from our insights can be summarized as follows: (1) Robo2Box helps to make children's ideas about a prospective robot design (which they have no prior knowledge about) concrete and consistent with the context-based uses; in this case a classroom setting. (2) Analysis of the form factors created by the Robo2Box offers a universal and verifiable method for different coders. (3) Having a variety of tools in the toolkit helps children to express the form and reflect on the role and the function of the robot more consistently with their design ideas. Thus, the set activities proposed in this study carry children beyond being informants or design-partners to become the protagonists (as suggested by [1, 12]) of future robot technologies that may be of service of them. (4) Combining a series of co-design activities not only helps children to elaborate more in-depth design ideas but also verifies whether their views may apply in the contextual use case. Thus, the design activities that we propose here complement each other to develop a holistic understanding about what children say-do-make.

4.4 Future Directions

Our study has several limitations that we would like to address here. First of all, the age range of the children in our study was rather large; from 8 to 15 years of age, and limited cultural diversity. As several studies have already shown, it is likely that design preferences for robots will vary by age. For instance in our study, younger children envisioned the physical appearance of a robot inspired from fictional characters that they see on the media, whereas children above 14 years tend to attribute more functional elements in the design of the physical aspects of the robot. Thus, one could limit the age range of the children in future work to specify requirements for a classroom robot designed for that particular age group. Moreover, previous work by Lee et al. [14] and Lee et al. [15] indicates that there may be cultural differences in how people imagine social robots. Therefore, studies may apply the proposed suite of activities to investigate children's preferences across cultures from different continents. In future development, it would be of value to build robotic platforms that are based on children's' insights, and test them in real educational contexts.

Finally, there are two more points of caution. First, as with all co-design activities, it may be the case that what the children design is not what they ultimately want to have in their classroom. Designers should probably use children's designs as first inspiration, and then involve children in iterations towards the final design. Second, while these co-design activities aim to involve children in the design of a classroom robot, teachers might actually have very different ideas of what a classroom robot should and should not be like. Since they are responsible for their children's well-being, they may also have several ethical concerns [23]. It is therefore necessary to involve teachers in the design of classroom robots as well, because their work will be affected by this new kind of technology in many ways. We are currently thinking of ways to involve teachers in the co-design of classroom robots.

The set of co-design activities presented in this paper helped children to elaborate their insight into multiple aspects of classroom robots that go beyond the form factors such as the personality, roles, types of tasks etc. Yet, one could argue that there are potential challenges for implementing children's preferences in real-world classroom robots pertaining to the applicability of design, considerations of ethics, privacy, and educational outcomes. Thus, further work should focus on involving multiple stakeholders in addition to children (e.g. educators, practitioners, designers, etc.) in these co-design activities to extract versatile insight into designing classroom robots in a real world context. To this extent, we believe that the set of co-design activities combined with the robotic toolkit presented in this paper offers a helpful approach towards building a holistic understanding to inform further research.

ACKNOWLEDGMENTS

This work was done in the help and support of the parents and children who agreed to participate. We would like to thank everyone who participated and supported this research activity. We extend our thanks to Dr. Wolmet Barendregt for her contributions and advice throughout the presented research.

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