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Method& Critique *Frictions and Shifts in RTD*

# CoCoCo: Co-designing a Co-design Toolkit for Co-bots To Empower Autistic Adults

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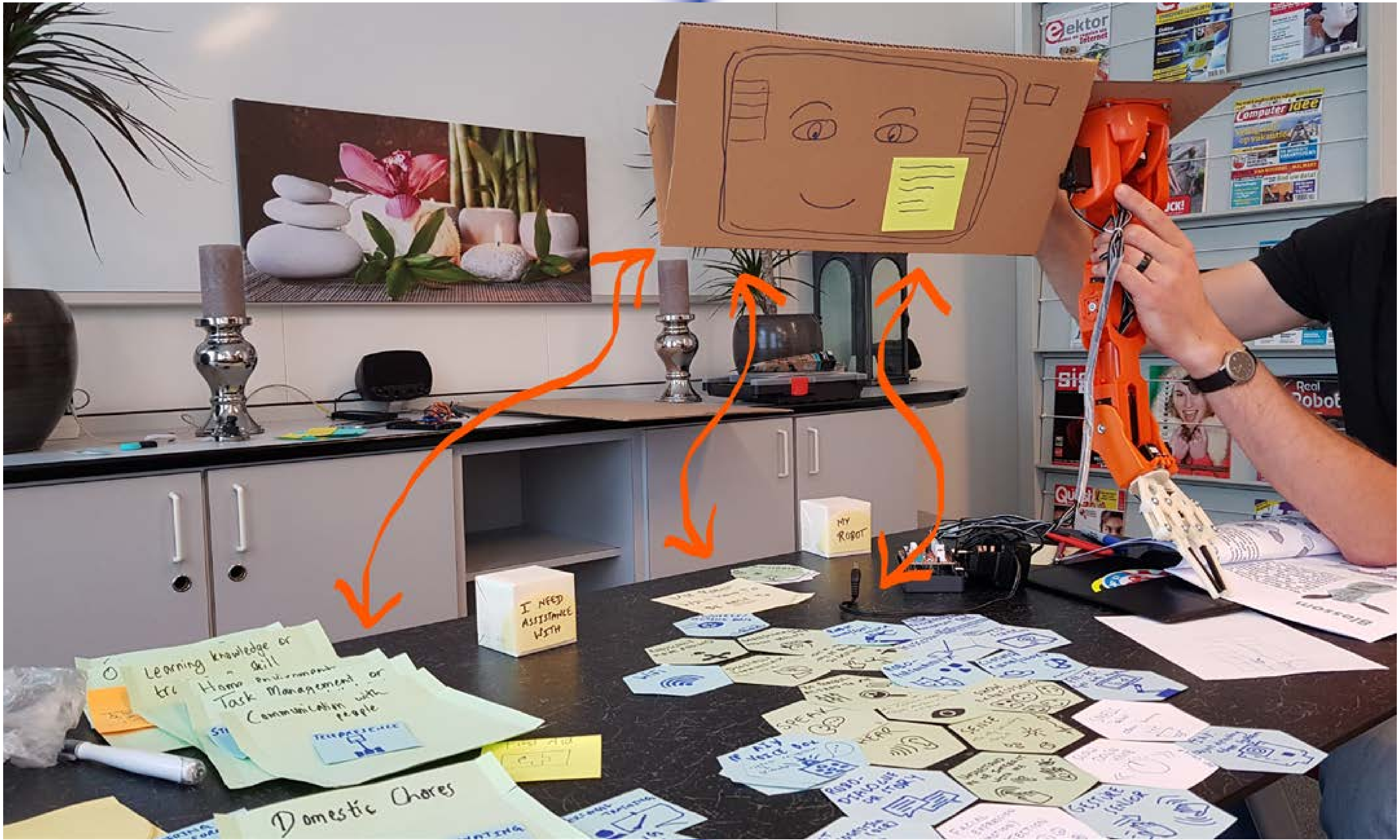
**Abstract:** Autism impacts 5 million people in the EU. Research has shown social robots as enabling robot-assisted therapy or providing assistance in everyday activities. However, given the strong heterogeneity of the target group, it proves to be difficult to design generic, one-size-fits-all assistive applications. Various toolkits have emerged for self-building of robots, yet these still require considerable technical skill. More importantly, such toolkits lack guidance in a structured design process, to uncover and translate real needs into coherent product concepts that can actually be built. To fill this gap, we engaged in CoCoCo (Co$^3$), an exploratory study to empower autistic adults to truly design their own (non-preprogrammed) collaborative robots. The Co$^3$ toolkit of linkable building blocks guides designer and autistic participant through an iterative co-design process. The toolkit itself has been co-designed, evaluated and tested with autistic adults at a FabLab-inspired activity centre for autistic individuals. We discuss how the toolkit elements are padded with cognitive and communicative scaffolding to bridge imagination and communication-related gaps in the interaction between designer and autistic participant. We present Co$^3$, a first step in open-source, scalable, democratized design of social assistive robots, with the aim to increase inclusiveness and democratization.

**Keywords:** Participatory Design; Autism; Social Robots; Socially Assistive Robotics; Empowerment; Co-design.



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## Introduction and Relevance

### The Co³ Project

In this paper we report on a project that entailed *Co*-designing a *Co*llaborative/assistive Robot *Co*-creation Toolkit: Co³. In this project we considered collaborative or assistive robots to be a class of social robots whose purpose is to work collaboratively with humans to assist them with various tasks. Our collaborative, assistive robots are *social*, with which we mean robots deliberately designed with a 'social interface', that is, a form of interaction that has social significance to the human user (Hegel, Muhl, Wrede, Hielscher-Fastabend & Sagerer, 2009). A social interface is not just a visual appearance with opportunities for input but includes the necessary social *behaviors*– i.e., social robots *do* the kinds of things to which a human user would attribute sociality. This does not necessarily mean that social robots have a humanoid shape or even a face. Social interaction may be characterized by patterns of interactive behavior that respond to another social agent so as to establish some form of *social coupling* (see e.g. Lévy et al, 2011).

### Social robots

Social robots, in one form or another, are becoming increasingly ingrained into society. The American think tank, Pew Research Center, predicts that by as early as 2025, "AI and robotics will be integrated into nearly every aspect of most people's daily lives". Agents with social intelligence will become increasingly competent at handling the tasks of our daily lives and will become ubiquitous in households, with impact beyond the general public: "Advances in AI and robotics will be a boon for the elderly, disabled [physical or mental impairments], and sick".

Recent research in Human-Robot Interaction (HRI) literature points out that robots are only going to become increasingly embedded within society, across functions and across domains (Royakkers & van Est, 2015; Young, 2010). Lohse, Hegel and Wrede's (2008) claim that their study provides substantial evidence on the significance that social robots will achieve in the future, within domestic settings. Fong, Nourbakhsh and Dautenhahn (2003) had also already conclude: "it seems clear that social robots will play an ever larger role in our world, working for and in cooperation with humans". From health care and office assistants, to tour guides and household staff, social robots will be closely cooperating with humans to assist them with tasks with a diverse set of domains, aims and complexities. Fong et al. (2003) emphasize the need for effective design of the interaction between social robots and humans. Their study magnifies that social robot development should not just be about adding technical capabilities to perform limited tasks, but also about designing HRI in such an inclusive, human-centered way that social robots can "participate in the full richness of human society". Robots offer the possibility to create multimodal user interfaces (MMUI), which tend to combine the pros of different modalities to optimize (across different situations) the: information communication (or system output) to the user and the input capabilities of the user (Mayer, Beck & Panek, 2012). Such an MMUI approach is especially incentivized by the emerging social robot toolkits, as they really give this possibility of customization, more on which below.

Collaborative assistive robots as part of ubiquitous technology in the home (sensors, networks, apps, smart homes etc.) are promising (Torta, Oberzaucher, Werner, Cuijpers & Juola, 2012). Aside from the advantages of their MMUI approach , their embodiment and multimodalities can provide numerous services in a single, cohesive package instead of multiple independent systems (Torta et al., 2012). Moreover, because people perceive robots more as social actors than mere tools, social robots offer greater chance for technology acceptance (both of the robot itself and the entire network of assistive technology it could be an interface to) (Tortal et al., 2012). Thus, while social robots may not always be as efficient as traditional UIs, they may offer a better user experience, arouse more positive feelings and are perceived as better motivators (Tortal et al., 2012).

### Autism and social robots

According to mainstream theory (see DSM-5[1]), three primary symptoms are all present to various degrees in an autistic individual: *Impairments in social communication* (linguistic impairments, difficulty in understanding and generating facial expressions, gestures or body language), *Impairments in social interactions* (difficulties with handling own and recognizing others' emotions; avoiding group activities; difficulties with social relationship development), *Impairments in imagination* (difficulty in abstract thinking; difficulty with generalizing insights and skills; difficult to live or think outside routines; problems with imagination and unfamiliar situations) (Happé & Ronald, 2008; Cabibihan, Javed, Jr. & Aljunied, 2013). In line with this characterization, social robots have seen a long interest as potential assistive technologies for autistic people (Diehl et al, 2012). Traditionally this is attributed to robots' predictable, deterministic nature, their simpler anthropomorphic appearance and their technological capabilities. Their envisioned function of such assistive robots is geared towards offering help with social or emotional deficiencies and training certain skills.

1 https://www.psychiatry.org/psychiatrists/practice/dsm

So, for example, it has been claimed that social robots's propensity for simple stimuli avoids overstimulation that autistic individuals can be prone to (Cho & Ahn, 2016). Secondly, because robots make uniform and predictable responses, they can be easier to trust and respond to (since they lack complex human nuances) (Cho & Ahn, 2016). Finally, because a social robot does not invoke the recollection of past negative experiences that a person might have had with humans, it feels more approachable and easier to interact with (Cho & Ahn, 2016).

This potential of social robots for people on the autistic spectrum is shown by various research projects: KASPAR robot at University of Hertfordshire; the exploration of KASPAR's potential by Huijnen, Lexis and de Witte in 2016; the European project DREAM (Development of Robot-Enhanced therapy for children with AutisM spectrum disorders); Darwin-OP2 for autism research and therapy at George Washington University; Buddy robot for helping children with an ASD; and the European DE-ENIGMA project for empowerment of emotion recognition and emotion expression capabilities in autistic children (using Zeno robot in figure 1).

Recently however, the 'impairment' theory of autism has been contested, amongst others by autistic researchers, who define autism as a variation in 'neuro-diversity' (Milton, 2012). According to the 'neuro-diversity' model, autism is not so much a disorder in and of itself, as it is a mismatch between the autistic brain on the one hand, and the existing cultural and technological structures that are based on a 'neuro-typical' norm in society. The problem, in that view, lies not purely in the person, but *in the interaction* between a person and a (largely culturally designed) environment. Designing in support of autistic life, then, would be focused less on training or compensating for the user but instead on enabling more smooth interactions with the environment, which could require some adaptations 'from both sides' (Milton, 2012).

### Social robot DIY toolkits

As said, there is a growing trend for social robots in domestic/household environments. Increasingly, such home systems allow for some degree of customization. This is further supported by emerging *toolkits* for full-blown Do-It-Yourself (DIY) design and customization of robots, like iCub, Poppy and Lego Mindstorms (Vandevelde, Wyffelsy, Vanderborght & Saldien, 2017). MIT's social robot (Soro) toolkit project (Gordon, Ackermann & Breazeal, 2015) is another such example. However, the social robot toolkit that stands out the most is the one behind the Ono robot (pictured in figure 2), and is called Opsoro (Open Platform for Social Robotics). Opsoro (and Ono) is an open-source, low-cost, DIY social robot toolkit that wants to democratize and simplify the building of social robots that are focused on tasks and research surrounding social expressiveness and emotions (Vandevelde et al., 2017). It derives its value from its tinkering-oriented DIY approach, from the freedom for modifications of robots it gives users and from its (relatively greater than typical) ease of robot development. Whilst social robot toolkits share a lot of common ground with the pre-manufactured, discrete social robot embodiment concepts, they are unique in that they put the authority and freedom of building or customizing certain aspects of the robot at the hands of the user. They tend to flip the manufacturing or robot design paradigm from a top-down approach, where a researcher or a designer develops a robot and thereafter puts it to use for a user; towards a more bottom-up approach, where the researcher/designer develops the building blocks that are needed to customize or develop a social robot, and delivers those blocks to the user– such that the process leaves some (or all) of the robot's design decisions up to the user. It is this paradigm shift that the Co³ Project aims to accomplish.

**Figure 1.** Zeno robot, used in the DE-ENIGMA project

**Figure 2.** Ono robot (Vandevelde et al., 2017)

## Three Gaps Concerning Social Robot Toolkits and Their Use for Autism

Opsoro (and Ono) takes a major step at advancing the state of the art of social robot toolkits and of HRI research using social robots, by giving a DIY reproducible design to enable HRI research to embrace a DIY paradigm, thereby enabling more affordable and faster HRI studies on social robots. However, there are three main gaps surrounding Opsoro and other related social robots (and social robot toolkits) that limit their scope of usefulness, tangible impact and HRI research and design potential–especially concerning people on the autistic spectrum:

### Gap (1): Prevalence of social robot designs that are conventionally anthropomorphic and whose interaction modalities cannot be fundamentally customized.

This gap is illustrated by, for instance, the modalities Opsoro offers that are mainly related to a robot's lips, head, eyes and eyebrows; and by Kaspar and Zeno being clearly anthropomorphic child-like or cartoon-like robots. However, HRI research and design can gain a lot of advantages by developing non-anthropomorphic robots. As Hoffman and Ju point out (2014): Non-anthropomorphic robots lower user expectations regarding robots' abilities, capabilities and efficiencies that arise from anthropomorphic embodiments (Duffy, 2003; Nomura et al., 2008), and that non-anthropomorphic robots avert the uncanny valley that was first conceived by Mori (1970). Furthermore, a non-anthropomorphic robot offers more "freedom of exploration", as the robot is not directly being designed to be a human replica and it is not compared against humans to gauge its effectiveness–enabling more open creativity in robot's design and interaction and enabling evaluation terms that are uniquely for the robot (Hoffman & Ju; 2014). Simpler robot designs, with less complicated features and lower degrees of freedom make non-anthropomorphic robots more economically feasible for real-world applications, and their cost and relatively greater ease of replication makes them better for rapid, hands-on prototyping (Hoffman & Ju; 2014). Whilst robots like Zeno and Kaspar can be programmed, their interaction modalities are fixed, and their embodiment is not meant to be customized; and in the case of Ono, whilst the embodiment design can be significantly modified, the interaction modalities are still limited to anthropomorphic features (eyes, lips, head etc.). Building upon the research of Leite, Martinho and Paiva (2013) and of Disalvo, Gemperle, Forlizzi and Kiesler (2002), Vandevelde et al. (2017) show that having attractive, personalized or interesting robot embodiments strengthen human-robot interaction and research. Vandevelde builds that capability into the Opsoro toolkit, already taking the state of the art to a point where the appearance of robots can be customized and personalized by individual users. However, it can be argued that empowering toolkit users to customize their social robots even more fundamentally, by being able to choose the robots' interaction modalities, aims, anthropomorphism, behaviors etc., can further enhance the quality and effectiveness of human-robot interaction.

This argument naturally follows on from Leite et al.'s (2013) "guidelines for future design of social robots for long-term interaction"; they propose HRI design recommendations concerning, amongst others, robot: appearance, behaviors, affective interactions and adaptation. What if robot users were empowered to be able to customize these other parameters (besides appearance) concerning robot design? It could be the case that the resulting social robot designs are more impactful and effective and give users a feeling of having something that is genuinely useful for them–another research and design opportunity that we address by incorporating customization possibilities for deeper interaction modalities of robots.

### Gap (2): Social robots being typically designed, manufactured, developed, and only then applied to the autism target group; rather than being co-designed with and for them.

This gap holds true for almost the entire state of the art: Opsoro, Zeno, Kaspar, Darwin-OP2, Probo, Nao etc., were all designed and thereafter put to use for HRI research with and robot-assisted therapy for autistic children. This assumes that the researchers already knows that the problem is that needs to be addressed, and often this would taken to be an external judgement of the person's impairment. We are however more interested in what people on the spectrum themselves define as problematic and how they could themselves come to define what they would need to be empowered in daily life. Frauenberger et al. (2017) clearly demonstrate the value of participatory design in their own co-designing experiences with autistic children. Participatory design enables designers and researchers to effectively learn about vulnerable groups and to design technology specifically for them; and is particularly powerful if the groups' lives and perspectives are distant from their own (Frauenberger, Makhaeva & Spiel; 2017).

Merter and Hasırcı (2016) also show how the use of participatory design for "special user groups" increases their life quality, illuminates their unique capabilities and potentials in society and gives designers an opportunity to mutually learn with such people. Whilst they carried out participatory design with autistic children, they highlighted how advantageous such an approach can be for autistic individuals in general, and how such an approach can bring knowledge that would be impossible to uncover otherwise, and how such an approach can create substantially more creative solutions that are fine-tuned for the various users with autism. What truly shows the value of participatory design in an autism context is their claim that participatory design is useful "in achieving more original products, and...in saving considerable time in stages that time would actually be lost." In fact, as the participatory design research of Makhaeva, Frauenberger and Spiel (2016) shows is that a participatory design approach can actually uncover participants' creativity; due to the flexibility and the ability to personalize solutions that participatory design offers.

### Gap (3): Narrow focus of social robots regarding their application scope and their target group within autism.

The narrow focus related to target group within autism concerns the use of social robots mainly for autistic children and the design of robot toolkits primarily for interaction experiments with children. Projects like DE-ENIGMA, Buddy robot, Probo, DREAM and Kaspar, have all been aimed at HRI experiments with autistic children, and there is not a lot of research work in HRI pertaining to autistic adults. Gaudion, Hall, Myerson and Pellicano (2015) investigated the state of the art regarding the inclusion of autistic individuals in design research and concluded the paucity of such projects that focus on autistic adults (as the large majority focus on autistic children). Whilst they investigated this more generally, their findings are just as relevant specifically for HRI research (as the aforementioned HRI projects demonstrate). They even call this intense research focus on autistic children (rather than also on adults) as, "highly inappropriate"; claiming the need to start focusing on autistic adults as well, due to there being marked differences between children and adults, and the fact that autistic individuals will typically live most of their lives as adults.

The narrowness of focus of social robots regarding application scope within autism concerns the minimal role of robot-assisted therapy for autism as mainly related to improving impairments regarding emotion recognition and expression. Most of the aforementioned HRI projects in this subsection are geared towards therapeutic improvement of autism impairments regarding emotion recognition and expression. However, the role of social robots regarding autistic individuals does not have to be just about the typical form of assistive therapy. It could redefine therapy as (self-) empowerment of those individuals. As Gaudion et al. (2015) aim for and demonstrate in their project, people with autism can be empowered to improve their everyday experiences by working with designers (if the design process is inclusive towards them).

Merter and Hasırcı (2016) also show that for autistic individuals, it is not just their impairments that create problems for them, it's also "the inappropriate design of their material surroundings". They show that if such individuals are empowered through participatory design, they can greatly improve their surroundings to solve their own problems. And for such empowerment to happen, it is paramount that besides embracing participatory design techniques for HRI designs, researchers start to include user empowerment within the activities and aims that underlie robot-assisted therapy. And if researchers go towards this direction, then naturally the user empowerment, assistance and/or improvement can be about much more than just improvement of autism impairments regarding emotion recognition and expression–something we aimed to achieve by enabling the emergence of robot concepts or assistive technologies that go beyond emotion recognition and expression.

## Research question

The three gaps above serve as opportunities for advancing the state-of-the-art regarding research on the use of social robots for autistic individuals, and on the participatory design methodology for co-designing such social robots. These gaps form the research space that this paper operates in. Within this space, as has been demonstrated within the three gaps, the Co³ Project takes the social robot toolkits beyond their current state of anthropomorphic modalities that are restricted to aesthetic customization; and beyond the way they are typically designed, without active involvement of (and participatory design with) autistic individuals right from the start. The research project also goes beyond the usual population of autistic children that HRI projects concerning social robots address; and tries to redefine robot-assisted therapy and to take it beyond emotion recognition and expression. The research question that the Co³ Project was then based on was therefore:

*How might we co-design a co-design method centered around a DIY toolkit for collaborative robots, aimed to support autistic adults in daily life?*

The contribution that the answering of this research question aimed to make was three-fold: (1) Developing a social robot toolkit specifically targeted towards autistic adults; (2) Developing knowledge on what a social robot toolkit for autistic adults should entail and how it should be scaffolded with and incorporated into a structured participatory design process; and (3) Generating guidelines for facilitating a robot-oriented participatory design process with autistic individuals.

## Research Methodology

### Participatory design (PD) as the central philosophy behind the research methodology

As was mentioned earlier, the authority for making decisions about robot applications and design has mostly been restricted to the robot designers or the researchers working on the human-robot interactions. But as Lee et al. (2017) point out, the depth and broadness of the societal impact such robots can have demands a more inclusive design process that is driven by participatory design methodologies. The success Lee et al. (2017) have regarding participatory design of social robot concepts with a group of extreme users suggests that users/participants can and should be much more than informants. They can be as equally authoritative as the researcher, as part of a process where there is mutual learning fostered between the researcher and the participants, enabling participants to actively articulate their ideas and concerns about the embedding of robots in their lives. This form of a bottom-up, participatory approach is also greatly encouraged by Gaudion et al. (2015) in their research, and is the philosophy that forms the foundation of this paper's research methodology.

### Empathizing with the target group and co-designing a collaborative robot toolkit

The overall purpose of the study was to co-design a social robot co-creation toolkit. However, this purpose would be entirely defeated without including the target group right from the start. Thus, after having done some initial research and having ideated some preliminary social robot toolkit ideas, an interview session was conducted with the target group that consisted of autistic adults at an autism care institute in the Netherlands. The session involved: *Understanding experiences of autistic adults and introducing them to social robots.* And this was done in line with Lee et al.'s (2017) effective methodology. This session allowed the researcher to empathize with the target group and to expose the co-design participants to and engage them in a discussion about existing social robots. Participants were encouraged to reinterpret the state of the art of social robots, and to think about them in ways beyond what they would conventionally imagine social robots to be.  For this, images, characteristics, physical embodiments and videos of existing social robots were used as prompts for the participants. The likes and dislikes of the participants were determined regarding the various robot concepts; and the participants tried to extend the robots' functionalities to better fit the robots with their personal use cases. The researcher understood how autistic individuals interpret social robots and their possible uses, and it validated or invalidated components of the researcher's preliminary research question/idea about creating a social robot toolkit, thereby enabling him to further refine the idea to make it more useful for the target group.

From this session there were two major insights that informed the (co-)design of the social robot co-creation toolkit. Firstly, it was confirmed that for a co-creation process of the nature of that in the Co$^3$ project, it can be said that fundamentally it is all about managing, facilitating and consciously guiding the interplay between freedom and structure. This was shown by how one participant seemed to need a lot of structure and guidance to help him with imaginative or abstract thinking. He constantly asked for examples and needed explicit demos before he could himself start thinking about how social robots could help him. Another participant found it way easier to be creative and abstract in thought, and was naturally divergent in thinking; that, however, also meant that he was really easily distracted and would go off on tangents. Thus, it was clear that the main principle to inform the toolkit's design would have to be a flexible way to balance structure-freedom interplay when conducting co-design sessions for developing social robots. This insight is directly supported by the research of Makhaeva, Frauenberger and Spiel (2016), who argue that the planning and conduction of PD processes can be greatly facilitated by viewing such processes as a set of structures and freedoms across which a PD participant can discover their own pathway (and their own balance); letting the participants' creativity unfold. They (Makhaeva et al.) tie this in with the thoughts of Malinverni et al. (2014), who demonstrate that within creative co-design processes, the "balance between creative freedom and structure" is paramount in co-design facilitation and in gradual experimentation with participants' creative boundaries, to uncover their creative potential.

The second major insight that the first session revealed was regarding the need for a process-centricity rather than primarily a technological one. The reason was that in the session a number of robot embodiments, possible building blocks and lots of media about robots was brought. However, it was clear that having such building blocks alone was not going to work. A technology-centric approach where social robot building blocks are presented to the target group and they are expected to come up with concepts that are actually useful and are embeddable in their households was just not possible. The participants' confused comments on the social robot material brought to the session made this really clear.

The session made it clear that having solely a technological toolkit cannot automatically bring technical familiarity, imagination-related skills and collaborative or social skills to an autistic target group (which is typically deficient in these). Thus, through this session, the Co$^3$ project was encouraged to think of another route towards enabling PD of social robots, one which was process-centric, rather than technology-centric: Where a process or a narrative would be established around developing social robots, and the technical building blocks were a part of that process, but not the only thing. It was clear that in such a process extra scaffolding would have to be incorporated to bridge the cognitive gaps of the target group, if they were to be empowered to really ideate and prototype concepts that would actually be useful to them.

### The Co$^3$ toolkit

We now discuss the toolkit that enables an individual on the spectrum to co-design their own robot together with a co-design facilitator. The first step involves the participant making choices or decisions about various aspects of a robot concept through a narrative-driven approach. These aspects concern: Robot application category, robot type(s), robot task(s), robot abilities and robot building blocks. The choices made by the participant about these aspects then form a recipe or a blueprint for the participant's design concept. Once such a blueprint is drafted, a prototype of the entire or parts of the concept can be built (with assistance from the facilitator), which can then be tested. These four steps are conducted in a flexible, iterative way with participants encouraged and able to move back and forth between them. It should be clear that moving along the process the specificity increases, the practical constraints increase and consequently the real-world "prototypability" at the final step is fed back up to the previous steps. As such, the process not only creates a solution but also promotes a reframing of the initial problem and a widening of the solution space (thinking out of the box) by the participant. The participant is nudged towards choosing, reconsidering, mixing, reflecting, diverging, reframing, in an iterative way.

The process as described was packaged into a concrete toolkit with physical cards representing the steps of the process (Figure 3: (1) the choice-based "Choose" and "Blueprint" steps and (2) the robot building "Prototype" and "Test" steps.)

For (1), the toolkit features Co$^3$ cards which divide the workspace into a problem space and a solution space (figures 4 and 5). The problem space (left-hand side of workspace) consists of a collaborative robot concept's aspects related to the participant's need(s), problem(s) or interest(s). It consists of cards regarding the application category of focus (e.g. domestic chores, offering infotainment, task management, well-being) and regarding robot type and task(s) (e.g. cooking robot that reads recipes and fetches food, companion robot that serves as a play partner etc.). And this problem or need space is where a participant starts with the process of blueprinting. Once decisions are taken regarding these aspects, the participant is iteratively moved to the adjacent solution space on the right-hand side of the workspace. This space consists of cards related to aspects of the social robot concept solution being developed: robot abilities (robot should be able to speak, hear, move, grasp etc.) and robot building blocks (robot should have speech recognition, mic, camera, wheels, arms, LEDs etc.). Meanwhile the facilitator creates a narrative-type scaffolding around the cards, in order to facilitate the choice-making process of the participant. The overall goal of having such a side by side problem and solution space is to encourage continuous and rapid iterations between the two spaces, through which the problem and solution at hand can co-evolve in a Schönean manner (Schön, 198$^3$), where the left-hand side of the workspace co-evolves with right-hand side of the workspace (figures 4 and 5). And as the process advances, the problem is refrained into a pragmatically useful need and the solution diverges towards various novel combinations of robot building blocks.

For (2), the toolkit contains co-creation building blocks for rapidly prototyping, integrating and testing (parts of) the concept (figure 5, bottom). They help with grounding into the real-world of and testing of the robot's blueprint(s) generated through the first two steps of the process. The preliminary build-

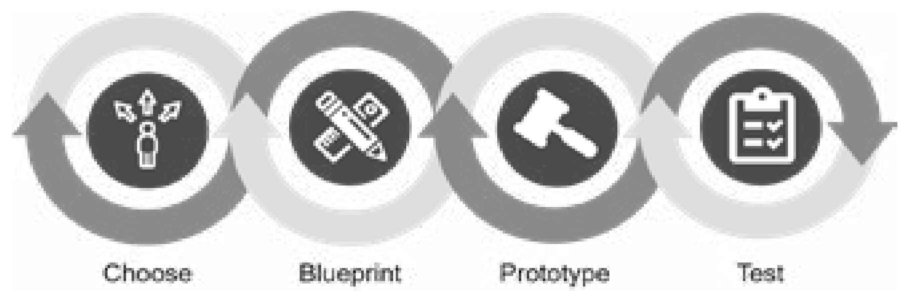


**Figure 3.** The Four Iterative Steps of the Co$^3$ Process

ing blocks included were chosen based on how diverse of robot abilities they could fulfill and how much they spanned the solution space. Some examples are: a robotic arm, the Google AIY voice box, an LED ring, a movable robotic base, an abstract robotic head (e.g. a robotic lamp), an object detection camera (e.g. Pixy) and a screen. These were accompanied with a microcontroller (Arduino) and a single-board computer (Raspberry Pi) for data processing, and for electronically “glueing” the various blocks together.

Hence, overall, the cards facilitate (1) “Choose” and “Blueprint” steps and building blocks facilitate (2) robot building “Prototype” and “Test” steps. In practice the movement between (1) and (2) is kept very flexible and iterative, to encourage constant revision and improvement of the Co$^3$ blueprint and the prototype at hand.

The Co$^3$ toolkit was developed through both empathizing with the target group (as shown in previous subsection) and through ideas contained within PD and robot literature. The idea of dividing the content up into application-type and technology-type categories aligns with the nature of the proven effective “Inspiration Card Workshop” concept from Halskov and Dalsgård (2006) where they also have a collaborative, card-based tool for

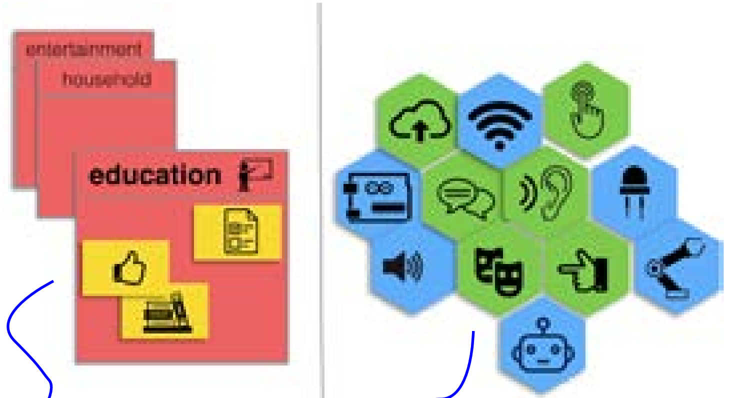


**Figure 4.** Two sided workspace with Co$^3$ cards.

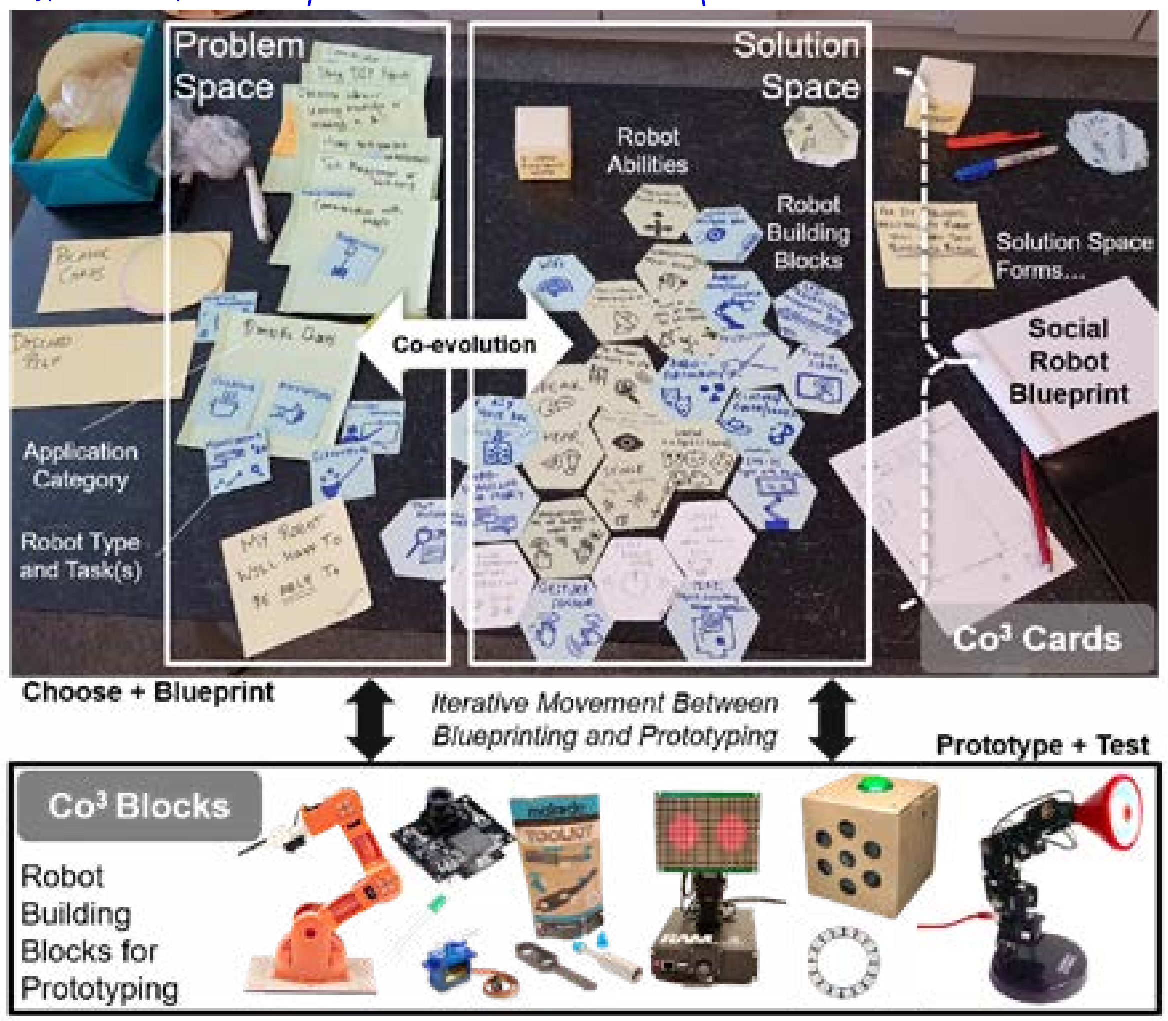


**Figure 5.** The Constituents of the Co$^3$ toolkit with (1) the problem/solution space (paper) and (2) the prototype + test phase

general co-design. Research of Makhaeva, Frauenberger and Spiel (2016), validates how a process where there are physical, methodological and social elements that together strike a balance between a guiding structure and freedom to be creative and contribute . Together this serves to empower participants to discover their own pathway for letting their creativity unfold. Cards were chosen as one of the primary media for embodying the process, firstly, because they align with the values behind Frauenberger et al. (2017) co-designing tool; and secondly, because they align with the ethos of the successful “Inspiration Card Workshop” concept from Halskov and Dalsgård (2006) where their co-design cards can be combined, recombined and co-created into new concepts for design in general.

The symbols used on the cards have been hand-drawn at first. In a second iteration of the process, the cards have been re-designed by one of the autistic participants with a background in design, to have a validation of interpretation and to safe-guard a certain uniformity. However, the ‘hand drawn’ nature of the original cards have a strong impact on the affordance during the process and stimulate to add more cards which can be drawn on the spot on a set of blanks present for this very purpose.

## Testing and further research using the toolkit

Once the toolkit was developed it had to be tested. Two further co-design sessions were conducted: a blueprinting session and a prototyping session. The third author took the role of facilitator given his professional “technical/DIY” facilitation role at the autism care institute where this study was conducted with three autistic adults (two males and one female). With all three participants the sessions were conducted in two iterative rounds (spaced some days apart) of 45 minutes each.

The blueprinting session involved, firstly, getting a participant acquainted with the Co$^3$ process and Co$^3$ cards by creating a narrative full of question prompts around it. Secondly, generating several (generic) social robot concept ideas through iterations between the problem and the solution space of the Co$^3$ cards. Thirdly, nudging a participant towards making their own choice(s) in the process by combining, recombining and reinterpreting the existing (pre-defined) Co$^3$ cards, and adding the emergent cards to the present Co$^3$ cards to further personalize them.

The prototyping session involved, firstly, the grounding of concepts generated in the blueprinting session into a participant’s actual household environment by asking the participant to describe or draw their rough floor plan and household, after which the facilitator can discuss how the concepts could be embedded into their household spaces. Secondly, prototyping and testing of already generated concept(s) from the blueprinting session by using Co$^3$ blocks in a way that a concept can be prototyped as far as possible (even if the prototype involves role-play). Thirdly, feeding back the results from prototype testing to modify the blueprint(s) and to retest the changes made.

### Insights from the test sessions

In this section we highlight two example designs from our test sessions, designed by Tom and Liz (not their real names, see Figure 6 and Figure 7). A third test session with Martin yielded results supporting our findings but have been left out. We discussing how the designs are personalized solutions and we point to a number of specific ways in which the toolkit served to scaffold (or in some cases failed to scaffold) the co-design process that led up to these designs.

The test sessions took place in a quiet room at the care institute. Prior to the session the table was laid out with the cards on piles, supporting robot components in the background. Participants were explained the procedure, with as goal to both help in (co-design) of a personalised robot solution, as well as evaluate the method itself.

In the first session with Tom it took a relatively long time to make the process clear. He went along in the process, the ‘aha’ moment came only during the second session *“oh, but this paper game is in fact the design! So now I can give it to somebody else to do the soldering and building”*. Participant Liz had more background knowledge as a designer, so the goal of the process did not need elaborate explanation.

### Insights concerning the resulting designs

Tom wanted to create a kitchen robot that would help with recipe following, ingredients addition or tracking, motivation for cooking etc. This became apparent during the first session. In the second session as grounding exercise the question was posed where to put this system in his home environment. A sketch of his home (floor-plan) was made on the spot with aid of the facilitator. His prototype ended up as a system mounted in the kitchen, under one of the cabinets right above the work surface. As quick prototype to visualize this, during the session a robot arm was attached to a cardboard screen that had a digital face and a separate touch menu (yellow post-it in figure 6, to the right) for choices.


**Figure 6.** Tom designed a cooking assistant with a digital face, an interactive touchscreen and an arm for cooking-related tasks

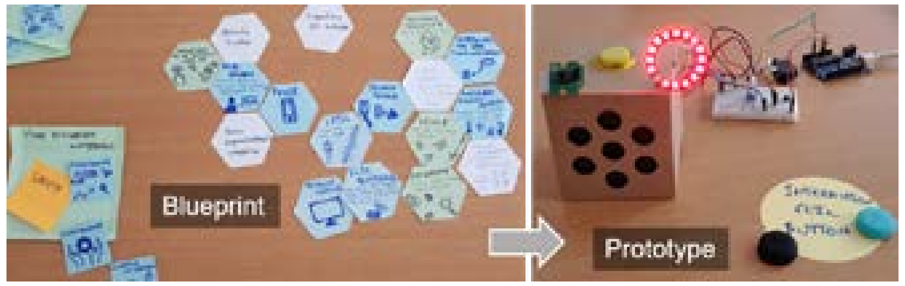


**Figure 7.** Liz designed a security, maintenance and well-being collaborative robot (system) that provides non-intrusive, task-oriented feedback through an LED ring or through localized button-activated speech

The $Co^3$ facilitator was surprised with the design choices that Tom was able to make, especially because at the beginning of the process (first session), Tom wasn't able to even grasp the idea of having a personalized robot, and here he was now making really intricate design changes to his concept prototype. **Prototyping social robot concepts empowers detailed, specific design preferences of participants to be uncovered.**

One key aspect in his explicit articulation of a need he had regarding his robot design, he said about his concept, *"A system that gives feedback, but does not tell me that I am wrong."*. **And this very personal and intrinsically important design need was a great outcome for use as a design requirement**; as the facilitator noted *"[such a comment] gives a designer an important ingredient to translate in the rest of design."*.

In the first session with Liz, one of the key aspects became 'feeling secure'. Since Liz has a hearing impairment as well, this means that (sudden) sounds of unknown origin can startle her. She has also the tendency on the one hand to lose herself in tasks (not know when to stop, or to shift focus)–or get gentle reminders of the tasks in the home she still needs to carry out. The process started with a category 'Home environment management', (see figure 7) with also newly added task 'Safety' (which was not a part of the original set).

Liz wanted a system which would give her some form of general feedback, but only upon request, such that only the system would provide feedback to her (system would speak) when that feedback (e.g. suggestions for activity) is requested (without having to speak, *"wouldn't a voice startle you"*) or when it is in a non-intrusive form (like an LED progress bar).

The situatedness of the design became an important feature, Liz was well able to provide(draw) a floorplan of her house, finding the spot where the system could have a screen showing task related information, as well as information obtained through internet about noisy events in her direct environment (i.e. festivals). A useful component in the toolkit for the concept design prototype were 'flic buttons' offering a modular, situated mode of interaction with the system without the dreaded level of intrusiveness.

In the case of Liz, the nature of the concept became much more a 'smart home' with 'social skills' rather than a social robot. However, the goal of the toolkit is not to restrict solutions to a strict definition of what a social robot must be.

Also, Liz's session led to some interesting results. As the facilitator pointed out, *"[Liz] could not interact with audio. Did not like sounds. So, [the AIY] Voice Box could be rejected immediately."* In this case the addition of flic buttons helped much: *"Flic buttons, since they are physically present, they also helped grounding the whole idea and tailoring to her [Liz's] living room, rather than being an abstract system".* Hence, even if a $Co^3$ block inherently has certain functions (AIY Voice Box having both "Speaking" and "Hearing" functions), the participant should be able to unbundle those functions and choose really the ones that they feel interested in. **So, allow unbundling of packaged functions, especially regarding interaction modalities** (voice interfaces, touch, speech, motion etc.).



**Insights concerning the toolkit's scaffolding role**

**Having physical building blocks for prototyping social robots really matter.** The $Co^3$ facilitator, when evaluating the process's proceedings, said, *"These kind of little things [referring to Tom's change in the position of the robot arm and Liz's need for avoiding speech interaction with voice box] only happened when and because physical stuff was lying around."* He went to on to say, *"Both [Liz and Tom] highlighted that the fact that we had some physical stuff lying around made the idea really concrete and visual".*

**Having simple, paper-based and hand-drawn $Co^3$ cards could create an affordance of the cards themselves being a modifiable prototype, that can be made a participant's own.**

This affordance was also highlighted by Liz herself, who said, *"Affordance of these [$Co^3$ cards] is good. Easy to expand the cards with building blocks and functions."*. However, she also noted that: *"It is harder to do this with the 'categories'. Tasks within categories however offer shifting around, that already solves a bit."*. She was referring to the category 'A' cards in the problem space (left-hand side) that are about application categories. Before the session, it was not expected that that is where personalization from participants' own card additions would be needed (since the idea was for them to add cards in the solution space where they make the robot), however, it was clear that the entire set of cards should be open to participants' own spin on them. Hence, it is important in the next iteration of the $Co^3$ cards to increase the personalization/modification affordance of the entire set of cards. **So, each card type should have a stack of blank counterparts (of the same color, type and shape), ready to be filled by participants' choices.**

## Discussion

The materials produced during the sessions (recordings, visuals, prototypes, feedback, interview results etc.) the materials produced through the researcher's planning and reflection between the sessions, and the materials produced through $Co^3$ facilitator's feedback were all analyzed to find the underlying inductive themes and the patterns embedded in those themes. These patterns are based on only a few case studies–as such they might only be limited to the particular situation and persons at hand. Although, our experience has shown that at least parts of the insights are translatable beyond the sample we had.

The $Co^3$ process that was developed in this project revealed several insights pertaining to conducting research through co-design. We used co-design to better understand the problems in our target group's (autistic adults') daily lives. We also used it to understand their perspective on possible design solutions to those problems. Here is an overview of the main insights that were revealed from using our co-design =process as a vehicle to conduct research:

**The project greatly advanced the social robot state of the art.** The state of the art went beyond anthropomorphic designs, beyond just typical emotion recognition and expression therapy, beyond the typical autistic children target group and beyond what can be created by a designer themselves. In words of the $Co^3$ facilitator: *"Concepts that came out were personal. Right there on the edge. Beyond the logical, simple first solutions. Flic buttons combined to a screen with a simple light. Having speech but no hearing. I would not have come up with this on my own.".* Hence, the $Co^3$ toolkit truly did empower autistic individuals to develop truly novel and personalized concepts that could not have been thought up solely by a designer. And that might have been because of how the $Co^3$ toolkit physically embodied and externally represented the $Co^3$ process on a table, which made the process sufficiently scaffolded for the target group. As the $Co^3$ facilitator noted: *"This [$Co^3$ process] is really good because it adds a second layer to the process where you talk about the objects... and material on the table instead of the [autistic] participants and their problems."*. The figures 6 and 7 show the results of two of the participants from both their blueprinting sessions and their prototyping sessions.

**The project empowered autistic adults to solve their own problems.** Perhaps Liz's session is the best example of true co-design and participant empowerment: *"I was a bit sceptical at first but I have the feeling that I really created [a system concept] here".* Hence, participant empowerment through the process is not necessarily technology-centric and about creating solutions that can sense and do everything. The solutions are tailored to individual needs doing real, personal and very specific tasks.

**The project created active engagement and inclusion of autistic adults in the $Co^3$ design process.** According to the facilitator, active engagement in the process was manifested and achieved by for example: *"Asking them [participants] to draw their rooms for grounding";"-Maintaining balance between structure and imagination"; "A problem explicitly originating from participants was a source of active engagement. They were working on their own problem".* On being asked about the degree of engagement of participants, the Co$^3$ facilitator remarked about the evidence that was visible: *"Each [participant] came up with a pretty original concept really tailored to specific and very personal issues...[for example] I could not have seen safety as someone's primary concern [regarding a Co$^3$ concept].";* *"The level of depth in which concepts arose were not just sketching exercises... [they were situations] where a robot had to solve a real problem".*

**The project showed flexibility and appropriateness of the Co$^3$ process to various situations, preferences and participant; and led to the emergence of diverse concepts.** It can be concluded, with confidence, that the process's flexibility was an asset. In the facilitator's evaluation of the sessions: *"If you see how the process facilitated three different people, with three different needs, in achieving the outcome. And coming up with radically different concepts. Security system with remote buttons, clutter detector, cooking arm...the process went completely different with the three of them. And accommodated their different ways of working and mindsets. It was open-ended in terms of outcome. So yes, flexibility criteria were met.".*

**The project highlighted the situatedness of autism and dependence of creativity on the right context.** Perhaps the biggest insight that the project revealed was that, contrary to popular belief, it's not that autism is not "typical". It's just that people who have it aren't provided with a context that is appropriated, situated and suited to their specific quirks, qualities, preferences and mindsets. Viewing autism as such and providing the right context for such situatedness to happen makes autism pragmatically "neurotypical" when it comes to the task at hand. For instance, the Co$^3$ facilitator said, *"But it [Co$^3$ process] was a meaningful thing...So, yes, I think and also based on his concepts, he [Tom] liked it and felt that he achieved something useful. Also, for [Liz] the same holds."* The facilitator reasoned about this usefulness of process and concepts by saying, *"Because... for them [participants] it was really about problems that were important to them".* And this is what situatedness can achieve. It involves providing the right context for a particular participant, their personality, personal problems and quirks (part of the more "physical" context provided by the Co$^3$ toolkit is featured in figure 8). A context that is best appropriated to them and their preferred balance of structure and freedom. And when that happens, *"Concepts that came out were...beyond the logical, simple first solutions... I could not have come up with this on my own.",* as the facilitator noted. Isn't that as competent as what one would imagine a neurotypical individual to be in such a creative task? That is how powerful providing the right situated cognitive scaffolding and the right context for co-design can be.

## Conclusion

This exploratory project has produced a toolkit of linkable social robot building blocks centered around which is a holistic, novel process for conducting social robot participatory design with cognitively impaired individuals. That process has artefacts meticulously designed with the participants in mind – giving the artefacts sufficient scaffolding to make co-design navigable by bridging the impairments in imagination and social interaction of the involved participants. The project aims to inspire a movement of open-source, scalable and democratized social robot co-design, which in the end can be facilitated by a social robot itself (which works with participants to co-design itself) and which can empower egalitarian inclusiveness in (co-)design of all users – to evoke questions on which human-robot interactions to design in the first place and why.

**Figure 8.** The Co$^3$ toolkit was designed to allow participants' creativity to emerge, by providing the right contextual materials. Materials that afford the occurence of highly situated and personalized concepts.



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