It Takes Two: Using Co-creation to Facilitate Child-Robot Co-regulation

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While interacting with a social robot, children have a need to express themselves and have their expressions acknowledged by the robot—a need that is often unaddressed by the robot, due to its limitations in understanding the expressions of children. To keep the child-robot interaction manageable, the robot takes control, undermining children's ability to co-regulate the interaction. Co-regulation is important for having a fulfilling social interaction. We developed a co-creation activity that aims to facilitate more co-regulation. Children are enabled to create sound effects, gestures, and light animations for the robot to use during their conversation. A crucial additional feature is that children are able to coordinate their involvement of the co-creation process. Results from a user study (n = 59 school children, 7–11 years old) showed that the co-creation activity successfully facilitated co-regulation by improving children's agency. It also positively affected the acceptance of the robot. We furthermore identified five distinct profiles detailing the different needs and motivations children have for the level of involvement they chose during the co-creation process.

CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**; **Natural language interfaces**; Gestural input; • **Social and professional topics** → *User characteristics*; • **Computer systems organization** → *Robotics;*

Additional Key Words and Phrases: Child-robot interaction, co-regulation, co-creation, user study

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1 INTRODUCTION

As more socially assistive robot applications for (mental) health interventions for children are being researched and put to market (e.g., see the overview by Kabacińska et al. [36]), it is essential

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for their effectiveness to understand how to create meaningful social interactions. It is the quality of the social interaction that these socially assistive robots aim to offer that stands at the core of the intervention [18]. However, currently most applications rely too much on the novelty of the robot instead of the quality of the social interaction. The novelty effect is an unsustainable motivation for children to interact with the robot, because as soon as the robot loses its newness, children lose their interest [5, 36]. Experiencing the interaction as more personal, meaningful, and fulfilling is a more sustainable motivation. More research is needed to design social interactions that are experienced as such.

The research discussed in this article is part of the Hero project. The aim of Hero, an autonomous social robot companion (a Nao robot), is to contribute to reducing medical traumatic stress for pediatric oncology patients [49]. We developed a narrative-based conversation and interactive storytelling activity that offers children an engaging distraction [55] and enables them to develop a supportive relationship with the robot [48, 50, 54, 56]. It is the captivating narrative that provides meaning to the interaction. Throughout the conversation, children learn more about the robot from the stories it shares about its adventures. Likewise, the robot learns more about the children from the information they disclose about themselves (e.g., their interests and preferences). We finally developed a personalization strategy that used children's self-disclosures to make the narrative conversation more personal. It successful facilitated a robustly engaging weekly interaction spanning a 2-month period [54].

By critically reflecting on our past work, we can identify ways to make the interaction more meaningful. The first thing that stood out was that, although children could influence the narrative by making decisions about the story, they expressed a need to express themselves more freely [55]. Given the requirement that the robot has to manage the interaction autonomously, it is necessary to constrain the possibilities to safeguard the synchrony of the interaction. The question then becomes how to feasibly add more self-expression opportunities for the children during the interaction?

One aspect of the interactive storytelling that provided an option for self-expression was the activity where children could co-create sound effects for the robot to use during its storytelling. It was a small part of the interaction, but it was one of the most appreciated elements. Adding more moments during the interaction where children can co-create interaction content seems to be a great opportunity to enable children to express themselves more. It furthermore addresses another aspect of novelty. To sustain an interaction (or a series of interactions) over time, novel interaction content needs to be provided [47]. It is not only a matter of quantity—the content must have a certain quality as well. In a social interaction, the content needs to be tailored to the individual and [it needs to be] personal [54]. Co-creation helps in this matter, because co-created content is inherently personal.

It was not the only thing that was missing. In general, during the interactive storytelling, children had a good time, paid consistently more attention to the robot, could recall more about the story, and felt more autonomous compared to a plain storytelling activity [55]. However, when breaking down these results, we discovered that a minority of children were not satisfied with the interactive components. In particular, some participants indicated that they did not want to make a choice or create a sound effect. In those cases, some children felt compelled to make a choice anyway, whereas others remained silent, inhibiting synchronicity during the interaction. The robot would eventually resort to a default answer, although not before going through three repair attempts. After asking for a sound effect, the robot would record regardless of how the child responded, sometimes recording a silence and playing that back in the story. All these scenarios undermined children's agency, made them uncomfortable, and damaged the interaction.

To summarize, increasing children's opportunity to take more ownership over the interaction will likely result in a more personal, meaningful, and fulfilling interaction. Philosophers such as Margaret Gilbert, for example, argue that parties to a social interaction need to have a shared agency [23, 24]. Social scientist James S. Coleman emphasizes the interdependence of parties to a social interaction when he writes that "a minimal basis for a social system of action is two actors, each having control over resources of interests to the other" [14]. When the robot dictates the interaction, a satisfying level of shared agency is missing. Both the child and the robot have to be able to regulate their shared agency and adjust themselves during the interaction. This is called *co-regulation,* and it is key for a fulfilling social interaction [34]. Our goal is not to achieve a human-level social interaction between the child and the robot. Instead, we explore what co-regulation means for a child-robot dyad in the context of interactive co-creation and use that new frame to propose practical design specifications for the robot to improve co-regulation during the interaction.

With the research discussed in this article,[1] we contribute in three ways. First, we provide three novel design patterns for a co-creation activity that enable children to express themselves more freely. Children can co-create sound effects, gestures, and light animations. Being able to co-create parts of the interaction increases children's agency. By displaying the content made by the children, the robot explicitly shows it has heard and seen their creative expressions. It allows the robot to furthermore create a more personal interaction. Second, we provide a design pattern for the robot that enables children to coordinate their involvement in the co-creation process. Together, these design patterns expand children's ability to co-regulate their interaction with the robot. Third, we validated the designs with a user study (N = 59 school children, 7–11 years old) and gained valuable insights into the different ways and motivations of how children want to coordinate their involvement during the interaction. In the rest of the article, we discuss the rationale of our design, in Sections 2 and 3, and we discuss the results of the user study in Sections 4 through 7.

2 RELATED WORK

Co-creation is a valuable tool in the participatory design toolbox [69]. Instead of using co-creation as a preparatory activity, we chose to embed it as a part of the active child-robot conversation. By directly involving children in the design of the interactive content during the interaction, we intend to achieve multiple things at once. First, we have the classical goal of co-creation to anchor children's needs into the final design [64]. Second, creating personalized content, especially in long-term scenarios, is generally a difficult task in human-robot interaction [54]. Because the co-creation happens during the interaction, it reduces the load of what needs to be created in advance. More importantly, because the co-creation happens one-on-one, the resulting content is inherently personalized.

Finally, and this is the focus of this article, we want to use co-creation to provide more opportunities for children to express themselves more freely during the interaction in such a way that is also affects the interaction itself. We do not only want children to experience more agency themselves, but to experience and manage the shared agency with the robot. In other words, we want to explore whether co-creation can be a vehicle for providing a more meaningful social interaction with the robot. In this section, we outline the different roles of co-creation in child-robot interaction and reframe what it means to be social for a robot.

2.1 Co-creation

Co-creation is a multi-faceted concept. Its most common use is that as part of a participatory design approach, where users are invited to contribute to the design phase [69]. There are powerful

[1] A first brief exploration of a part of the collected data is discussed in our previous work [53].

examples available where a wide range of aspects of a social robot were co-created. For example, Opsoro is a Do It Yourself (DIY) robot platform that allows children to tailor the robot's appearance and animations to their liking [15]. Dressing children with diabetes up as a robot and letting them act out what they want from a robot partner was one of the co-creation activities used to inform the design of a robotic partner for diabetes self-management [28, 60].

Co-creation can also be the act of creating together with a robot. The robot can act as a partner [3] or tool [2] in a creative process. The co-creative process can be the goal of a whole interaction [2] or serve a different (e.g., therapeutic [3]) purpose. In our design, the robot acts as both a tool to create expressive content and a medium to display the created content.

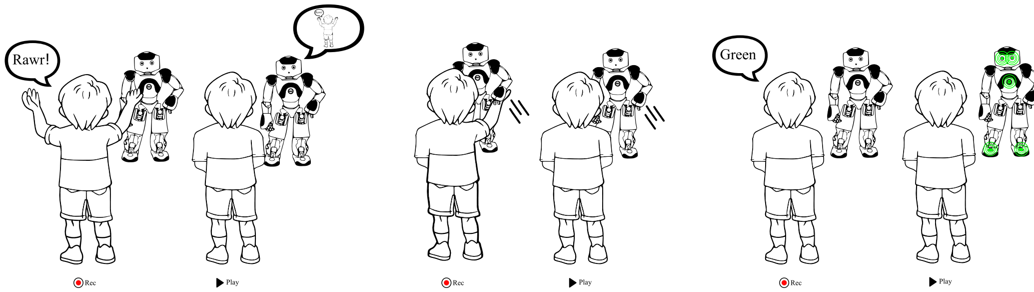
2.2 A Social Interaction

De Jaegher et al. [34] define a social interaction as "two or more autonomous agents co-regulating their coupling with the effect that their autonomy is not destroyed and their relational dynamics acquire an autonomy of their own." This coupling is engaging in nature "as it starts to 'takeover' and acquires a momentum of its own" [34]. It is this engaging aspect of a social interaction that is important for why many social robot applications have tremendous potential [9].

However, autonomy for a robot in a social interaction, let alone co-regulating a coupling with a child on a human level, is currently impossible. It is not hard to see why, when looking at what it takes to facilitate a human-level social interaction. Parties to a social interaction simultaneously pursue a joint goal and to achieve this goal jointly depend on each other [23, 24]. It requires interpredictability of their attitudes and actions [44]. For this to succeed, a common ground needs to be established, and this requires a lot of (implicit) communication [12]. This back and forth communication is how social actors coordinate their interdependence [34]. An example of such coordination is leaving pauses in a conversation to allow the conversational partner to take the turn [22]. Social actors continuously and reciprocally influence each other's actions during the social interaction [26], which requires agency on the part of each actor. It is important that during the interaction a sense of shared agency is maintained, as without it, the coupling between actors is lost [7, 24]. In a social interaction, there cannot be one actor fully dictating how the interaction evolves [84].

There are many challenges that need to be overcome if we want to go in this direction. Some are technical in nature. For example, natural language processing and social signal processing are not yet equipped to provide the level of understanding required for this intricate social process [37]. Others are more fundamental in nature, like defining and formalizing what common ground is between a human and artificial agent [57].

For the time being, we propose a pragmatic way forward. We view this human level of social interaction as a dot on the horizon and instead like to rethink how a child-robot interaction can be social considering the current limitations. Our goal is not necessarily to (re)define what a social interaction is, but rather to provide a practical operationalization of what it means for a child-robot interaction to be social enough, to design meaningful robot behaviors. As a minimum, it requires both individual agency for the child and the robot and a shared agency over the interaction. This means the child interacts voluntary with the robot and the robot has some level of autonomy during the interaction. The more balanced the shared agency is, the better, but it is not a hard requirement for it to be equal. It requires some kind of coupling. The child's experience is leading here. They have to experience the coupling, be engaged by it, and enjoy it. Feeling in sync with the other could be a practical concept that captures the coupling [29]. Finally, both the child and the robot must be able to coordinate their shared agency to maintain that coupling.



Sound effects Gestures Light show

Fig. 1. Illustration of the three different co-creation modes: sound effects (left), gestures (middle), and light animations (right). Each left child-robot pair shows the creation of content: the recording of a sound effect, moving the arms of the robot, and picking colors for a light show. Each right child-robot pair shows the robot using the created content.

3 DESIGN RATIONALE FOR CO-REGULATION THROUGH CO-CREATION

In our design, co-creation is not a separate activity. Bits of co-creation are interwoven into a narrative conversation. The robot is telling about its (fictional) visit to the zoo. It wants to reinforce parts of its story with non-verbal expression using sound effects, gestures, and light animations. Throughout the conversation, the robot would ask the child to co-create this expressive content (Figure 1).

Co-creation provides opportunities for children to co-regulate the social interaction they have with the robot. Children will co-create expressive content for the robot, together with the robot, that will displayed by the robot during the interaction. The act of co-creation gives children direct influence on the interaction, and they get to experience their influence throughout the interaction. This increases their agency. In a previous study, we found that children indeed experience more agency when they are given direct ways to influence the interaction [55]. The co-creation of the content is a collaborative effort. The robot provides the boundaries of the co-creation, namely when co-creation can take place, the modality, and what the goal of the co-created content is. The child does the creation within these boundaries. This creates a joint action and joint agency that the child and the robot need to navigate. From our previous work, we found that some children found the co-creation process too directive [55]. Therefore, we propose to give children the ability to coordinate their involvement during the co-creation process.

Because the robot needs to facilitate this process autonomously, we need an explicit behavioral design. We adopt the concept of **Interaction Design Patterns (IDPs)** as the format for the design specifications. In this section, we discuss our design process, the design specifications for autonomously facilitating a narrative conversation, three novel IDPs for co-creation, and a pattern for coordinating the co-creation process.

3.1 Design Process and Structure

Design patterns originate from architecture where Christopher Alexander observed countless patterns in buildings and towns and described them systematically for others to use them when constructing new or improving existing structures. Design patterns found its way to software engineering in the 1990s [21] and human-computer interface design in the early 2000s [80]. It led to the creation of pattern libraries that designers still benefit from (e.g., [75] or [82]). Design patterns for human-robot interaction have only been scarcely proposed (e.g., [39, 56, 59, 70]). The main reason is that the field is, in comparison, still young, so not many tried and tested patterns have emerged. We therefore propose a more proactive approach where we specify proto-patterns and validate them by systematically testing them.

The patterns we put forward each contain a description of the *problem* they try to solve, the core *principles* of the solution, and an example of the *solution* (i.e., how we implemented it). It provides a blueprint for other researchers and developers to replicate and re-use the designs. Ever since the replication crisis in psychology, a field interwoven with the field of human-robot interaction, safeguarding the replicability of HRI studies has become more important [5, 30, 33]. The patterns are only truly validated when many other community members adopt. We see these patterns not as final, but rather as a first and very specific suggestion on how to support co-creation and co-regulation. Many community-wide iterations are likely necessary to reach a level of maturity that will lead to a wider adoption rate.

Due to COVID-19 restrictions, we could only directly involve children in the validation of the patterns and not the creation of them. Instead, we based our design directions on recommendations from past work (i.e., [55] and [56]). We used a rapid prototyping approach involving primarily the researchers to fine-tune the concrete implementation. We ran a single pilot study with two children to test the experimental setup as a whole. No major elements were changed throughout this process.

3.2 Narrative Conversation

The base component for the conversation are the minidialogs. A minidialog is a self-contained unit of discourse in the conversation. It is the dialog equivalent of a paragraph in written text. A minidialog is an ordered collection of templated utterances, animations, and questions. A minidialog also has metadata that contains the id, topic, and dependencies of this minidialog. There are two types of dialogs. The first are narrative minidialogs that are ordered sequentially and provide a narrative progression throughout the conversation. The second type are functional minidialogs that fulfill a specific function, like a greeting or co-creating one of the content elements. The functionality of the co-creation minidialogs are discussed in the next few sections.

To manage the conversation autonomously, the robot keeps the initiative during the conversation. The possible roads the conversation can take is fixed in advance by a session template, but the exact route the conversation takes depends on the child. By asking questions the robot learns about the child's interests and preferences. This information is used to fill in the template gaps in the minidialogs and select the most fitting minidialog.

We developed a rule-based artificial cognitive agent to allow a robot to autonomously manage the conversation. Sensor data, like audio from the robot's microphones and button presses, are streamed to the agent. The agent has access to Google Dialogflow for speech and intent recognition. The minidialogs and the session template are part of the agent's knowledge base. The agent has a rule base that specifies rules for dialog management. The rule base is an implementation of the IDPs for dialog management discussed in our previous work [56]. For example, there are rules in place specifying the recognition and repair pipeline. Children get two speech attempts first and can fall back to entering their answer using a touch-based repair mechanism. Using the incoming data, the available knowledge, and rules, the agent can reason about which action to take next. It selects actions on a micro level (e.g., turning on a microphone, speaking, or gesturing) and on a macro level (e.g., which minidialog to select next).[2]

We created a storyworld as a tool for creating the minidialogs. A storyworld is a transmedia narrative that situates the robot in a fictional world and connects it to the real world [52]. Our

[2]A full overview of the artificial cognitive agent can be found in previous work [52] (appendix C3). Code: https://github.com/HeroProject/HeroGoalAgent.

storyworld describes the robot as a story character, with hobbies and quirks, but it takes into account its real physical and cognitive capabilities and limitations. This provides the necessary anchor points and topics for writing short connected dialogs. Hobbies can, for example, include cooking (albeit clumsily) but not swimming (because it would short circuit). A key quirk is the robot's curiosity. It provides a motivation for why the robot asks so many questions. The storyworld furthermore provides fictional goals the robot wants to achieve. For example, the robot likes to talk about its hobbies. The storyworld also describes goals the robot wants to achieve in the real world. In this particular case, the robot needs help to create gestures, sounds, and lights.

The dialog content for the current user study was created around the robots interest in animals. The main narrative is a visit of the robot with its friends to the zoo. The robot is telling about how they walked through the zoo and saw different animals. Minidialogs were created about a visit to the habitat of the elephants, lions, tigers, and a visit to a dolphin show. The minidialog about the elephants and the dolphin show were fixed, but dependent on the preference of the child, the robot would either talk about the visit to the lions or tigers. The robot would ask the children to create an elephant gesture, the roar of a lion or tiger, and a light animation for the dolphin show. The conversation was ended with a goodbye. The robot needs a gesture, sound, and a light animation for the goodbye.

3.3 IDP1: Co-creating Sound Effects

3.3.1 Problem. The storytelling experience primarily takes place in the auditory domain. Allowing children to express themselves more freely in this domain will support their agency and engagement [4, 11]. How to integrate children's vocal expression into the storytelling experience?

3.3.2 Principle. The robot has the ability to record and replay verbal expressions made by the child. To frame the expressions in a suitable way, the robot can invite the child to record a sound effect. The children can comply with the robot's request in any way they see fit. The robot can use the recorded sound effects throughout the story. Additionally, adding sound effects to the story creates additional stimuli to increase engagement [1, 58].

3.3.3 Solution. The robot asks the child if they want to help the robot by making a particular sound (see the left pair in Figure 1)—for example, "Can you help me by making the sound of a squeaking mouse?" Next, the robot will count down before it starts recording. For example, "Squeak as a mouse in 3, 2, 1, start." The robot starts recording for a specified number of seconds (default is 3 seconds). After the recording, the robot thanks the child. The recording is played back, embedded in the story, at least once—for example, "When the truck backed up, it squeaked as a mouse [play sound effect]."

3.4 IDP2: Co-creating Gestures

3.4.1 Problem. Non-verbal expressions are an important part of how people communicate. They carry meaning, reinforce a message, and create common ground [13]. The primary way the Nao robot can non-verbally express itself is using arm gestures. The better these gesture match with the verbal content, the bigger the impact of the gesture [20, 88]. How to co-create gestures for the robot?

3.4.2 Principle. The child can demonstrate the gesture to the robot. With modern computer vision tool kits, this is a doable task—certainly less difficult than when the child would describe a gesture. There is an easier solution, however, and that is letting the child physically move the robot's joints around and record a gesture.

The physical embodiment of the robot allows for a physical interaction to take place, and positive effects of robot touch on people's well-being are well established [31]. Often cuddly robots are used for a touch interaction, like the Paro [40] or Huggable [76]. However, also a touch interaction with the Nao has been shown to reduce stress and strengthen the human-robot relationship [31, 87]. However, it is likely that the act of touch is not solely responsible for the positive effects—it matters how it is embedded in the context of the interaction [31]. A successful touch interaction is determined by what is being touched (e.g., which body part), who does the touching (e.g., a child or adult), how they are touching (e.g., are they hitting, poking, caressing the target), and why they engage in a touch interaction (e.g., is it functional or social) [86].

Our objective is to co-create a gesture for the robot by moving its joints. The robot can record the motions by storing the changes in joint angles over time. The movable parts of the Nao robot are its head, its arms, and its legs. We considered the practical and social implications of creating a motion using each of these movable parts.

The Nao robot typically stands during the interaction, but even if it would sit down, there is a high risk of the robot falling over when the legs are manipulated. Moving the head and arms does not have that limitation. However, the head has a special social status. When moving the body parts of someone else, it affects their bodily integrity and might be experienced as uncomfortable for both parties [6]. In case of human-robot interaction, the robot experiences nothing when its body parts are moved around, but children might still feel a little uncomfortable [83]. This is especially prevalent when involving someone's head. Holding someone's hands and moving their arms around, however, is far more common, especially among children. That is why we selected to only co-create gestures with the arms of the robot.

3.4.3 Solution. The robot invites the child to create a gesture with its arms (see the middle pair in Figure 1). The robot can ask for a specific gesture (e.g., "I could really use a wave") or give a more general instruction (e.g., "Let's make a fun gesture for a greeting") depending on how specific the context is of where the gesture will be used. The robot tells the child they can think about what they want to do and to press a button on its foot (indicated with a green light) when they are ready to start recording. After the child presses the button, the robot instructs the child to grab its arms and wait until the countdown finishes to start moving. The robot counts down from 3 to 1 and starts recording the motions for a fixed amount of time. This can be different depending on the complexity of the requested gesture. The robot counts down from 3 to 1 to let the child know when to stop and let go of its arms. The gesture can be optionally replayed right away or be kept as a surprise for when it is used later during the interaction.

To reinforce the robot's bodily integrity, the robot explicitly invites the children to move its arms around, specifies a specific starting and stopping point, praises the result of the created gesture, and actively looks at his hands and follows the movements with its head when the child is moving them around. During the co-creation, the robot stands still (no motions) and the robot's arm motors are turned off (i.e., stiffness is set to 0) to allow for safe and smooth movements.

3.5 IDP3: Co-creating Light Animations

3.5.1 Problem. A unique quality of a lot of robots (Nao included), compared to humans, is that they carry an array of LED lights. The LEDs can be utilized to enhance the storytelling or for emotion expression [65, 66, 79]. When the robot uses these affective expressions, children appreciate the robot [81] and the story [88] more. What light expressions can the child co-create, and how can they create it?

3.5.2 Principle. Both affective and story-specific light expressions were considered. A benefit of creating affective expressions is that children can easily recognize them. However, children are quite able to recognize the affective state of the robot using a color scheme already [79], especially combined with other behaviors like gestures [88]. Yet, if the children create the robot's affective expressions, it might reduce (children's perception of) the robot's affective agency. Enabling children to create story-specific expressions with lights is the more straightforward option. To help the child, the robot would request a light expression for a specific scene in the story. We call each light expression a *light show*.

The co-creation itself is embedded in a conversation, so it makes sense to use the conversation as the way to co-create the light show. The viable full-color LEDs of the Nao are in its eyes, on the chest button, and on its feet. The eye LEDs, for example, are actually an array of LEDs themselves that can individually be controlled. Besides picking all kind of different color combinations, this opens up the possibility to add different animations as well. However, making the choices too complex is not only bad for usability but also can negatively impact children's sense of agency [73].

3.5.3 Solution. The robot invites the child to create a light show for a specific purpose (see the right pair in Figure 1)—for example, a light show to accommodate a couple of dolphins goofing around in the water. The robot tells the child they can think about what they want to do and to press a button on its foot (indicated with a green light) when they are ready. When ready, the children are offered a set of choices.

To make it not too complicated, children can either choose to pick static colors or a light animation. When they chose the static colors, they can pick three colors that would be used for the eyes (combined), chest, and feet (combined), respectively. The light animations involve all the LEDs simultaneously. Children can choose between a blinking and alternating animation. For the blinking animation, children can compile a list of colors (at least two) that would be displayed on all the LEDs in a continuous series. For the alternating animation, children would have to pick a left and right color. These colors would alternate between the left and right eye and foot LED (e.g., like a police siren). After creating the light show, the robot would praise the child for its creation and tell them it looks forward to see it in action.

3.6 IDP4: Coordinating the Co-creation Process

3.6.1 Problem. The three co-creation patterns aim to increase children's agency. However, making it a required component of the interaction not only is likely to inhibit this effect but also would leave a number of children dissatisfied with the interaction. Not everyone wants to create a sound effect, for example. How can we give children more control over the co-creation process?

3.6.2 Principle. The first question is what kind of control can we give children over the co-creation process? Making the co-creation not required seems to be a good step. The act of co-creation, and the freedom it gives, only makes sense when children are free to make use of it. However, the positive effects of the product of the co-creation should not be overlooked. By using the co-created content, the robot communicates to the child that it has heard and seen them. This is an important need for the children [55]. Furthermore, the created content is de facto a highly personalized expression the robot can use to keep children engaged during the interaction. At least some involvement of the children in the co-creation would be beneficial.

Enabling children to coordinate their involvement in the co-creation process is a way to make sure that at the end there was some involvement of the children in creating the content, while making it a less restrictive process. Children can choose between three levels of involvement. They can choose to create the content as specified in the three patterns ('high'), choose between two premade options ('mid'), or let the robot pick a premade option ('low').

Increasing children's ability to coordinate the co-creation process has two benefits. First, it is likely to increase the agency-supporting effect of the co-creation by making it a less restrictive process. Second, it will add opportunities for the child to co-regulate the interaction, which increases the sociability of the interaction [34].

3.6.3 Solution. Any co-creation process is started by the robot expressing a need for a specific piece of content (i.e., a sound effect, gesture, or light show). Instead of directly starting the act of co-creation as described by IDP1, 2, and 3, the robot first asks if the child wants to create it themselves or that the robot needs to download two content candidates. If the child chooses the former, the co-creation process continues as discussed in the previous patterns.

If the child chooses the latter, the robot shows a purple spinning eye LED animation indicating it is "downloading" the content. Once downloaded, the robot displays the two candidates and offers the child the option to either pick one of the two or let the robot pick its favorite. For example, after the robot plays two different samples of a roaring lion, it asks "Do you like the first or the second roar? Or do you want me to pick my favorite?"

Note that in our current implementation, there is no actual downloading necessary, because we premade all the pieces of content. However, in a future implementation, searching and downloading pieces of content might be possible. Yet, it is likely more feasible for sound effects than the other two types of content. Additional steps need to be taken to safeguard the quality and appropriateness of the content—for example, by using curated sources. Currently, the downloading step is kept in to fit with the narrative of the robot not having that piece of content.

3.7 Ethical Considerations

Working with children, especially with new technology, warrants a critical ethical reflection. We would like to highlight our considerations regarding two aspects that are especially relevant for our design. Those are children's physical safety and their right for privacy.

3.7.1 Physical Safety. We are using a well-maintained commercial Nao robot that has a certified (CE) conformity with European health, safety, and environmental protection standards. This means that within normal use, its users should not be in physical danger. We have a responsibility to ensure children know how to properly physically interact with the robot. There are two physical interactions that are part of the design: pressing the robot's foot bumpers and holding and moving its arms around to create a gesture. Both elements are practiced during a guided tutorial. To prevent the robot from accidentally hitting the child or falling on top of them, the child is required to sit at a minimal distance. When the child has to come closer to engage in one of the physical interactions, the robot does not move. In case an accident does happen, the researcher in the room can immediately stop the interaction. With its 57 cm, the Nao robot is roughly twice as small as the child, making it unlikely a child would sustain serious physical injury when the robot would accidentally hit them or fall over. In none of our studies (involving 500+ children) using these protocols, no one was injured by the robot.

3.7.2 Privacy. During the interaction between the child and the robot, there many aspects of the child's privacy that can be affected. For example, privacy sensitive aspects are their physical privacy over personal space, psychological privacy over thoughts and values, social privacy over their interaction with others, or information privacy over personal information [46, 67].

To protect children's physical privacy, they have agency of how close they want to sit near the robot. There is a minimal distance to protect their physical safety (see the previous section), and there is a maximal distance for the microphones to have enough signal to pick up what they are saying. We placed a rug on the floor to indicate the zone in which they can choose any position to sit in front of the robot. This reduces the risk for violations of personal space [85]. Physically interacting with the robot is always optional. That is one of the core motivations for IDP4. In case of the touch-based repair mechanism, they can choose to not answer, and the robot would continue with a default answer.

A big concern for conversational agents is the collection, processing, and dissemination of personal information. Children's psychological and social privacy is at stake during these processes [74]. The robot is asking children questions about their favorite animals and why they like them. We view whatever children self-disclose in response to these questions as inherently personal. To protect children's privacy, we have several safeguards in place.

The first is again agency. Children are free to withhold information or elaborate as much as they want. The second is transparency. The robot is telling the children what it will do with the information (i.e., to tailor the narrative conversation to their interests). The agency and transparency are the two most important factors to protect children's privacy regarding eliciting self-disclosures [89]. The third safeguard is to reduce the risk of oversharing. We designed the questions to not elicit too sensitive responses. They all revolve around children's interests and preferences regarding the zoo and the co-creation.

The next few safeguards relate to the processing of the information. We use Google Dialogflow for automated speech recognition. The robot records the audio of a response, sends that as input to the system, and receives a transcript with additional information (e.g., an intent). We consider the audio signal (voice) of the children to be personal information. Although parents gave explicit permission for using Google Dialogflow, it does not give the children or their parents direct control over their data. After the experiment is done, we request Google to delete the data, and officially Google is bound by the GDPR regulations to adhere to this request.[3] They claim that they will remove all the data within 180 days. It is unclear what exactly happens with the data in the intermittent time.

There are three possible violations of privacy that can happen here: if the audio contains something that was not meant for the robot, if the child wants to retract or change something about their response, or when the child cannot oversee the consequences of disclosing particular information. Reducing our dependency on external, commercial, and non-transparent services would be a good step to reduce the privacy risks for children. Currently, Google still outperforms open source alternatives [41], like Kaldi [63], but the alternatives are getting better [43]. To protect children's privacy while using a service like Dialogflow, we haven taken the following step. We only record and send audio that is contained to a specific query. Instead of continuous speech recognition, we only turn it on when necessary. For each question, we set a maximum recording time. Often only a few seconds of audio is necessary to get the answer. This prevents unnecessary audio to be sent to Google and reduces the risk that unintended speech (from the child or bystanders) is processed.

4 METHOD

We have developed a co-creation process that includes three patterns for co-creation and a pattern that allows children to coordinate their involvement in the co-creation process. With a user study, we aim to validate that the patterns for co-creation, and primarily the coordination pattern, facilitate co-regulation. A total of 59 school children participated in the study and were either assigned to the *coordination* condition or the *control* condition. In both conditions, children co-create six times. In the coordination condition, children can coordinate their level of involvement, which they cannot in the control condition. To not skew the control condition to either no co-creation or full co-creation, we fixed the level of involvement on the middle level (i.e., choosing between two content options).

[3]https://cloud.google.com/security/gdpr.

4.1 Research Questions and Hypotheses

The direct aim for enabling children to coordinate their involvement is to create a less restrictive co-creation process. If the co-creation process is indeed experienced as less restrictive, children would experience more agency and their coupling with would not be hindered by the coordinating acts. Coordinating the involvement takes more steps than just directly selecting the content. The additional load of these steps could be considered as a hindrance. Furthermore, with these additional steps, also more points of failure are introduced. By failure, we mean that children were not able to successfully create the content they envisioned—for example, because the speech recognition failed, when children would struggle while sculpting a gesture, or when children were not able to choose a specific color they wanted. A concept that captures children's experience of the coupling is called *interactional synchrony* [29]. To validate co-creation with coordination, we formulated the following research question.

> *RQ1. What is the effect of co-creation with coordinating the involvement on children's (a) sense of agency and (b) sense of synchrony?*

The coordinating pattern provides children with an active choice on how to proceed during the co-creation process. This choice itself warrants an increase in children's sense of agency [71]. Furthermore, the lack of being required to follow a specific route warrants an increase in children's agency [10]. Therefore, we hypothesize that co-creation with the coordinating pattern will result in a higher sense of agency compared to a process without coordination ($H1_a$). If the pattern functions properly, we expect that children's sense of synchrony will not be negatively affected and no difference will be observed with or without the pattern ($H1_b$).

The overall aim for enabling children to coordinate their involvement in the co-creation process is to improve children's co-regulation ability. The more children can co-regulate the interaction, the more social the interaction should be [34]. This should reflect positively on how children experience the interaction and the robot. In the current study, we evaluated this by looking at the satisfaction with the interaction and the social acceptance of the robot, respectively. This gives us the second research question.

> *RQ2. What is the effect of co-creation with coordinating the involvement on children's (a) satisfaction with the interaction and (b) social acceptance of the robot?*

We expect the interaction with coordination to provide an additional level of comfort. The opportunity for children to create the content themselves is likely experienced as more fun. Therefore, we hypothesize that children are more satisfied with the interaction when they can coordinate the co-creation process ($H2_a$). Furthermore, because the robot is the one who explicitly offers the children the opportunity to co-create, we hypothesize that they will accept the robot more ($H2_b$).

In the coordination condition, participants get to coordinate their involvement with each co-creation opportunity. It is interesting to study if the same child always chooses the same or rather a different option with each opportunity. A wide variety of routes would reinforce the importance of enabling children to coordinate their involvement in the interaction. Furthermore, identifying recurring patterns and getting insight into children's motivations during their decision making is useful to improve the existing patterns and inform future designs.

> *RQ3. How involved do children choose to be during a co-creation process, and what motivates their involvement?*

Finally, not only the effectiveness of the IDPs is important but also how satisfied children are with them. Do they value getting a choice, or would they rather just stick to one option? And why do they value it or not? What do children think about touching the robot or controlling its lights?

Does co-creating gestures and light animations add something, and how does it compare to the sound effects? These questions are all a part of the following research question.

RQ4. How satisfied are children with the interaction design patterns for co-creation?

4.2 Participants

A total of 59 participants (28 girls and 31 boys, 7–11 years old) completed the study. They were recruited via the after school care programs of four different Dutch primary schools with written consent from their parents. This study (ECIS-2020-07) was approved by the Ethical Committee for Information Sciences of our institution. The participating schools were all located in the same moderate-high income neighborhood. Most participants had experience with interactive technologies (e.g., voice assistants or toy robots), but none had a conversation with a robot before. The age and gender of the participants were kept balanced while assigning participants to a condition. Participants with the same age and gender were randomly paired. A pair was randomly split between the coordination (N = 32) and control condition (N = 27).

4.3 Experimental Design

The focus of the user study is to validate the IDPs. Therefore, the inclusion or exclusion of the patterns is the independent variable. In the coordination condition, the robot employs all four patterns to structure the co-creation process. To properly evaluate the patterns, we need to compare them against a fair baseline—one where the interaction is as similar as possible apart from those specific behaviors. The control condition is the interaction with no coordination, and the level of involvement is fixed on the 'mid'level. The child always has to choose between one of two content candidates. All other aspects are the same.

Because it is hard to assess one's attitude toward the robot for one condition independent of the other, the independent variable is a between-subjects factor. Children's sense of agency and synchrony, their satisfaction with the interaction, and acceptance of the robot are the four dependent variables.

4.4 Measures and Instruments

To measure the sense of agency, sense of synchrony, satisfaction with the interaction, and acceptance of the robot, we composed a self-report questionnaire containing a Likert scale for each measure. The items are available in Appendix A. *Robot acceptance* is the only one of our outcome measures that has an instrument that was properly developed and validated for a child-robot interaction with the Nao robot [16]. The items for the remaining constructs were translated to Dutch with a vocabulary suitable for children, and the robot's name, Hero, was used to refer to the robot. For uniformity, the rating scale from the robot acceptance instrument was used for all constructs.

A lot of work has been done measuring people's *sense of agency*, mostly revolving people's movement or in low-context tasks, in psychological and neuroscience research [78]. Inspired by the general construct of Tapal et al., we developed an explicit four-item scale for children's sense of agency that is tailored to our more localized and contextualized task.

The *sense of synchrony* is a measure of how smooth the interaction goes according to the participants. We used a three-item Likert scale from the Player Experience of Need Satisfaction (PENS) instrument [35, 68]

No generic construct exists for *satisfaction with the interaction.* Fitrianie et al. [19] aggregated items for many constructs evaluating human-agent interaction. Attitude toward interaction is one of them, which aggregated items from 16 different papers. We selected the three most fitting items focused on satisfaction.

A Cronbach's alpha analysis was performed to investigate the internal consistency reliability. The scales respectively were moderate-weak internally consistent ($\alpha_{soa} = .6$, $\alpha_{sof} = .6$, $\alpha_{soi} = .6$, $\alpha_{acc} = .7$) [25]. None of these scales could be significantly improved with removing an item. Although not ideal, scores between .6 and .7 are suitable for an explorative study like ours [62]. We therefore decided to calculate an average score for each scale.

We logged each coordinating decision and asked children to motivate some of them in the closing semi-structured interview. First, the motivations for the participants were categorized following a thematic analysis process [8] by two researchers. The semantic value of children's words, meanings, and utterances were used to group motivations and assign them to a meaningful category. The grouping was done individually by the researchers, and differences were resolved in a discussion. The categorization was done together. Independently from this process, participants with similar involvement decisions were grouped. These groups were grouped themselves according to their similarity and were labeled based on their most prominent feature. This allowed us to construct the *routes of involvement* participants took, the reasons for taking a particular route, and identify common routes. Furthermore, the motivations for (not) including an animation element in the 'closing show' provided insight into how satisfied children were with the co-creation of the sound effects, gestures, and light show.

Finally, the last instrument was a short semi-structured interview where we asked participants in the coordination condition to rate how satisfied they were with making a choice each co-creation opportunity and to what extent they wanted to just stick to one option on a 5-point scale. The latter question was reverse coded, and both scores were averaged to get a score for the *satisfaction with the coordinating pattern*. More importantly, we asked children to motivate their answer. We furthermore asked children to review the pattern for creating gestures, sound effects, and light animations, to be able to evaluate their *satisfaction with the co-creation patterns*. A similar thematic analysis process [8] was used, by the same two researchers, to group and categorize the participant's satisfaction with the different design elements.

4.5 Setup and Procedure

The study was conducted in a separate room (e.g., counselor's office) in the school. The robot was standing on the ground, the children were asked to sit in front of it. The researcher remained in the room but was positioned behind the participant, at an appropriate distance, to avoid unnecessary contact between the researcher and the participant. The researcher in the room was only part of the interaction during the tutorial. Once the conversation started, the researcher refrained from any interventions. Participants came in one-by-one.

When ready, participants were first introduced to the robot. This included a tutorial on how to talk to the robot by the researcher and, in case of the coordination condition, practicing with the different co-creation modes. This included a guided introduction to safely touch and move the robot. The script of the tutorial is available in Appendix B. When ready, the researcher started the interaction that ran fully autonomously the rest of the way. The core of the interaction was a conversation about the zoo. The robot and the child chatted about animals, and the robot shared three anecdotes about things that happened at the zoo. The first anecdote involved elephants, and the robot asked for a gesture illustrating an elephant splashing water with its trunk. The second anecdote involved a lion, and the robot asked for a roaring lion sound effect. The third anecdote involved dolphins goofing around, and the robot asked for a light show to accompany that. At the end, the robot asked the participant if they wanted to create a closing show including all elements. Children could optionally include a sound effect, gesture, and light animation. This provided an additional level of evaluation. Not including one of the elements might be a

Table 1. Overview of Co-creation Opportunities During the Interaction

	1: Elephant's Trunk	2: Lion's Roar	3: Dolphin Show	4–6: Closing Show*
IDP1 Sound effect		X		X
IDP2 Gesture	X			X
IDP3 Light show			X	X

*Each element was optional.
Note: In the coordination condition, participants coordinated their involvement (IDP4) with each opportunity. Opportunities 1 through 3 were required, and opportunities 4 through 6 were optional.

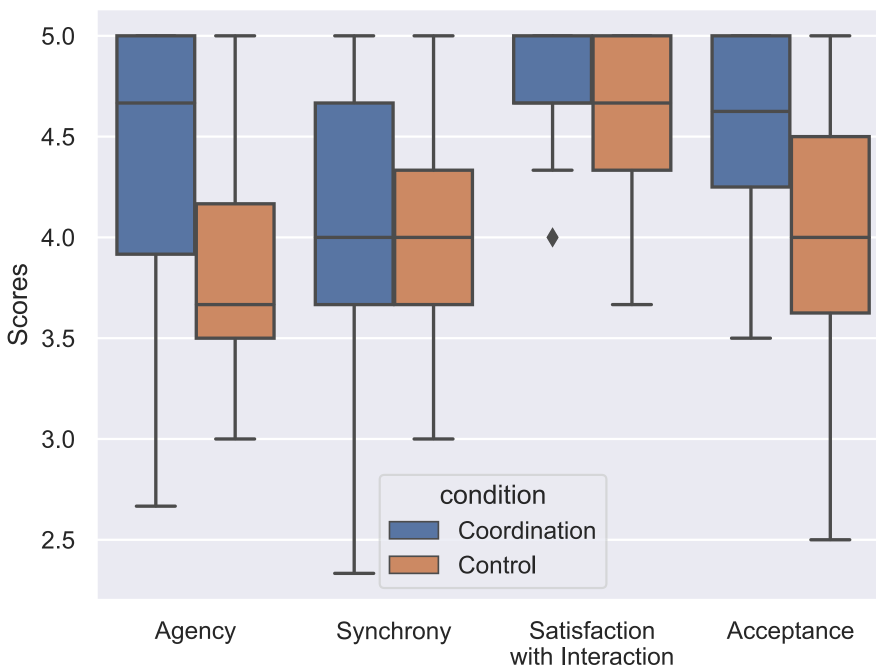


Fig. 2. Boxplot showing the scores, from left to right, of the sense of agency, sense of synchrony, satisfaction with the interaction, and robot acceptance per condition.

reflection of how (dis)satisfied the participant was with that option. This means that in total there were three required and another three optional co-creation opportunities during the interaction (Table 1).

The conversation in both conditions was the same apart from the dialogs that are part of the co-creation process and the content elements that are created. After the conversation, the participants filled in the questionnaires and were interviewed. When finished, the participant went back to their classroom and called the next participant. The instructions, interaction, and questioning took approximately 5, 15, and 10 minutes, respectively.

5 RESULTS

Because the scores of the measures (Figure 2) were not normally distributed, we used Mann-Whitney U tests to test our hypotheses. Reported data points are median [25% quartile, 75% quartile]. $N_{coordination} = 32$, and $N_{control} = 27$. A Bonferroni correction was applied to correct for the inflated chance of a type I error as a result of multiple testing ($\alpha_{bon} = .0125$).

5.1 Sense of Agency

The median sense of agency scores were statistically significantly higher in the coordination condition (4.7 [3.7, 5.0]) than in the control condition (3.7 [3.3, 4.3]), $U(59) = 639$, $p = .001$, Cohen's $d = .89$.

A Pearson's product-moment correlation was run to assess the relationship between the sense of agency and the number of times a participant chose to co-create.[4] There was a no statistically significant correlation between number of co-creations and the sense of agency, $r(30) = .34$, $p = .06$, with the number of co-creations explaining 12% of the variation in the sense of agency.

5.2 Sense of Synchrony

No statistically significant difference was found in the sense of synchrony scores between the coordination condition (4.00 [3.67, 4.67]) and control condition (4.00 [3.67, 4.33]), $U(55) = 378.5$, $p = .952$. We ran the TOST (two one-sided tests) procedure [45] to test whether both groups can be considered equivalent and reject the presence of a SESOI (smallest effect size of interest. Given the available participants and the effect sizes found in previous studies, we set the SESOI to be .5 (medium effect size). This gives us the equivalence boundaries of [−.5, .5]. If the 90% CI (confidence interval), of a sense of synchrony effect, completely falls inside these boundaries, we can conclude that the scores of the co-regulation and control condition are equivalent. Using the results of the Mann-Whitney U test, we construct a 90% CI of [−.43, .46], meaning we can conclude equivalence.

5.3 Satisfaction with Interaction

No statistically significant difference was found in the satisfaction with the interaction scores between the coordination condition (4.7 [4.7, 5.0]) and the control condition (4.7 [4.3, 5.0]), $U(59) = 445.5$, $p = .829$.

5.4 Robot Acceptance

The median robot acceptance scores were statistically significantly higher in the coordination condition (4.6 [4.3, 5.0]) than in the control condition (4.0 [3.5, 4.5]), $U(59) = 661.5$, $p = .0004$, Cohen's $d = 1.02$.

5.5 Routes of Involvement

5.5.1 Overview of Involvement. During the conversation, there were six co-creation opportunities (two of each modality). The first three were spread out over three anecdotes the robot was telling, and the last three were part of the same goodbye show. For the goodbye show, participants could first decide if they wanted to include a gesture, sound effect, or light show before engaging in the co-creation process. In the coordination condition, we logged for each co-creation opportunity which level of involvement participants chose. In Table 2, we present the total distribution of participants' selected level of involvement for both sets (anecdotes and goodbye show) of co-creation opportunities.

During the anecdotes, participants were equally split between creating it themselves (49%) and letting the robot download candidates (51%). For the goodbye show, 22% chose to skip it. Those who did want to include it slightly favored creating it themselves (56%) over downloading it (44%). When selecting a candidate, children mostly picked their favorite themselves (69% in the first half, 90% in the second half).

[4]Only applicable in the coordination condition.

Table 2. Overview of How Involved Participants Chose to Be (Only Applicable in the Coordination Condition) During the First Three Co-creation Opportunities (Anecdotes) and the Last Three (Goodbye Show)

	Anecdotes	Goodbye Show
Create	49%	44%
Child Picks Candidate	35%	31%
Robot Picks Candidate	16%	3%
Skipped		22%

Skipping the co-creation was only possible while creating the goodbye show.

5.5.2 Breakdown of Routes. Looking at the individual route each participant took, we see that most participants had different preferences at different points. A route is a specific set of choices the participant made for each co-creation opportunity. Of the 32 participants in the coordinating condition, there were 28 unique routes.

Although almost none of the routes were exactly the same, we were able to identify five different categories of routes. The categories are the creators (31%), the downloaders (19%), from-creator-to-downloader (19%), from-downloader-to-creator (15.5%), and modality avoiders (15.5%). We furthermore asked each of the participants to motivate the route they took and to pick their favorite level of involvement.

The *creators* chose to create the content in the majority of cases. Creating a sound effect for the goodbye show was the main exception. In most cases, the creators decided to not include it. They all indicated they preferred creating the content over the other two levels of involvement. They motivated that creating is more fun (60%), fits more with their creativity (30%) (e.g., "I like to try stuff out"), and gives them the opportunity to do something together with the robot (20%) (e.g., "Because only then you are doing something together with the robot").

The *downloaders* took the opposite route and predominately chose to let the robot download two candidates. All but one preferred the download option. That individual still preferred to have both options just in case they want to create something. The two main reasons for being a downloader is by either experiencing a lack of competence (83%) (e.g., "I did not know how to create a light show") or a lack of inspiration (33%) ("I like all colors, so I wanted the robot to decide"). The downloaders indicated that they thought downloading was easier and therefore preferred it, they felt unsure about how the creation process worked, they had no inspiration for the content they were asked to create, or a combination.

Where the creators and downloaders were consistent with their choices, the participants in the other three categories changed course during the interaction. Participants in the *from-creator-to-downloader* category started as creators and became downloaders. Half of them chose to create content for the first one or two co-creation opportunities and then decided to switch to downloading. Their preferences and motivations were similar to downloaders. This is not surprising considering they also mostly chose downloading overall. The other half switched in the end and chose to download during the last two opportunities. They indicated that they either preferred creating or both, but they switched in the end because they wanted to explore those options as well.

In the fourth category, *from-downloader-to-creator*, participants switched the other way around. All but one chose the download option during the anecdotes (the first half of co-creation opportunities) and wanted to create the content for the goodbye show. They all explicitly preferred to have both options available to them. They argued that downloading is easier or gives better results, but

Table 3. Overview of How much Participants Chose to Create a Gesture, Sound Effect, and Light Show (Instead of Downloading) and How much Chose to Include it in the Goodbye Show (Instead of Skipping it)

	Create	Included in the Goodbye Show
Gesture	61%	88%
Sound Effect	25%	56%
Light Show	53%	91%

they became curious later on and wanted to try—for example, "At first downloading is easier, and after a while it was more clear what how it works, then you want to try for yourself." The remaining individual preferred the download option and did not feel comfortable to create content until the very end and tried it during the last opportunity.

In the fifth and final category, participants avoided creating content for a specific modality, the *modality avoiders*, and had a general mixed strategy for making their decisions. One only chose to create gestures because they only had ideas for creating gestures and not for the other types of content. They did indicate to prefer to create in general. Another only created lights shows because that was the only modality they preferred. The last three indicated they had trouble with some creation attempts and avoided them the next time. They ended up preferring the download option because it was easier to use.

5.6 Satisfaction with the Coordination

We asked participants in the coordination condition to rate how satisfied they were with making a choice each co-creation opportunity. The resulting median [quartiles] satisfaction score was 4.5 [3.75, 5]. More importantly, we asked participants to motivate their answer. A total of 47% of them reported they enjoyed the freedom of choice. For example, one participant stated, "I liked to have that choice, it made me feel all grown up." A total of 28% explicitly appreciated to have a fallback when they did not know how to or what to create. One participant reported, "When you don't have the inspiration and you don't know what to do, it's nice to have that choice and let Hero download something." Finally, a total of 25% of the participants valued the control the coordinating acts gave them. One participant said, "It helps me get my way, and I like getting things my way," and another said, "I don't like unexpected things, this makes sure the robot doesn't do something I don't want."

5.7 Satisfaction with the Co-creation

Participants' choices regarding creating or including a specific type of content is an indicator for their satisfaction with the (usability of the) co-creation design patterns. In Table 3, an overview is provided detailing per modality for how many of the co-creation opportunities a participant chose to create the content as well as what percentages of participants wanted to include a modality in their goodbye show. Especially creating or including sound effects was avoided. Only 43% of participants indicated they were satisfied with creating sound effects. Some participants reported that the sound quality of the recording was too low. Others reported that they did not feel able to create the sound effect they wanted. One participant suggested to include more attributes to create sounds with. The low satisfaction might explain why a big portion of participants decided to leave it out during the goodbye show.

Participants were more satisfied with creating gestures (77%) and light animations (83%). Participants reported that it was fun to touch the robot, albeit strange at first. Some had no issues with moving the arms of the robot, whereas others reported that the arms were a bit stiff. Most participants were very careful moving the arms, which can explain why they felt stiff because a certain level of force is necessary to adequately move them around. The most heard complaint about the light show was the minimal explanation in the beginning. Where participants could actually practice with creating a sound effect and a gesture, the practice session of a light show was removed to save time. The robot just explained the process instead. This seems to have been a suboptimal decision in hindsight, likely explaining why a lot of participants chose to download a light show in the first opportunity. More participants created a light show the second time around (24% increase), whereas overall there was a minor decrease of creating in the second half. They liked doing it and thought it was easy to do. Some preferred to have more light animation options available to them.

6 DISCUSSION

6.1 Validation of IDPs for Co-creation

The results show that co-creation with coordination of involvement improves participants' sense of agency without inhibiting their sense of synchrony. We therefore can accept hypotheses $H1_a$ and $H1_b$. The results showed no effect of the co-creation process on the satisfaction with the interaction. This leads to a rejection of hypothesis $H2_a$. The results did show that participants accepted the robot more when they could coordinate the co-creation. This allows us to accept hypothesis $H2_b$.

There are two factors in the coordination condition that could contribute to the increase in agency. It could be a result of the co-creation itself or a result of coordinating the process. Or most likely, both contribute at the same time. Although a dedicated experiment is needed to distinguish between both factors, we can use the current data to draw some preliminary conclusions. There are participants who co-created less than others who reported a higher sense of agency. The results of the preliminary correlation analysis between the sense of agency and the number of times a participant co-creation suggest that co-creating more is by itself not a sufficient explanation for the variation in the sense of agency scores. The act of coordination is likely a bigger factor. Thus, to better support co-regulation during a co-creation interaction, children need to be able to coordinate their involvement.

The sense of synchrony scores in both conditions are equivalent. This means the children did not experience any additional hindrance in the interaction from the more elaborate dialog tree that comes with the coordination pattern. The coordinating dialogs are quite similar, and the concern was that repeating them too often might be experienced as annoying and disruptive. This seems not to be the case. Perhaps when used more often, it would still be beneficial to add more variation in at least the dialog surrounding the co-creation and the coordination. In general, the sense of synchrony is high in both conditions, indicating that the co-creation in general contributes to a maintaining a sense of coupling between the child and the robot.

Participants also rated their satisfaction with the interaction as very high across conditions. This shows, once again, that interacting with a robot, regardless of behavior manipulation, is a fun activity for children. In hindsight, given the similarity of the overall experience in both conditions, a difference on a general level of satisfaction would be hard to find. Additionally, trying to quantify the satisfaction with a subjective experience might not be all that insightful for validating the patterns anyway. It is more useful to look at the qualitative data that focuses specifically on children's satisfaction with the patterns.

The satisfaction scores of the coordinating pattern were generally high, at 4.5 out of 5. None of the participants in the coordination condition reported to have not wanted to coordinate. They appreciated both the level of freedom and control the coordination gave them, as well as that the pattern practically supports them through the co-creation process. If they had an idea they could create content themselves, and if they did not feel like it, they could let the robot download some options for them.

The robot is the one who explicitly gives children a choice of how involved they want to be with the co-creation. It is behavior that improves the robot's sociability. Children, in the coordination condition, indicated during the interview that they greatly appreciate this behavior of the robot. We reason that it is this explicit offering of a choice, and particularly the choice about how to coordinate the co-creation process, that is responsible for the improved acceptance rating. In other words, the coordination of the co-creation improves the social relevancy of the robot, which has a positive effect on its acceptance.

We can conclude that co-creation in general sustains the social coupling between the child and the robot. Children can co-regulate the shared agency they have with the robot during the co-creation better when they can coordinate their level of involvement, because it support their own agency and their ability to affect the shared agency. Children appreciate the choices they are offered by the robot, and they view it as a more socially relevant entity, increasing their acceptance of the robot. We consider the patterns validated.

6.2 Routes of Involvement

Almost all of the participants uniquely navigated the decisions that were offered to them by the coordination pattern. Collectively, the choices for creating content or letting it be downloaded are quite evenly spread. Both behaviors confirm the usefulness of including the coordinating pattern. It offers children more personal freedom, which is something they make use of heartily.

We were able to identify five categories of routes participants followed by looking for commonalities in the actual decisions the participants made and their motivations for those decisions. Those who enjoyed creating content, described themselves as creative, or especially liked doing something with the robot chose predominately for creating the content. We call them the *creators*. Their counterparts are called the *downloaders*. They reported a lack of competence or inspiration, and considered letting the robot download content to be easier for them. Not knowing what to create or just wanting to take the easier route are perfectly valid reasons to choose the download option. However, not knowing how to create is something that needs to be addressed. It is unclear whether those participants actually did not know how to create the content or rather felt too insecure to try. The participants all received the same scripted instructions. Practicing more during the instruction phase would perhaps be a solution for both reasons.

The next category, from-creator-to-downloader, has two subtypes. The first are those who started with creating but ran into trouble or were not satisfied with the result. They switched after the first one or two creation attempts to downloading the rest of the content. This shows the importance of having robust co-creation behaviors. An improvement could be to include an option to remake a piece of content if the child is not satisfied. Additionally, a behavior can be added to reintroduce co-creation to those who had some trouble during a previous attempt. Giving children the opportunity to practice again might make them more comfortable to choose for creating at a later opportunity.

The second from-creator-to-downloader subtype includes those who we can consider as curious creators. They prefer to create and selected that option until the last two opportunities. They expressed they were curious what the robot would do when they picked the download option. The coordination pattern offers children various options and enables them to explore those options. It accommodates both curious children as children who have strong preferences for one or the other options.

The fourth route category is from-downloader-to-creator. Children who belong to this category are hesitant at first to create. They choose downloading because it is the easier option, and they felt the most comfortable with that option at first. After a round of seeing which way the wind blows, their curiosity gets the better of them and they take the step to create the content for the goodbye show. At the end, most of them reported that they especially appreciate to have both options available to them.

The final category includes the modality avoiders. In most cases, children had a bad experience with creating one or more of the modalities and mostly avoided creating them in a future co-creation opportunity. The same suggestions to improve the robustness of the co-creation are valid here. However, some children in this category did not want to create content for a specific modality from the get-go. They did not know what to create or felt they could not get the same quality as the candidates the robot would download. One had a strong preference and only wanted to create content for one modality and did not care about the others. In those cases, they would pick the easier route of downloading. The coordinating pattern enables children with these preferences to tailor the interaction to their liking.

6.3 Satisfaction with Co-Creation

Overall. most children (88%) selected the creation option at least once. They selected to create gestures the most, followed by the light show. Creating sound effects was not so popular. Unlike in our previous study [55], children were not as satisfied with creating the sound effect. The implementation did not significantly change in the meantime. Perhaps in contrast to creating gestures and the light show, which both technically performed well, the low audio quality of the recording was more of a problem. Another reason might be that the sounds the robot requested this time were less fitting. Especially the sound effect for the goodbye show was a bit too broad. Some children reported a lack of inspiration or competence to create a suitable sound effect. Creating a gesture and a light show for the goodbye ceremony were more clear for the children.

Children did appreciate creating the gestures and the light animations to a high degree. We initially worried the children might damage or break the robot's arms by accident, but instead the children were sometimes even too careful. After an initial hesitation, most children reported they did not find it strange or uncomfortable to touch the robot. They were impressed by its accuracy of replaying the gesture. Regarding the light show, the children reported it was easy and fun to do, although they would have appreciated an actual tutorial at the start (e.g., gestures and sounds) rather than just an explanation. This would have likely boosted how many children would have picked to create a light show.

From these results, we can conclude that the patterns for co-creating gestures and light animations performed to satisfactory levels. The pattern for sound effects did not. Improving the audio quality will likely improve the satisfaction. It is important for all co-creation patterns that children get ample time to practice with them and that the goal for co-creation is clear and specific enough.

6.4 Additional Lessons Learned

Children reported many different reasons for their coordinating decisions. Three of them are not only relevant for the coordination process itself but also for improving many aspects of the child-robot interaction. They are the curiosity and insecurities of children regarding interacting with the robot and their dissatisfaction when they could not co-create the content they wanted.

6.4.1 Allow Children to Be Curious. Children in some cases switched between creating and downloading or vice versa because they were curious about the other options. Curiosity is a key cognitive motivator for decision making and learning, and especially essential for a healthy development of children [27, 42]. Providing children with enough things to discover during the interaction is likely necessary to keep them engaged for the long term [47]. We can learn from video game design, where by clever and content-rich design people are particularly eager to explore every aspect of the game [38]. For example, by hiding 'secrets' in a level for players to discover or by gradually unlocking abilities or items, players are continuously enabled to be curious and engaged [17].

6.4.2 Address Children's Insecurity About Interacting with the Robot. Some children indicated they felt insecure about how to proceed when creating the content themselves. They were unsure about what to do exactly or what to make. This can partly be addressed by improving the tutorial on how to create content to make sure that children at least technically know how everything works. However, suddenly having to touch the robot or make a sound the robot will replay can lie outside the comfort zone of some children. The coordination pattern accommodates these children by offering them an alternative. However, there were also children who wanted to try to create content but their insecurity initially held them back. Allowing them to practice more or giving them an escape if they try, by allowing them to change their mind or redoing a creation, might give them the confidence they need. Additionally, by allowing children to explore certain interaction modalities in a low-stakes setting might help break the ice. For example, including a casual tickling game where children can touch various buttons on the robot to make it laugh might make children more comfortable to touch the robot. This does not only apply to the specific context of co-creation but also to all aspects of interacting with a robot. Steps need to be taken to identify what children are insecure about, what makes them feel unsure, and how to best accommodate them.

6.4.3 Enable Children to Undo and Change (Parts of) the Interaction. In the current implementation, children can only go forward during the co-creation and not undo and change it. As we discussed in the previous section, allowing children to change the co-creation might give them the confidence to try it at least. Another more pressing reason is that some children reported being dissatisfied with the outcome of the co-creation. They indicated they wanted to rectify a mistake or had a better idea afterward and wanted to create that instead. Both options were not available, leaving them disappointed.

Permitting easy reversal of actions is one of Shneiderman's eight golden rules of interface design [72]. This applies just as much to a screen interface or a robot interface when creating something. By allowing children to change their mind after they made a decision or even switching an answer (e.g., "My favorite animal is a dog, [not] a tiger!") will likely increase children's agency and the robot's sociability even more. If nothing else, it will at least increase the usability [61]. A proper undo and redo strategy is often missing in human-robot applications [32].

6.5 Limitations

There are six limitations of our study we would like to highlight. First of all, although we were quite happy with the sample in times of COVID-19, the size of and especially the representation within our sample is limited. The participating schools were all located in the same moderate-high income neighborhood. A larger and more diverse sample is not only beneficial for statistical inference but greatly important for developing social robots that are inclusive for children with many backgrounds.

Second, the interaction was a single session, but the robot should ultimately engage children for multiple sessions. Although we feel confident that the positive effects of the co-creation will persist for more sessions, we need a multi-session user study to confirm that.

Third, a limitation of our experimental design is that we did not compare the co-creation without coordination. Because both the co-creation patterns and the coordination pattern aim to support children's agency, it is especially relevant to be able to study the effect of both patterns on agency separately. The current study setup did not allow us to make that disambiguation. Although we collected some preliminary results, a new user study that is dedicated to making that comparison is necessary to make statistical inferences about the individual contributions of the patterns to supporting agency.

Fourth, a core part of our instrument set are self-reported questionnaires that are not fully validated. This does not mean the results are not reliable, especially when they are prepared with care [51]. However, additional care is needed when interpreting the results. We backed up the main conclusions with qualitative interview results. Ideally, also more objective behavioral observations would have been included.

Fifth, the patterns were designed by the researchers based on their experiences during earlier studies involving child-robot interactive storytelling. Ideally, the co-creation activities would have been developed in a participatory design fashion. This would have more strongly anchored the children's needs into the design.

Finally, the patterns are designed with the Nao robot in mind and are only validated with a Nao robot. Adaptions in various degrees might be necessary to use the patterns on a different robot platform. For some robot platforms, the patterns are not compatible at all. For example, for recording and replaying sound effects, a microphone and speaker needs to be part of the robot. We would like to encourage other researchers to adopt and adapt the patterns and share how they are (not) compatible with other robot platforms. This collaborative effort will only increase the reach and validity of the patterns.

7 CONCLUSION

We started this article by remarking that children's co-regulation ability is often undermined when they interact with an autonomous social robot. We reframed the notion of how a social robot could support the co-regulation ability of children. We identified that co-creating expressive content during the interaction is a viable strategy to facilitate more co-regulation. We set out to explore that solution. We presented four IDPs that allow children to co-create sound effects, gestures, and light animations and, most importantly, allow children to coordinate their involvement in the co-creation process. The results showed that the co-creation patterns provide a novel way for the robot to acknowledge the children's expressions and for the children to see something of themselves in the robot (RQ4). It improved children's sense of agency without inhibiting their sense of synchrony (RQ1). The coordination of involvement, furthermore, provided children with a concrete way to manage the shared agency during the co-creation. Because it is the robot who explicitly offered children to choice, it had the additional benefit of making the robot more socially relevant. This ability was recognized and greatly appreciated by the children, shown by their increased acceptance of the robot (RQ2).

Children use this freedom extensively, and almost all managed their involvement differently. Nonetheless, we identified five categories of routes children took, revealing the different needs and motivations children have when interacting with the robot (RQ3). Some just really enjoyed creating the content themselves and considered it a creative outlet. Others preferred to take the easier route of letting the robot download the content. Some were unsure about how and what to create or had some trouble creating, leading them to avoid that modality or switch to downloading entirely. Others were just so curious that they wanted to try all levels of involvement. These different needs, preferences, and styles regarding the interaction reinforces the importance of enabling children to co-regulate the interaction. The interaction design pattern for coordinating involvement provides that ability. And with that, we have created a more inclusive robot.

For any socially assistive robot, maintaining the social coupling is key to its effectiveness. Interactive co-creation with coordination of involvement provides a concrete way to add more co-regulation to the interaction. Co-regulation is essential for maintaining this coupling. Our design patterns therefore contribute to creating more inclusive, effective, and meaningful socially assistive robots for children.

APPENDICES

A MEASURES AND INSTRUMENTS

A.1 Pattern Effectiveness

Sense of Agency	Ik kon geluiden, bewegingen, en lichten maken zoals ik wilde. *I could create sounds, movements, lights the way I wanted to.* Ik bepaalde hoe de geluiden, bewegingen, en lichten er uit kamen te zien. *I dictated how the sounds, movements, and lights would look like.* Soms moest ik geluiden, bewegingen, of lichten kiezen die ik niet wilde. (r) *Sometimes I had to pick a sound, movement, or light I did not want to. (r)* Ik kwam altijd uit op een geluid, beweging, of licht waar ik tevreden mee was. *I always ended up with a sound, movement, or light that I was satisfied with.*
Sense of Synchrony	Het gesprek verliep soepel. *The conversation went smoothly.* Ik hoefde niet te lang op Hero te wachten. *I didn't had to wait long on Hero.* Hero luisterde goed naar wat ik zei. *Hero listened well to what I said.*
Satisfaction with the Interaction	Ik ben tevreden over het gesprek met Hero. *I am satisfied with the conversation with Hero.* Het gesprek met Hero was saai (r) *The conversation with Hero was boring.* Ik raad mijn vrienden het gesprek met Hero aan. *I would recommend the conversation with Hero to my friends.*
Robot Acceptance	Ik wil Hero graag opnieuw zien. *I would like to see Hero again.* Ik wil graag opnieuw met Hero spelen. *I would like to play again with Hero.* Het zou leuk zijn als Hero en ik opnieuw iets kunnen doen samen. *It would be nice if Hero and I could do something together again.* Ik zou Hero mee naar huis willen nemen. *I would like to take Hero home.*

The sense of agency items are inspired on the agency item of Tapal et al. [78]. The satisfaction with the interaction scores are based on the aggregated items as collected by Fitrianie et al. [19]. The robot acceptance measure is developed by De Jong et al. [16]. All measures are scored on the rating scale depicted in Figure A.1, which is developed by Van Straten et al. [77].

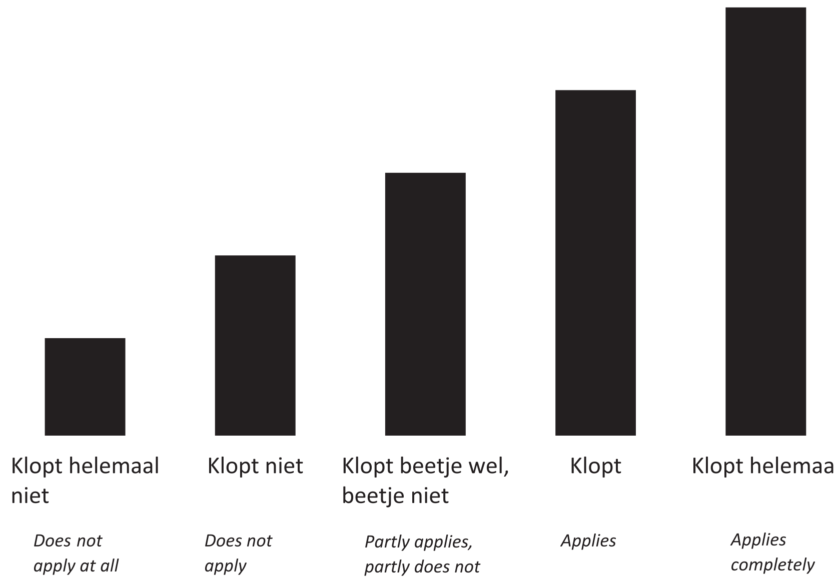


Fig. A.1. Rating scale developed by Van Straten et al. [77] and also used by De Jong et al. [16].

A.2 Pattern Satisfaction

Route Motivations	Vraag kinderen hun coördinerende keuzes te motiveren. Voorbeeld: Waarom maakte je X zelf en koos je bij Y voor downloaden? *Ask children to motivate their coordination decisions.* *Example: Why did created X, but chose to download Y?* Kies je het liefste voor maken of downloaden? Waarom? *Which option do you prefer: creating it yourself or downloading? Why?*
Satisfaction with Coordination	Ik vond het fijn dat ik steeds mocht kiezen tussen het zelf maken, uitkiezen of de robot laten kiezen van geluiden, gebaren en lichten.* *I appreciated that I could choose between creating, picking, or letting the robot pick sounds, gestures, lights.** Ik zou het fijner hebben gevonden als ik niet steeds hoefde te kiezen.* *It would have been better if I didn't have to choose every time.** Kun jij je scores uitleggen? *Can you explain your ratings?*
Satisfaction with Co-creation	Was je tevreden met het maken van [geluiden / gebaren / lichten]? Waarom? Wat ging goed en niet goed? *Were you satisfied with the creation of [sounds / gestures / lights]? Why? What went well and what didn't?* * Rated on the rating scale depicted in Figure A.1.

B CO-CREATION TUTORIAL DIALOG

Hi [first-name], my name is Hero and I'm a social robot.
I am practicing to become a friend for children in the hospital.

Thank you that you want to help me.
I like to chat and tell stories.
I like to add sound effects to my stories.
I can also add gestures and light animations to the stories.
Watch this. I'm driving a race car.
[play racecar.wav], [gesture racecar.xml], [led alternate orange purple]
Cool, no?

The only thing is, I don't have the right sound effects, gestures, and light animations for every situation.
Luckily you can help me with that.

Speech

Mike and I will first explain how this all will work.
Let's start with how we can talk to each other.
I will ask you questions.
And you can just answer them.
I will help me out if you can talk loud and clear.
After a question, I'll beep like this [beep].
It's important that you answer after the beep so I can hear you.
Let's practice this. Here is my first question.

[led faceLeds blue]
Which color are my eyes now?
Correct: They are blue indeed. Well done!
Incorrect: They can get that color, but this time they were actually blue.
Fail: Thank you. Don't forget to answer loud and clear.
[led faceLeds white]

Touch

Sometimes I have trouble understanding people.
If I can't hear you, you can use my feet!
Because I have buttons on my feet.
Can you show them, Mike?
The light above the yes button is green, and the light above the no button is red.
For some questions, I will list a number of answer options, and if you hear an answer you like, you can press the yes button.
Let's practice this.

What color are my shoulder blades? Press the yes button if you hear your answer.
Options=[purple, light blue, dark grey, green]
Correct: Yes! They are dark gray indeed.
Incorrect: I wish they had that color, but my shoulders are dark gray.
Fail: My shoulders are dark gray. Don't forget to firmly press the buttons.

Sound Effect

Let's move on to creating a sound effect.
I will ask you to make a specific sound. For example, the squeaking of a mouse.

Then I will count down, and you can create the sound effect. You can, for example, say squeak, squeak, squeak.
Let's practice this.
Squeak like a mouse in 3, 2, 1.
[record mouse].

Nicely done.
This is how your sound effect sounds.
[play mouse]
Nice! This will come in handy later.

Gesture

Like you probably have noticed by now, I like to wave my arms around.
I feel it supports what I am saying.
Mike, can you show [first-name] how to make gestures with my arms?
[stiffness arms 0].
[wait-for-button-press head].
[stiffness arms 100].
Well done.

Let me explain some more.
Just before I start recording a gesture, I will play this sound.
[play ready-to-record-gesture.wav]

And just before I will stop recording, I will count down from 3 to 1.
Let's just practice this.
I would like a gesture like I'm waving a magic wand.
If you are ready to start, you can press my left toe where the light is green.
[wait-for-button-press left-toe]

You can grab my arms now.
[play ready-to-record-gesture.wav]
[start-recording-gesture magic-wand]
3. 2. 1. Done.
[stop-recording-gesture]

Let's check out the gesture you just made.
[gesture toverstaf]
Cool cool cool cool!

Light Show

Last, I also have lights all over my body that I can use to create a light show.
I can change the color of the lights in my eyes, chest, and feet.
[led eyes:blue chest:red feet:green]

Cool, no? I can also animate the lights.
I can let the lights blink.
[led blink purple, blue, green, yellow, orange, red]

Or let the lights alternate.
[led alternate red blue]

By answering questions, we can create a light show together.
I will first ask you if you want to animate the lights.
If you say no, you only have to pick the colors for the lights.
If you say yes, you can choose between a blinking and alternating animation with the colors you want.

Coordination

You have learned how to create a sound effect, gesture, and light show.
It's fine if you don't want to create it yourself.
I can also download sound effects, gestures, and light animations from the internet.
You can always choose between creating it yourself or letting me download some options.

Wrap-up

I guess I explained everything now.
Do you have any questions?
Yes: Mike, can you help out [first-name]?
[wait-for-button-press head].
No: Great!

Let's start with our actual conversation!

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