# Patricc: A Platform for Triadic Interaction with Changeable Characters


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**Figure 1: Parent-toddler-robot triadic interaction (parent gave consent for publication of image).**


## ABSTRACT

While social robots for education are slowly being integrated in many scenarios, ranging from higher-education, through elementary school and kindergarten, the use case of robots for toddlers in their homes has not gained much attention. In this contribution, we introduce Patricc, a robotic platform that is specifically designed for toddler-parent-robot triadic interaction. It addresses the unique challenges of this age group, namely, desire for continuous physical interaction and novelty. Patricc's unique design enables changing characters by using dress-able puppets over a 3D-printed skeleton and the use of physical props. A novel authoring tool enables robot behavior and content creation by non-programmers. We conducted an evaluation study with 18 parent-toddler pairs and compared Patricc to similar tablet-based interactions. Our quantitative and qualitative analyses show that Patricc promotes significantly more triadic interaction, measured by video-coded gaze, compared to the tablet and that parents indeed perceive the interaction as triadic. Furthermore, there was no novelty-induced significant change in task-oriented behaviors, when toddlers interacted with two different characters consecutively. Finally, parents pointed out the benefits of changeable puppet-like characters over tablets and the appropriateness of the platform for the target age-group. These results suggest that Patricc can serve as the first gateway of toddlers to the emerging world of social robots.



## CCS CONCEPTS

• **Human-centered computing** → *Empirical studies in HCI*; • **Applied computing** → *Interactive learning environments*; • **Computer systems organization** → *Robotic autonomy*.

## KEYWORDS

Toddler robot interaction; English as Second Language; Parent-child-robot

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# 1 INTRODUCTION

Social robots are slowly being integrated into our daily lives, in work spaces [40], educational systems [17] and our homes [33]. Social robots for education are blooming, with applications ranging from language [3] to science [36].

Most of these educational applications of social robots target children [3], starting from preschool [17], through elementary [43] and adolescence [2]. Few studies have been conducted with toddlers, ages 1-4 years, and those were conducted either in an educational settings with groups of toddlers [27], or were teleoperated [35].

In this contribution we focus on social robots for toddlers, which are a unique target group, with special HRI-related requirements.

**Mode of interaction.** The common educational mode of interaction with social robots are one-on-one, i.e. a single robot interacting with a single child [17, 26]. Several studies have reported on a more traditional frontal teaching mode [43] and addressing the challenge of small group activities have only been reported recently [21, 32]. However, one-on-one with a robot is rarely an option for toddlers, and group activities can only be applied in the private educational system. The most common social scenario for toddlers is interaction with their caregiver, e.g. parent, yet to the best of our knowledge, no study has addressed a toddler-parent-robot interaction.

**Physical interaction.** Toddlers' renowned exploration and inquisitiveness extend to the tactile modality. Few social robotic platforms have integrated physical props as a mode of interaction for education [10].

**Long-term interaction.** The holy grail of educational social robots is long term effective interaction [6, 20]. Toddlers, with a much shorter attention span, create an even greater challenge in this aspect. While personalization of content [23] and social behavior [13] has been studied and implemented, the importance of large amount of content and continuous novelty cannot be overstated [20, 33]. Generation of HRI-appropriate content requires both pedagogical foundations and robot behavior variability [22]. While easy-to-use interfaces and programming languages have been developed for HRI [8, 31], fluent, generic and versatile tool for non-programmers are scarce .

Here we present Patricc, a **P**l**A**tform for **TR**iadic **I**nteraction with **C**hangeable **C**haracters. Its main features are: (i) a 3D-printed upper-torso skeleton, with changeable puppet-like characters; (ii) an accompanying platform for physical educational props and; (iii) easy integration of content via an authoring tool for non-programmers. Furthermore, during the interaction the toddler's parent is taken into consideration to both facilitate smoother interaction and enable emotional and social support.

We conducted an evaluation study, in which we chose English as a Second Language (ESL) as the educational content. We used our authoring tool to easily integrate novel robotic behaviors with sound pedagogical activities, supported by content-appropriate props. 18 pairs of parents and toddlers interacted with Patricc. We performed quantitative and qualitative analyses of the interaction, and compared it to similar activities performed with a tablet.

The paper's main contributions are: (i) a novel robotic platform designed for toddler-parent-robot interaction; (ii) a novel authoring tool for non-programmers to introduce content and behaviors and; (iii) an evaluation study with the platform.

# 2 RELATED WORK

Several robot platrforms have been used in recent years for educational purposes with children. While the most common one is the Nao platform, it is relatively expensive, has a hard exterior and is usually aimed for older children. While Jibo has been recently used for home applications [33], it also has a hard exterior and was used in conjunction with a tablet for content. Several plush-like robots have been used successfully for long-term engagement, such as DragonBot [34] and Tega [41]. However, they had a squash-and-stretch behavior, that does not support pointing or gestures [7]. While Blossom, a recent addition to the robot zoo, has introduced the concept of changeable exteriors [38], most of the social robots have a single look and character, that may hamper continuous novelty and interaction for long-term engagement.

Children in preschool, elementary school and adolescence have been mostly interacting with social robots in one-on-one interactions [17, 26]. Most educational scenarios involved an additional screen, e.g. tablets, to supply the content and an object for joint attention [12, 33]. The role of the robot in these one-on-one interactions can be either a peer [17], younger peer [12] or tutor [43], and can facilitate personalization of content [23] and affective behavior [13, 28]. Several studies have started to address interaction with groups of children [21, 32], but toddlers' group interaction occurs mainly in the private educational system, since public education starts at older ages.

While several robot studies addressed children ages 1-4, the robots were either not autonomous, i.e. were teleoperated [35], or interacted with a group of children in an educational facility [27].

Toddlers' attention span is much shorter than older children [37], and hence requires shorter interactions. However, in order to maintain long term engagement, varying content for each interaction is key [20, 22]. Integrating new content and robot behaviors to an increasingly larger repertoire of activities, is thus an important aspect of any robotic platform [8, 22]. Enabling non-programmers to perform this task can increase its scalability. Moreover, because it is usually the educational personnel who creates the ideas for the learning activities, enabling them to also implement the activities in the robot shortens the process for creating new content. Several friendly user-interfaces have been used in recent years [25], such as the Nao's Choreograph [31], Keepon [18], Lego Mindstorm [15], and more generally programming by demonstration [5]. An analysis of robot APIs have shown that there should be different levels of abstraction for programming social robots [8].

In this contribution we use English as a Second Language as our educational content. Numerous studies have been performed with social robots for language learning [4, 14]. However, most have been conducted with older children, starting with preschoolers [17, 29] up to elementary school children [26, 43].

Toddlers' second language learning requires different pedagogical considerations [9]. Five basic principles have been shown to be of prime importance: (i) face-to-face interaction; (ii) addressing using "parentese"; (iii) encouragement of verbalization; (iv) high quantity of input and; (v) multiple native English speaking characters. A social robot aimed specifically for toddlers should implement these challenging requirements.

## 3 DESIGN CONSIDERATIONS

The main objective of the Patricc platform is to deliver content to toddlers in an entertaining long-term interaction. The focus of the designed platform is its differentiating target group, namely, toddlers. This age group presents many challenges that are overlooked in older children and are specifically addressed in our design criteria:

**Continued novelty**. To overcome challenges in long-term toddler's engagement, our platform's entire design, namely, physical appearance, content and expressivity, should enable continued novelty. In other words, the platform should enable novel exterior appearances, easy introduction of new content and fast integration of new expressions.

**Physical interaction**. Toddlers are a highly curious and explorative age group. Hence, our platform must have a very physical presence, that can be touched and felt. In addition, physical interaction modules that the toddler can hold and manipulate lead to a more natural and embodied language learning [30].

**Childish expressivity**. Toddlers, as opposed to older children, are not yet set to the "traditional robot" appearance of hard (metal or plastic) exterior and "robotic" expressivity [39, 42, 44]. Hence, our platform should have a soft, puppet-like exterior that is more accessible to toddlers of all genders.

**Low cost design**. One of our main design criteria was to create a relatively low-cost, easily assembled platform, to enable future scalability and applicability to many types of interactions.

We next elaborate on our design decisions and their compliance with our design criteria, see Table 1.

### 3.1 Patricc's appearance

Our first and foremost design decision was to separate the structure and control of the robot from its exterior appearance. For this purpose, we have designed a "robotic skeleton" upon which puppets can be "dressed", Fig. 2. The main purpose of this design feature is to create a richer interaction and delay the novelty effect. Once on the robot, the puppet remains connected to the robot by utilizing a set of strong magnets. Another advantage is that letting the toddler choose the character she prefers to interact with and letting her "dress up" the robot may increase the toddler's engagement in the educational activities. Furthermore, interaction with robots is an unfamiliar situation for the toddler and parent. By designing the robot as an anthropomorphic plush puppet, the toddler can relate to prior experiences of playing with dolls.

The skeleton itself was designed as an upper torso, with head, neck and two arms. This design decision stemmed from our desire to enable naturalistic and easily interpretable expressivity. In other words, we opted for human-like gestures that enable understandable expressions, e.g. waving hello, interactive-oriented gestures, e.g. pointing, and informative content-related gestures, e.g. up and down [7].

The shoulders and neck joints were designed in a manner where the axes of the links of the robot's mechanism and the axes of the joints were non-orthogonally connected. This sort of configuration complies with the childish expressivity criteria and was aimed to create the illusion of a higher amount of degrees of freedom.

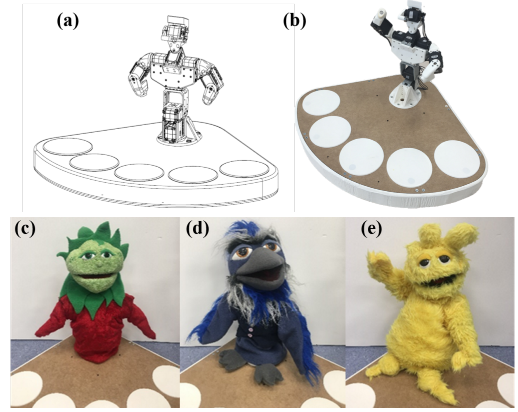


**Figure 2: Patricc robotic platform and puppet characters. (a) Mechanical sketch. (b) Patricc's upper-torso skeleton. (c)Tutty. (d) Bluejay. (e) Fuzzy.**

The last appearance design decision was a stationary platform, to facilitate the props' console, Sec. 3.3 and triad parent-toddler-robot interaction Sec. 3.5.

### 3.2 Action and Perception

While new robotic platforms boast in a large array of sensors, such as multiple RGB-D cameras, directional microphones and touch screens, we have opted for the other end of the sensor spectrum. Our initial robotic platform has sensors only on its console, thus supporting only props-mediated interaction, Sec. 3.3. This complied with our low-cost and physical interaction criteria. While we acknowledge that future platforms will probably include a larger sensor-suite, currently we address this lack via introducing the parent-toddler-robot triad interaction mode, Sec. 3.5.

As for the actions and expressivity of the robot, we opted for a relatively highly expressive skeleton that is important for introducing novel content, creating joint attention and expressing engaging gestures. While this slightly contradicts our low-cost criteria, it is aligned with the physical interaction and childish expressivity criteria.

### 3.3 Console

The platform included not only the robot skeleton, but also a console for physical props. This decision was made to comply with the physical interaction criteria and enable children to physically touch and manipulate the objects.

Furthermore, the console enables the introduction of numerous content-related props, also complying with our continued novelty criteria. Each session can include different low-cost props, thus maintaining long-term interest of the toddler in the interaction.

The console should also include electronics and sensors of the entire platform, and serve as a stable basis for the stationary skeleton. Thus, the toddler will be unable to pick-up or topple the robot, due to its stable console-based foundations.

Finally, the console-robot configuration automatically conveys a proper interaction direction, where the toddler sits in-front of the robot, with the props on the console serving as a joint physical

**Table 1: Design criteria and decisions.**

| Criteria | Appearance | Action & Perception | Console & Props | Authoring tool |
|---|---|---|---|---|
| Continued novelty | Puppets | Human-like skeleton | Content-related | For non-programmers |
| Physical interaction | Plush characters | | Physical props | |
| Childish expressivity | Upper-torso | Gestures, Pointing, Mouth | | Kinect-robot transformation |
| Low-cost design | 3D-printed | RFID only | 3D-printed or bought | |

space. Thus, Patricc can point and look at a specific prop to instigate joint-attention with the toddler.

## 3.4 Authoring Tool

The continued novelty design criteria dictates that there should be an easy integration of novel content. For this purpose, we have decided to develop an authoring tool for the platform: the expressions of Patricc's skeleton should be easily recorded and not programmed; audio should be easily integrated into the interaction and; interaction flow should be easily inserted and changed. Our design decision was to create a tool that non-programmers can easily use to insert new content and interaction, to facilitate large amounts of educational interaction sessions.

## 3.5 Toddler-Parent-Robot Interaction

A major novel design decision of the platform interaction mode was to include the parent (or other caregiver) of the toddler in the interaction. This triad, namely, toddler-parent-robot, is crucial for the fluid dynamics of the interaction for several reasons.

First, the parent serves as a buffer for the lack of a comprehensive sensor-suite in the platform. Thus, the parent can mitigate the robot's sometimes inaccurate perceptions of the toddler's actions, e.g. via the props manipulation.

Second, due to the young age of toddlers, there may be a lack of understanding of Patricc's instructions and directions during the interaction. The parent can facilitate such misunderstanding and enhance the flow of the interaction.

Third, the parent serves as emotional support for the toddler. Due to the aforementioned challenges, the toddler may at times feel either frustrated or shy and the parent can lend emotional support to continue the interaction.

While it may seem that the parent should "solve" Patricc's deficiencies, our design decision goes much deeper. Especially in toddlers' education, parental support is crucial from social and emotional viewpoints. Hence, we view the parent as a full participant in the interaction. While Patricc is not addressing the parent directly, the interaction will be designed such that the entire session will be perceived as a rewarding experience for both parent and toddler.

# 4 PATRICC

We next describe in detail Patricc's final design.
(Models and code are open-source and can be found at
https://github.com/CuriosityLabTAU/Patricc).

## 4.1 Robot's skeleton

The robot's skeleton is 29 cm tall and its height with the puppet on is 42 cm. These dimensions were set to facilitate a comfortable interaction whether the toddler is sitting or standing. The skeleton's proportions were set to resemble human body proportions.

The robot has 8 degrees-of-freedom (DOF). It has two motors at its base which turn the whole robot sideways and tilt it forward and backward. Each arm has two motors, one at the shoulder joint which rotates the whole arm up and down and another motor at the elbow joint. There is also a motor at the neck joint. Because the head's main axis is tilted with respect to the motor's axis, motion of this motor causes the head to simultaneously move sideways and upwards. This configuration of motors enables the robot to direct its gaze towards objects and towards the toddler and parent. The neck DOF, despite not being critical for directing the robot's gaze, was added to make the robot's motion less rigid and more life-like. The arms were designed to enable accurate pointing at objects and to perform various gestures, such as waving, signalling the toddler to pick up and put down objects and explaining vocabulary (i.e. up/down, left/right). The last motor is situated in the robot's head and is responsible for moving the robot's mouth synchronously with its speech.

## 4.2 Puppets

We designed 3 puppets which can be easily "dressed" on the robot to let the toddlers interact with multiple characters using only one robot, Fig. 2. For each puppet a unique character was defined. Our guideline in designing the characters was to differentiate each character from the other under the constraint of keeping the same morphology. The purpose for this was to: (i) Increase the chance that most of the toddlers will find at least one character that they like. This contrasts with designing three mostly similar characters, e.g. having the same overall appearance but different colors. (ii) Create a unique experience interacting with each character, and by this, to delay the novelty effect.

The three chosen characters are: (i) Tutty- A perky, teen aged girl with an appearance inspired by a strawberry. (ii) Blu Jay- Old male, amusingly strict with an appearance inspired by a bird. (iii) Fuzzy- A laid back, gender-less character at age of about 20-30 years old with an appearance inspired by a yellow color blob.

With these three characters, we created many variable interaction-axes, namely, color (red/blue/yellow), gender (female/male/other), age (teen-age/old/adult) and roles (older sibling/teacher/other). Hence, each toddler can find a desired character.

## 4.3 Console

The console is the means by which the robot senses the toddler's actions. There are five RFID readers integrated in the console, controlled by an Arduino micro-controller. Each RFID reader continuously detects the prop which is situated above it, thus enabling the system to receive feedback regarding which prop the toddler has picked up.

The props are the tool by which the toddler and parent communicate with the robot. Each prop is a plastic 3D model representing the vocabulary term taught during the interactions. An RFID tag is attached to the base of each prop. The size of the props was set to be easy for a toddler to grasp and also large enough for the robot to accurately point at. During the evaluation study, 13 distinct props of animals, fruits and vegetables were used.

The dimensions of the console were set according to the robot's ability to point at objects in its perimeter. An important requirement is that the toddler and parent should be able to accurately understand which object the robot is pointing at. Therefore, ample spaces were left between the RFID readers that serve as the platforms for the props.

## 4.4 Actuation

Patricc has 8 Dynamixel Ax-12 smart servos. One of the main reasons we chose these motors was because of their internal circuits that can be programmed to shut down a motor if it exceeds temperature, torque or current limitations. These features are important as they serve to ensure the safety of the robot and toddler, for example, in the likely situation that the toddler decides to hug the robot and exerts a large force on its motors.

## 4.5 Fabrication

Our main guideline in choosing methods for fabricating and assembling the system was to make it possible for educational facilities and research labs to manufacture and upgrade their own systems. Patricc's structural parts are off-the-shelf Dynamixel motor brackets and new designated brackets designed and 3D printed in the lab. The console's parts were 3D printed except for the upper and lower plates which were laser-cut. All the electronic modules are off-the-shelf products besides a designated PCB which connects the 5 RFID readers to the Arduino micro-controller.

The costumes were designed for easy mounting and un-mounting from Patricc's skeleton. The costumes were sewn using three fabric types: (i) The exterior is made of synthetic fur or fleece which were chosen for their appearance and tactile pleasantness. (ii) The interior was made of fine cotton cloth to enable the costume to "slide" on the robot's skeleton smoothly. (iii) Synthetic stretchable cloth was used in the shoulders to enable the full motion of the arms without the costume applying any force constraining the motors' motions.

Plastic inserts were integrated in the costumes. The mouth insert is designed to enable easy mounting of the head while keeping accurate mouth-motor synchronized motion. The robot's arm has two parts. The upper arm is connected to the robot and the forearm is a plastic insert integrated in the costume. The purpose of this separation is to shorten the distance needed to insert the robot's hands in the costume hands, simplifying the mounting process. During the robot's operation, the costume moves accurately with the robot by magnetic contacts between the robot in the costume's inserts.

We used PLA for all the 3D printed parts and the laser-cut parts were made out of poplar plywood. These are widely available and low-cost materials. The total cost of the skeleton was roughly 500 USD (mostly due to the 8 motors), the console cost was less than 150 USD (including props) and the puppets final cost, after a long design process, was roughly 50 USD per costume. Thus, the total cost of the prototype was less than 800 USD.

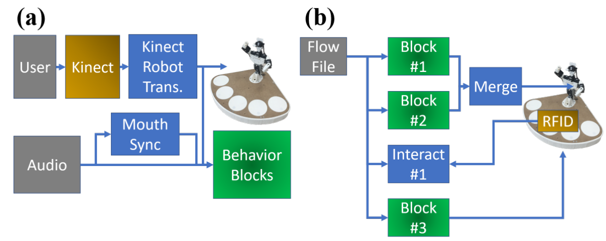


**Figure 3: Authoring tool. (a) Robot behavior module. (b) Interaction-flow module. Grey: input from user; Green: recorded behavior blocks; Blue: algorithms and ;Orange: sensors.**

## 4.6 Authoring tool

We designed a dedicated authoring tool for Patricc, with the goal of enabling non-programmers to add content and robot behaviors. For this purpose we developed two integrated modules: robot-behavior module and an interaction-flow module, Fig. 3, where all code was programmed with Python and ROS.

The robot-behavior module consisted of several components, Fig. 3(a). (i) A Kinect sensor that can detect human body skeleton parameters, e.g. joints, in a dynamic (30 fps) and relatively accurate manner. (ii) A transformation matrix from the Kinect-perceived human body angles to Patricc's motor-driven angles. This transformation was performed in real-time, such that the person enacting the behavior could see the robot's movement during the enactment. (iii) A recording component that captured the motor commands sent in real-time from the transformation to behavior *Blocks*. (iv) An audio component that integrated recorded audio files and synchronized mouth movement into the behavior Blocks. This module's output were recorded Blocks that synchronized audio and robot's motorized movements. These Blocks were then used in the interaction-flow module.

The interaction-flow module introduced a simple text-based flow of the recorded Blocks with the console RFID sensor, Fig. 3(b). The structure of the flow of a short lesson is presented in Fig. 4. Lines 1 and 3 specify which puppet and props are used in the lesson. These parameters are displayed in the experimenters GUI. After the experimenter chooses the desired lesson, the GUI informs the experimenter which puppet should be dressed on the the robot and which props should be placed on the console. Line 2 indicates in which folder the block files are. Line 4 is the first line of the lesson flow. All the lines of code that are part of the lesson flow begin with the line number and end with the number of the next line to play. This is true to all lines except the first line of the flow which is denoted by the word "start" and the end of the last line which is denoted by the word "end". In each line a behavior type is called, for example "block" behavior, followed by the name of the block.

```
robot, tooty
path, lesson_1
props, strawberry lemon orange cucumber tomato
start, block, tooty_hello_my_name_is_tooty, 2
2, block,tooty_lets_sing, 3
3, mixed, Every Day Long, tooty_Every Day Long_inter_block, 4
4, block, tooty_lets_learn, 5
5, point, lemon, tooty_this is a lemon.mp3, *, 6
6, interaction, lemon, 7
7, block, tooty_goodbye_see_you_later, end
```

**Figure 4: Lesson flow text file example**

Currently there are four types of behaviors that can be called in each line: (i) Block: The robot synchronously speaks and moves according to prerecorded motion and audio files. (ii) Point: The robot synchronously speaks and points towards the specified object. The location of the object on the console is detected by the RFID readers. (iii) Mixed: This is the same as a block with the option to merge point behaviors into it at specified times. The mixed behavior is usually used when playing songs where the robot performs a prerecorded dance and also has to point towards objects on the console during the song. (iv) Interaction: This is an interaction component built from block and point behaviors which are played according to feedback received from the RFID readers. In the interaction, the toddler is asked to pick up an object. If the toddler picks up the correct object the robot gives the toddler positive feedback. If the toddler picks up the wrong object, the robot tells the toddler the name of the wrong object and encourages the toddler to try again. If the toddler does not pick up any object the robot encourages the toddler to try again as well. Only after the toddler picks up the correct object does the lesson continue to the next line in the flow.

During the real-time run of the flow, different behavior blocks were concatenated. However, since they were recorded separately, the start and end position of Patricc were not necessarily aligned. For this purpose, we programmed a simple *Merge* algorithm that smoothed the motor positions of each block's last 10% movements and the following block's first 10% movements using low-pass filters. This created a smooth animation of Patricc's behaviors.

The authoring tool currently supports only a limited number of interaction blocks, but developers can easily add new ones. Non-programmer end-users can use the GUI for recording the behavior Blocks, whereas the Flow file is a simple text file, that can be executed with another dedicated GUI (not shown). A full usability study of the authoring tool is beyond the scope of the current paper, but is planned for future research.

## 5 EVALUATION LAB STUDY

We conducted a lab study to evaluate Patricc's design features and to learn about the triadic interaction between the toddler, parent and robot. Toddlers' and parents' behaviors were addressed using video-coding, whereas parents were also interviewed regarding their impressions of the interaction.

More specifically, we investigated in the study how parents will react to being a part of the interaction, despite not being directly asked to. The parent was expected and complied with interacting with the robot and toddler in several instances: First, due to the fact that Patricc spoke only English, the parent was expected to bridge between robot and toddler. Second, any misunderstanding of the toddler was expected to be addressed by the parent. Thus, while not physically designed to directly interact with the parent, the entire interaction design was evaluated for full robot-toddler-parent cooperation.

### 5.1 Interactive tablet application

A designated interactive tablet application was developed for the evaluation study. The goal of the application was to enable us to evaluate the differences in the way the toddler and parent interact with a tangible robot compared to a robot presented on a tablet screen. Therefore, the main requirement of the application was to keep the two experiences as similar as possible. To achieve this requirement we recorded short videos of Patricc while playing all the blocks (see Authoring tool section) we created. This enabled us to control the application interactions using the same interaction flows which controlled the real robot. In the application, the toddler interacted with the robot by pressing the objects which appeared on the virtual console; this replaced the action of picking up objects from the tangible console.

### 5.2 Protocol

A couple of days before the study, parents were sent a link to an online survey system where they were asked to fill a consent form, demographics and a designated questionnaire regarding their opinions on the robot's design and about their toddler's play patterns. When they arrived to the lab, the experimenter explained the study procedure and parents signed another consent form. In the lab, the toddler and parent participated in three 8-minute learning sessions. In two of the sessions the toddler and parent interacted with Patricc and in one session they interacted with a tablet displaying an interactive video of the same robot. Before the first session, the robot was presented without a puppet on it, i.e. in skeleton form. In the beginning of the session the experimenter introduced the session's character to the participants, giving the toddler an opportunity to touch the puppet and to participate in dressing up the robot. Another preparation for each session was to place the specific props on the console. Toddlers were also given the opportunity to participate in this action as well. Throughout the interaction, Patricc was portrayed as a puppet teacher. After completing the three sessions, the parent was interviewed regarding the experience, while the toddler played with toys and crafts.

### 5.3 Conditions

The study had a within-subject design, where each toddler-parent pair interacted once with a tablet (TABLET) and twice with Patricc (ROBOT1, ROBOT2), each time with a different character. To overcome order effects, one group interacted with the tablet in the first session and with the robot in the second and third sessions and the second group interacted with the robot in the first two sessions and with the tablet in the third session. It is important to note that all participants experienced the learning sessions in the same order but on different mediums. Participants were assigned a group in a pseudo-randomized manner.

## 5.4 Lessons

During the study the toddlers and parents participated in three learning sessions, adopted with permission from Helen Doron's English teaching schools [16]. Each lesson had its vocabulary set and was taught by a specific puppet (see Table. 2). Each lesson began with the puppet introducing itself followed by a song which included the vocabulary of the lesson. During the song the robot danced and every time it sang about one of the vocabulary words it pointed and gazed towards the correct object. After the song, one by one, the robot pointed and gazed towards the objects on the console. This was accompanied by saying the object's name and then asking the toddler to pick the object up. After teaching all the five objects the robot asked the toddler once again to pick up the objects, yet this time it did not point towards the object before asking to pick it up. Whenever a toddler picked up the correct object the robot responded with a positive feedback response such as waving its hands and saying "Very good! That's great!". If the toddler picked up the wrong object, the robot would tell the toddler the name of the object that was picked up, ask the toddler to put it down and then repeat the name of the correct object to pick up. In cases where the toddler did not pick up any object the robot would encourage the toddler by saying "Try again, you can do it!". Only after the correct object was picked up did the robot continue to the next word. After finishing going over all the words the robot would wave its hand and say "Goodbye, see you soon".

All lessons were created using the authoring tool. The aforementioned behaviors were recorded using the robot-behavior module and the entire lessons' flow was written using the interaction-flow module. It is important to stress that no programming was performed once the authoring tool was operational. Thus, converting a 8-minute lesson curriculum took less than two-hours of operating the authoring tool, a huge benefit for scaling content introduction.

**Table 2: Lessons' characters and taught vocabulary using physical props.**

| Lesson | Puppet | Vocabulary |
|---|---|---|
| 1 | Tutty | Cucumber, Tomato, Strawberry, Orange, Lemon |
| 2 | Blu Jay | Fish, Goat, Rooster, Sheep, Donkey |
| 3 | Fuzzy | Duck, Cow, Cat, Sheep, Donkey |

## 5.5 Video coding

Video and audio data were collected during all the sessions. Each of the 18 toddler-parent pairs participated in three learning sessions. Each session took by average 8 minutes. To analyze the videos we used the thin slice approach [1] with 15-second slices. The interactions were manually coded post-hoc by two coders. One coder coded 60% of the videos and the other the remaining 40%. Inter-rater reliability was assessed (Cohen's kappa) on a set of 200 randomly selected videos (10% of the data). The average Kappa score was 0.85 with the lowest score at 0.62, indicating substantial to almost perfect reliability for all codes [19]. There were two main categories for video coding: gaze and object manipulation. Within the gaze category the following behaviors were coded: (i) The toddler gazed toward the robot, tablet or the parent; (ii) The parent gazed toward the robot, tablet or the toddler; (iii) Mutual gaze of the toddler and parent towards the robot or tablet; (iv) Mutual gaze of the toddler and parent at each other. In the object manipulation category, object manipulation was defined as picking up or putting down an object. Within this category we distinguished between four events: (i) The toddler independently manipulated an object; (ii) The toddler manipulated an object following the parent's request; (iii) The parent manipulated an object independently; (iv) The parent manipulated an object following the toddler's request.

## 5.6 Interviews

In order to grasp parents' experiences and opinions, semi-structured interviews were carried out. A semi-structured interview is a verbal interchange in which the interviewer prepares a list of predetermined questions which unfold in a conversational manner offering participants the chance to explore issues they feel are important [24].

The semi-structure interviews inherently resulted in parents answering only part of the questions presented in the study. The percentage of responses reported below are from those parents who answered the questions, and not from all parents who participated in the study. A total of 18 interviews took an average of 21 minutes. Five of the interviews were significantly interrupted by the toddlers, causing the interviewees to be impatient and impaired the quality of the interview, where one was stopped in the middle.

The interviews were conducted in Hebrew and were recorded and transcribed by the interviewer. All interviews were analyzed with ATLAS.ti, a computer program used in qualitative data analysis. The materials were coded following "grounded theory" protocol [11] by which the coding should be performed exclusively with reference to data (open coding), an inductive ("bottom-up") thematic analysis in which concepts emerge from the data. The coded citations were grouped into 19 themes (e.g. "parent's experience") in which 9 major themes and 10 secondary themes were identified (see Supp. Info for full interview analysis).

## 5.7 Participants

A total of 18 parent-toddler pairs were recruited through parents' groups in social media networks (Facebook, WhatsApp). All toddlers were native Hebrew speakers and had no substantial prior English exposure, such as, extracurricular classes or a close family member who regularly spoke with them in English. This was a prerequisite for participating in the study. Out of 18 toddlers, 9 were male, and 9 female with ages between 1.9 years to 3.9 years with an average age of 3. 11 of the toddlers were home-schooled and 7 attended kindergarten. Of the participating parents there were 16 mothers and 2 fathers of an average age of 36.

All participants signed a consent form and the study was approved by the Institutional IRB.

# 6 RESULTS

We report below mixed results analysis, presenting quantitative results based on video-coding and qualitative results, based on the semi-structured interviews with the parents after the interaction. In case a theme was expressed only by part of the interviewees, the percentage reported is calculated respectively.

### 6.1 Robot-Tablet Comparison

To evaluate the advantages of Patricc over a tablet-based activity, we video-coded the triadic interaction using six gaze measures, (see Supp. Info. for full video-coding analysis). We compared gaze data from the TABLET and the first robot ROBOT1 conditions, as they represent the first interaction with the platform. A MANCOVA analysis was performed, with the order of presentation as the co-variate and the six gaze measures as the dependent variables. The analysis shows that Patricc and the tablet were significantly different ($F(6, 28) = 5.827, p < 0.001$, Pillai's Trace= 0.555) and the order of presentation was not ($F(6, 28) = 0.588, p = 0.737$, Pillai's Trace= 0.112). The most significant differences were the increased parent's gaze at the toddler in Patricc's condition ($F(2, 36) = 11.5, p < 0.001$, ROBOT1 =0.86(0.03), TABLET=0.54(0.01)) and the increased mutual gaze at the tablet in the TABLET condition ($F(2, 36) = 8.89, p = 0.001$, ROBOT1 =0.86(0.03), TABLET=0.98(0.01)).

Qualitative analysis showed that most parents (10, 56 percent) saw the robot as a better means of teaching language than the tablet. These noted contributing characteristics such as being "three-dimensional," "tangible," "can be played with" and that it activates "other senses besides hearing and seeing [touch, movement]".

Regarding the triadic interaction, half of the parents (8, 50 percent) saw the game with the robot as a parent-toddler activity. Some (5, 31 percent) as a toddler-independent activity and others (3, 19 percent) as activities that can be carried out jointly or independently. Parents who preferred to see the activity as shared emphasized that "in these ages toddlers need *mediation.* Especially if it is something new that will take a while for a toddler to connect to. Toddlers first need confidence and mediation and to be guided what to do".

### 6.2 Changeable Characters

To evaluate possible novelty effect mitigation by changeable characters, we compared gaze and object manipulation data of the ROBOT1 and ROBOT2 conditions. A MANCOVA analysis was performed, with the order of presentation as the co-variate and all gaze and manipulation measures as the dependent variables. The two conditions were not found to be significantly different ($F(10, 24) = 0.882, p = 0.562$, Pillai's Trace= 0.269).

Qualitative analysis revealed that most parents (8, 67 percent) thought that changing the robot's characters contributed to the activity, "I think he liked it that the robot was dressed up. A boy who has it at home can play with it". It was also argued that the puppet exchange allowed the toddler to play with her preferred character, "He reacted differently to each character. Tutty was cuter to him and the parrot less". On the other hand, it was argued, "I do not see the replacement of the characters with added value. The toddler becomes attached to the character, she becomes a friend. Then relating to a new character is unpleasant".

Furthermore, there were varied opinions regarding the appearance of the robot. Those who supported the puppet-type design claimed that "they [the toddlers] love puppets even though they are boys, noting that they are "cute "," funny "," interesting "," friendly "and" not frightening. " Because "she [the girl] prefers a puppet character rather than a robot". One mother noted that the puppets resemble familiar characters from stories or TV shows, "I saw Blue Jay and I had an association with Disney's Blue Parrot." The fur was also noted as an advantage, "The fact that it is a furry creature really makes a difference".

## 7 DISCUSSION

In this contribution, we aimed to address the unique challenge of a robotic platform for toddlers' education. The evaluation study of Patricc shed light on whether we met our goals.

Patricc promoted more triadic interaction between the toddler, parent and robot, compared to the tablet, which attracted most of the attention, in expense of toddler-parent dyadic interaction. Moreover, parents commented that the interaction was indeed perceived as a joint one, incorporating them as well as the toddler and the robot.

Interacting consecutively with two different characters may have mitigated the novelty effect, causing no significant reduction in triadic interaction or task-related object manipulation. Furthermore, parents commented that the changing characters contributed to the activity, by enabling the toddler to react differently to each character and have a favorite. This main novel feature of Patricc contrasts to most robotic platforms who have a single character and appearance [38].

Finally, parents also commented on several disadvantages of the experience. Most common comments were about the interaction itself and its lack of responsiveness, variation and duration. These drawbacks can be easily overcome in future interactions by using our novel authoring tool for non programmers, that can easily add more content and more interactivity, such as storytelling and memory games based on the props. However, the low-cost design of the robot which integrated only RFID sensors, cannot enable richer perceptual-driven interactions. Integration of cameras and microphones are probably inevitable for long-term engagement.

## 8 CONCLUSIONS AND FUTURE WORK

We have introduced a novel platform for toddlers' HRI. An evaluation study was performed and gave many insights on the interaction itself, as well as parents' perceived advantages and drawbacks of the system.

Future work will entail increasing the repertoire of content and interaction via the novel authoring tool, as well as testing more advanced perception hardware, that will enable interacting directly with both parent and toddler. A long-term study in toddlers' homes is also planned, to test the possible advantages of changing characters in prolonged engagements.

Finally, even though Patricc's design was aimed for toddlers and the toddler-parent-robot triad, it can be used for other age groups (preschoolers) and scenarios (kindergarten) due to its other novel criteria, such as changing characters and authoring tool.

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## CONFLICT OF INTEREST

G.G. and O.G. are co-founders and employees of Curiosity Robotics Ltd.

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