Computers & Education 70 (2014) 53–64

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education

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A R T I C L E I N F O

Article history:
Received 22 August 2012
Received in revised form
7 July 2013
Accepted 8 July 2013

Keywords:
Architecture for educational technology system
Elementary education
Intelligent tutoring systems
Interactive learning environments
Interdisciplinary projects

A B S T R A C T

Kindergarten Social Assistive Robotics (KindSAR) is a novel technology that offers kindergarten staff an innovative tool for achieving educational aims through social interaction. Children in a preschool setting have previously been shown to benefit from playing educational games with the KindSAR robot. The experiment presented here was designed to examine how KindSAR can be used to engage preschool children in constructive learning. The basic principle of constructivist education is that learning occurs when the learner is actively involved in a process of knowledge construction. In this study, storytelling was used as a paradigm of a constructive educational activity. An interactive robot served as a teacher assistant by telling prerecorded stories to small groups of children while incorporating song and motor activities in the process. Our results show that the children enjoyed interacting with the robot and accepted its authority. This study demonstrates the feasibility and expected benefits of incorporating KindSAR in preschool education.

1. Introduction

1.1. Robots and education

Robotics technology has recently become a fashionable tool for supporting the educational process at the middle and high school levels. Benitti (2012), in a summary of recent research on incorporation of robotics in the educational process, point outs that most of the work in this area describes the use of robots as a platform for the teaching of subjects that are themselves closely related to the robotics field, such as robot construction (including mechatronics and electronics) and programming. The robotic tools in such cases have been employed to engage students in motivated learning in the fields of physics and mathematics. In addition, they have helped to develop or improve problem solving, logic, and scientific inquiry. Ages of the research participants varied between 6 and 16. Most of the experiments involving robotics activities were not integrated into classroom activities, but took place in an after-school or summer camp program. Moreover, the robotics mostly were applied as an extracurricular activity, always involved a “group of tutors”. Prominent among the robotic tools used for educational activities were Lego robots, with variations in the models used (NXT, RCX, and Evobot).

The author also mentions studies in which robots does not used as a platform for the science teaching, but as an active teacher’s/therapist’s assistant in the development of social communication skills in individuals with autism. This area of robotics is called Social Assistive Robotics (SAR).

1.2. Social assistive robotics

Assistive robotics makes use of a broad class of robots whose function is to assist users in their daily activities, mainly out of preschool education. SAR (Feil-Seifer & Matarić, 2005) utilizes robots that assist users primarily through social rather than physical interaction, and typically address critical areas in medical care by automating the supervisory, coaching, motivational, and companionship aspects of

Abbreviations: KindSAR, kindergarten social assistive robotics; SAR, social assistive robotics; EC, eye contact; IL, interaction level; P, performance level.

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0360-1315/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compedu.2013.07.043

interactions with vulnerable individuals. Up to now the main populations in whom SAR has been applied are the elderly, patients with dementia and cognitive/motor disorders (Heerink, Krse, Evers, & Wielinga, 2008; Klamer, Allouch, & Heylen, 2011), and children with autism (Goodrich, Colton, Brinton, & Fujiki, 2011; Thota, Kearney, Boirum, Bojedla, & Lee, 2011; Villano et al., 2011). Unlike treatments based on computer technology, e.g., video instruction (Shukla-Mehta, Miller, & Callahan, 2009), or on virtual peers through the internet (Tartaro & Cassell, 2008), SAR creates opportunities not only to learn from a non-threatening, three-dimensional inanimate object, but also to learn through interaction, thus encouraging autonomous social behavior. From a technological point of view, SAR is an advanced field of robotics that merges challenging state-of-the-art research on machine-learning algorithms, artificial intelligence, and real-time control issues (Feil-Seifer & Matarić, 2011; Lee, Kieser, Bobick, & Thomaz, 2011; Shim & Thomaz, 2011).

In the field of child care, several studies have demonstrated positive effects of SAR on typically developing children and on children with social disorders (e.g., Kozima, Nakagawa, & Yano, 2004; Tanaka, Movellan, Fortenberry, & Aisaka, 2006). iRobi, a humanoid teaching-assistant robot, has been tested in elementary school (Han, Jo, Park, & Kim, 2005; Han & Kim, 2009; Kanda, Hirano, Eaton, & Ishiguro, 2004; Shin & Kim, 2007; You, Shen, Chang, Liu, & Chen, 2006). This wheeled robot conducts educational activities (such as storytelling and English language learning) mainly through embedded computer-based games. AIBO, a robotic pet, was introduced by Yamamoto, Tetsui, Naganuma, and Kimura (2006) into class work for 4–6-year-olds.

SAR technology is still in its infancy, but assistive robotic platforms hold promise for extrapolation to hospitals and other venues for training and therapeutic programs that monitor, encourage, and assist their users. Tapus, Matarić, and Scassellati (2007) describe the broad scope of socially assistive robotics and propose a list of milestones and the grand challenges of this field.

1.3. *Existing storytelling systems*

Storytelling is essential for children's development of language expression, logical thinking, imagination, and creativity (Wright, 1995). Most of the existing systems of storytelling adopt emerging technologies that enhance children's enjoyment and encourage their engagement in developmental interactive stories (Table 1). In these systems children compose their stories; the system captures their voices and movement, and an embodied robot then acts out the story. These systems have been applied for purposes of rehabilitation (Plaisant et al., 2000), learning English (Lu, Changgogo, & Chen, 2007; Wu, Chang, Liu, & Chen, 2008), or simply to enhance children's creativity. Other researchers have shown how the same idea can be applied with a virtual robot (Table 1), or with an application for the teaching of programming (Kelleher, Pausch, & Kiesler, 2007), or for collaborative story composition (Wang et al., 2009).

Only a few researchers have proposed incorporating augmented reality into storytelling systems. Montemayor, Druin, Chipman, Farber, & Guha (2004), for example, created a physical interactive environment to enrich the storytelling system.

We are aware of only one storytelling system that was created to support teachers in the learning process (Shih, Chang, & Chen, 2007). That system was used to assist the educational staff to teach English.

The above systems have been applied in elementary and high school education (Table 1), but never in a preschool setting. Moreover, there is no available information on how a storytelling system can be utilized to assist teachers in the educational process or how to support constructive learning.

Table 1
Existing storytelling systems.

Task	Reference	Age of subjects	Sample size	Equipment	Applications
Children teach the robot to tell a story	Hsieh, Su, Chen, Chen, and Lin (2010)	NA	NA	Furry robotic bear, Web camera, notebook	Story composition
	Plaisant et al. (2000)	CP, 5 yr old ADSD, NA	2	Notebook, furry robot, variety of body sensors	Story composition for rehabilitation
	Lu et al. (2007)	10	34	Humanoid robot	Learn English
	Wu et al. (2008)	NA	NA	NA	Learn English
	Vaucelle and Jehan (2002)	5	NA	Dolltalk toy	Story composition + enhancement of children's creativity
	Ananny and Cassell (2001)	6–7	22	TellTale toy, looks like a caterpillar, consists of 6 individual pieces	Story composition activities
	Mutlu et al. (2006)	20	19–33	ASIMO robot (Honda)	Investigation of emulating human-like gaze behavior by robot
Children teach the virtual agent to tell a story	Wang et al. (2009)	6	NA	Virtual agent	Collaborative story composition (create roles and share stories)
	Sadik (2008)	6–15	35–45 students × 8 classes	Microsoft Photo Story on Notebook	Investigate the story composition process
	Kelleher et al. {2007}	Middle school students	88	Virtual agent	Introduce girls to computer programming
Children teach the robot to tell a story, using augmented reality	Ryokai and Cassell (1999)	5–8	36	StoryMat: a soft cloth quilt with appliquéd figures on it	Collaborative fantasy play and storytelling
	Montemayor et al. (2004)	4–6	11	Physical interactive environment	Story composition
	Sugimoto (2011)	9–12	24	Handheld projector, tortoise robot	Story composition
Robot acts as a teacher assistance	Shih et al. (2007)	High school students	20	RoboSapien	Learn English

ADS, autistic disorder syndrome; CP, cerebral palsy; NA, not available.

1.4. Constructive learning: existing tools

Computer-supported instructional tools are the most popular of a range of engaging learning environments that are available for children today. These tools are exemplars of the constructivist concept of learning, in which learners are encouraged to undergo learning experiences in different ways and through different senses. The tools empower children to take active control of their own learning (Cassell, 2002; Druin et al., 2003; Kafai, 1996; Malcolm, 2002), allow them to plan and monitor their own learning process (Kafai, 1996; Malcolm, 2002), encourage an environment where learning can be applied to new situations (Malcolm, 2002), and foster collaborative learning activities (Cassell, 2002; Druin et al., 2003; Malcolm, 2002). Social activity is a core concept of constructive learning: progressive education recognizes the social aspect of learning and uses conversation, interaction with others, and the application of knowledge as an integral aspect of learning. This principle laid a basis of Social Constructivism theory (e.g. Derry, 1999; McMahon, 1997), widely used up today (e.g. Ernest, 1998; Kukla, 2000).

Computer-supported educational tools also provide examples of "stealth education" (Falstein, 2005), i.e., situations in which children learn, both in and out of school, without realizing that they are being taught. Stealth education, which presents entertaining features of the learning situation in a seamless, game-like way, provides an important way to make this happen. The inherent principles of computer-supported learning as a scalable, transferable medium allow children to explore and learn from material both inside the classroom (e.g., creating fraction games; Kafai, 1996) and outside it, in working together, for example, on science projects (Malcolm, 2002), creating digital libraries (Druin et al., 2003), and translating each other's e-mails (Cassell, 2002).

However, there is continuing concern about the physical effects of children's use of computers (Dockrell, Earle, & Galvin, 2010). As distinct from robots, which allow and indeed encourage children to be mobile during a game, computer games have been found to be negatively associated with several health outcomes of preschoolers' sedentary behavior. Another concern of developmental psychologists is that the use of computer games can reduce children's social involvement and promote isolation (Hofferth, 2010). Verenikina, Harris, and Lysaght (2003) cite Singer (in Alliance for Childhood, 2002), who "warns about the very limiting nature of the new generation of electronic toys such as talking and walking dolls as they don't leave enough room for children's imagination and creativity."

Social assistive technology, given its embodied interactivity and ability to mediate in playing activity, thus has enormous potential as a tool for constructivist educational activities. Our proposed assistive robotics technology is by no means intended to substitute for the kindergarten teacher. However, a robot can assist teacher to provide a constructive learning experience supported by several senses: visual, auditory, and touch. To the best of our knowledge, however, there are no published studies on the application of SAR technologies in preschool education.

1.5. A social assistive robotics technology for preschool education

We have developed Kindergarten Social Assistive Robotics (KindSAR), an application of social assistive technology for educational purposes, concentrating initially on preschool education. KindSAR is an assistive robotic technology that offers kindergarten educational staff a novel educational tool based on social interaction. The primary purpose of KindSAR is to provide assistance to the staff by engaging the children in educational games. The technology potentially provides a valuable contribution to the existing repertoire of tools for children's cognitive and social development. KindSAR mitigates the typically high child:teacher ratio in the kindergarten classroom (average of $\approx$35:2 in Israel), which limits child–adult interactions in this environment. Moreover, KindSAR monitors children's progress and concurrently provides both the children and the educational staff with detailed feedback on game/task performance.

We adopted the core ethical principles of SAR as the basis for addressing ethical issues (Feil-Seifer & Matarić, 2011) for KindSAR. Our KindSAR system is designed to ensure that the robot does not apply force on the user. The user, however, can touch the operative robot. As reported in a previous study (Feil-Seifer & Matarić, 2005), users may become emotionally attached to the SAR platform. In KindSAR this is prevented, as far as possible, and misunderstandings (on the part of children or parents or both) are minimized, by providing users in advance with the maximum amount of available information about the KindSAR robot, including information about possible upgrades or future modifications that might change the robot's appearance or behavior, and the fact that the robot will eventually be taken away. A practical implementation of such ethical issues is described in Section 2.3.2 below.

KindSAR provides children and the educational staff with detailed feedback on the game/task performance and concurrently monitors children's progress over time. Visual, audio, and task performance data can then be used both by kindergarten teams and for further study by researchers studying cognitive development. A complete anonymous database that contains information on cognition for all children who participated in the study is available and can serve as a starting point for further research.

To test the applicability of KindSAR in the kindergarten environment, we conducted the study described below. We chose typically developing children as our target population for the present study, although our intention was also to apply the proposed technology in the future for therapy and education of children with cerebral palsy (CP) (Fridin, Bar-Haim, & Belokopytov, 2011) and children with ADHD/ADD (Fridin & Yaakobi, 2011). The research presented here describes part of the KindSAR repertoire.

1.6. Present objectives

The experiment was designed to show how a KindSAR robot, acting as an embodied interactive storyteller, can assist the kindergarten educational staff by telling the children prerecorded stories, thereby playing a social role in supporting the children's literacy development and acquisition of new knowledge while also improving their motor skills. In most of the previously reported robotic systems for storytelling (except for that described by Shih et al., 2007), the system was aimed at creating the story. In contrast, our aim was to create the KindSAR system where the robot, playing the role of teacher's assistant, used as storyteller. The procedures were designed to promote constructive learning. We considered it important to test this system for the first time in the experimental setup of real preschool environment, with subjects of preschool age.

We examined the hypothesis that children can learn through their interaction with the robot during storytelling. In addition, we showed how additional available technology can be incorporated in the storytelling system, for example via presentation by the robot of characters in the story (e.g. the duck, the swan) on the screen.

Video and audio data were collected during the experiment and analyzed. To test the hypothesis we considered two variables separately: interaction between a child and the robot, and performance of motor/cognitive tasks. We also examined the possible influence of gender on children's interaction and performance levels.

2. Methods

2.1. Experimental platform

The robot used as a platform in this study was Nao, a small toy-like humanoid robot previously shown to have a positive impact on child-robot interaction (Fridin & Yaakobi, 2011). Nao is a smart, non-threatening educational tool that creates pleasurable interactions for both the kindergarten staff and the children. It speaks in a child-like voice, expresses emotions (through verbal and non-verbal cues) and uses proper vocabulary and grammar. Nao has 25 degrees of freedom, allowing it to perform various motor actions (Fig. 1).

A technician, who sat near the robot, provided the system with binary information regarding the success of the children's performance. According to this information the KindSAR system automatically decided on the flow of the current procedures.

2.2. Experimental environment and participants

The experiment was conducted in a kindergarten, a natural environment for the children. A total of 10 children, 5 boys and 5 girls, ranging in age from 3 to 3.6, participated in the experiment. A group of five children participated in all procedures (Table 2). Children who participated in the first meeting also participated in the subsequent storytelling sessions.

For the experiment we used a room used by the staff when working with small groups of children. One teacher was present in the room, seated approximately 0.5 m from the imaginary line connecting the robot and the children. Two video cameras placed behind the robot photographed the experiment. One technician was present, seated approximately 0.8 m from the robot (Fig. 2).

2.3. Procedure

The experimental procedures presented below were originally designed by a development psychologist and specialist in human–robot interaction. The design documents setting out the robot's movements, speech, emotional expressions and program flow (Fig. 3) were coded by a programmer using Python language and the Nao system's graphical user interface.

Procedure protocols were designed according to a constructivist approach (Caine & Caine, 1994), in which learners base new knowledge on their existing conceptual frameworks (Taylor, 1993). The robot, using appropriate vocabulary, thus introduces novel concepts to the children in terms based on their previous knowledge. A classroom environment containing a robot is a much more interactive setting than a traditional classroom, allowing children to learn through interaction with the robot in a social setting (Tobin & Tippins, 1993), supporting principles of social constructivism theory. Constructive learning also encourages learners to experience the content in different ways, using different senses. The robot is suitably programmed to provide this multisensory learning experience: it displays images on a screen, tells a story and discusses it with the children, and incorporates singing and motor activities in the process.

2.3.1. Pre-process

First, we prepared documents describing our experimental procedure. The documents were distributed to the parents, who were asked to sign their informed consent to their children's participation. The kindergarten staff not only participated in the design of the procedure, but also approved its final implementation.

2.3.2. First meeting procedure

The purpose of the first meeting procedure was to introduce to children the humanoid robotic tool, a mechanism that selectively emulates aspects of human-like appearance and behavior (Kemp et al., 2008).

With the children seated approximately 2 m from the KindSAR robot Nao, in compliance with a conventional definition of proximity (Hall, 1969), Nao started the procedure from a sitting position in the children's social space. It woke up, made a yawning sound, and introduced itself to the children by singing a well-known Israeli greeting song. It initiated personal contact with the children by moving into

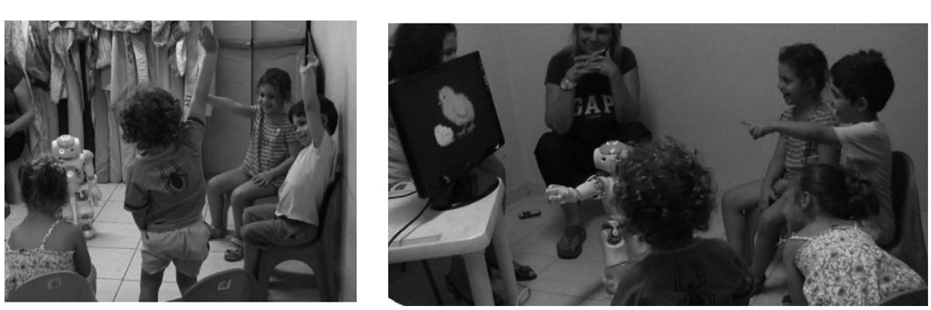

Fig. 1. Children playing with the KAR robot during storytelling. Left, "Pluto" story; right,: "ugly duckling" story.

Table 2
Study participants.

Procedure	Group[b] No.	Boys	Girls	Total
First meeting[a]	1	2	3	5
	2	1	2	3
	3	2	1	3
	4	1	2	3
	Total	6	8	14
Storytelling “Pluto” and “Duckling”	1	2	3	5
	2	3	2	5
	Total	5	5	10

[a] Children who participated in the first meeting also participated in the storytelling sessions.
[b] Children’s ages ranged from 3 to 3.6 years.

their personal space and conducting short conversations with the children. Nao explained that it had come to play with the children, and proposed playing “Simon Says” as an illustration. Successful performance by the children during this game was rewarded by positive feedback given by the robot, with verbal encouragement (e.g. “Well done!”) accompanied by the body expression of happiness (raising its hands, nodding its head, blinking).

To explain its limitations and in keeping with the study’s ethical requirement of preventing the children, as far as possible, from becoming emotionally attached to it, Nao emphasized its non-human character, by repeatedly stating that it is a robot and incapable of understanding everything (Fig. 4). It explained possible changes in its appearance and behavior by telling the children that it sometimes becomes ill and needs to be taken to a “robot doctor”. It also explained that it could not play with children for a long time, because it would often need to be taken away to “eat” and “sleep” (meaning to be electrically charged).

2.3.3. Storytelling

Approximately a week after first meeting we came back to the kindergarten. The kindergarten teacher, who functioned as the main authority in all activities with the robot, invited a group of five children to participate in the day’s activity with the robot. After obtaining their agreement the teacher allowed Nao to initiate the storytelling procedure, which comprised two identical storytelling sessions, one week apart. At each session the robot initiated the storytelling procedure by entering the personal space of the seated children, greeting them, and explaining the current activity. Two well-known stories had been selected: *Where is Pluto?* by the Israeli author Leah Goldberg, and Hans Christian Andersen’s *The Ugly Duckling*. The latter story has strong emotional content, while the main content of the former story is knowledge. For the additional technology used in the Ugly Duckling story (presentation of images illustrating scenes from the story), a screen was placed near the robot. No additional technology was used to enhance storytelling in the Pluto story.

Nao told the prerecorded story, while expressing appropriate emotions both bodily and vocally. While telling the story, it taught the children new concepts. First it asked the children if they knew some of the terms related to the story (“reflection” and “cost” in the Pluto story; “darker” and “ridicule” in the duckling story; see Fig. 5). Nao gave positive feedback for any answer volunteered by the children, and then explained what the terms mean. It then asked the children what sounds are made by the animals in the story, and produced the animal sounds for them to hear. It also incorporated singing during the procedure (a cradle song during the Duckling story, for instance) and introduced motor games (such as playing “Simon says”, with the children asked to imitate the robot’s movements like animals in the stories). During the procedure Nao constantly moved in front of the children, turned its head, and changed the color of the light in its eyes, simulating a human-like shift of attention to different children.

2.4. Measures

Considering the age of our target population, post-hoc analysis of video footage of interaction sessions is the only feasible method of data collection and analysis. To evaluate the quality of child-robot interaction, we used the KindSAR interaction measurement index (previously described in Belokopytov & Fridin, 2012; Fridin & Yaakobi, 2011; Fridin, Angel, & Azery, 2011; Fridin, Bar-Haim, & Belokopytov, 2011; Keren,

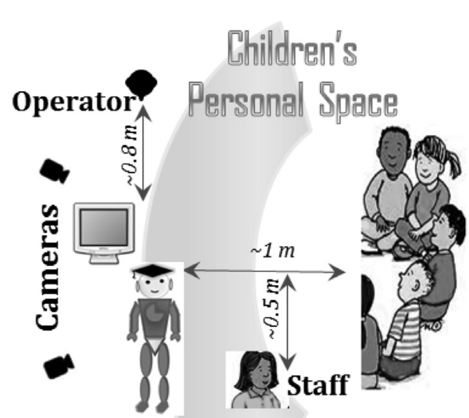

Fig. 2. Experimental setup.

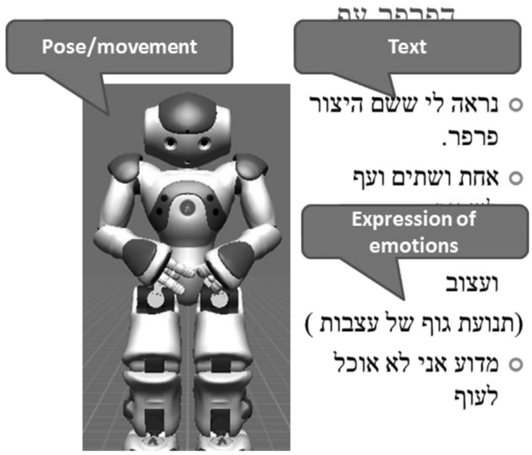

Fig. 3. Sample page of the design document in Hebrew.

Ben-David, & Fridin, 2012). The index was created to measure levels of children's interactions with the robot. This index has been used in the evaluation of children with attention deficit hyperactivity disorder (Fridin & Yaakobi, 2011) and children with cerebral palsy (Belokopytov & Fridin, 2012; Fridin, Angel, & Azery, 2011; Fridin, Bar-Haim, & Belokopytov, 2011), as well as with normally developed children (Keren et al., 2012; Fridin, Angel, et al., 2011; Fridin, Bar-Haim, et al., 2011). Although computed manually in the present work, the index was designed to be automatically computed online by the KindSAR system.

The following measurements were recorded for each child participating in the study.

2.4.1. *Child-robot interaction level*

To measure children's interaction level (IL) with the robot, we measure eye contact (EC) and affective factor (F). Gaze is an essential component of human–human communication and is often used to communicate syntactic or semantic signals during interaction sessions (Argyle & Cook, 1976). According to Mutlu, Hodgins, and Forlizzi (2006), having as much mutual gaze as possible results in the highest level of attention and therefore the highest degree of engagement in the human–robot interaction during a storytelling session.

Emotion is a fundamental component of any human–human interaction (for instance Darwin, 1872), and the role of emotions is essential for understanding the behavior of users when they participate in different applications of human–computer interaction (for instance Brave, 2003). Emotion has been identified as an important part of human–robot interactions (for instance Breazeal, 1998).

In our scheme of measurement, EC = 3 if a child looks at the robot during the interaction, EC = 2 if the child needs the support of the surrounding children, and EC = 1 if the child needs additional support or explanations from the kindergarten teacher. If the child does not become engaged in the interaction session at all, EC = 0.

We measure several emotional factors, such as facial, body and vocal expressions of emotion. Our motivation for multimodality is based on the fact that in number of automatic recognition systems (for example Balomenos et al., 2004; Chen & Huang, 2000), emotion-recognition systems are improved by the use of multimodal information. Similar phenomena have been described for human recognition [for instance Jessen & Kotz, 2011, de Gelder & Bertelson, 2003). A common way to measure emotion, easily done with pencil and paper, is to ask people to rate their feelings along valence-arousal dimensions, for example by using the self-assessment mannequin of Lang and Friestad (1993).

Three affective factors (F)—facial, body and vocal expressions of emotion—are represented by subscripts 1, 2, and 3, respectively. W_F, a binary variable, indicates whether the child express emotion or not. The overall strength of emotional reaction is measured by ($\sum_{F=1}^{3} W_F F$). Thus, the index of child-robot IL at stage S of the interaction session is given by:

$$IL_S = EC_S * Sign_S * \sum_{F=1}^{3} W_F F \tag{1}$$

Fig. 4. Outline of the first meeting procedure.

Fig. 5. Outline of the storytelling procedure.

where EC_S is a variable measuring the child's eye contact at stage S of the interaction session, and $Sign_S$ indicates a positive or negative interaction (+1 or −1, respectively), measured by two-dimensional valence and arousal space (for instance Ueki, Morishima, & Yamada, 1994). $W_F F$ thus represents an affective measure.

Intuitively, the proposed Formula (1) indicates whether a child engages in interaction with the robot (if not, then EC = 0, so $IL_s = 0$); whether the interaction is positive or negative (Sign); and finally, the strength of interaction ($\sum_{I=1}^{3} W_i I$). If a child expresses emotions only facially (for instance smiles), then $W_i I = 1$; if the child's body moves in response to the robot, $W_i I = 2$, considered a stronger interaction. Finally, if the child expresses emotion vocally, the interaction is considered to be even stronger ($W_i I = 3$).

How to combine emotional information from different channels (body, face, and voice) is still an open question. Only a few facts are provided by the literature. Meeren, Van Heijnsbergen, & de Gelder (2005) showed that observers judging a facial expression are strongly influenced by emotional body language. A similar effect on recognition of facial expressions was reported for the combination of a facial expression and an emotional tone of voice (Van den Stock, Righart, & de Gelder, 2007). Recognition of emotional tone of voice is also influenced by task-irrelevant emotional body expressions (Van den Stock, Grèzes, & de Gelder, 2008).

Cronbach alpha calculation yielded 0.86 for the first meeting procedure, 0.88 for the Pluto story and 0.65 for the Ugly Duckling story.

2.4.2. Children's performance

In the course of the interactive session the children are asked to perform various motor and cognitive tasks. If a child completes the motor task or gives a complete answer to the question, the child's performance (P) is recorded as 2. Partial performance is recorded as 1, and absence of response as 0. For tasks comprising more than one movement or question, P is as computed as the mean of all component scores.

2.5. Data analyzes

For the purpose of analysis, the entire procedure is divided into logical sections. Thus, for example: robot tells a story/robot plays motor games/robot teaches children new concepts or animal voices/robot displays images (in the Ugly Duckling story) on a screen. IL and P are measured for each section and for both sessions. These measurements, obtained for each child, constitute the input data for the following statistical analyzes.

2.5.1. Interaction level

To analyze the level of children's interactions with the robot, we use repeated measures ANOVA with four between-subject factors, where IL is the main effect and trials are the repeated measures. There are four between-subject factors: story (*Pluto* × *Ugly Duckling*), experimental phase (story × motor game × cognitive game × presentation), gender (boy × girl), and group (1 × 2).

2.5.2. Performance

To analyze the level of children's performance during their interaction with the robot, we use repeated measures ANOVA with four between-subject factors, where performance (P) is the main effect and sessions are the repeated measures. There are four between-subject factors: story (*Pluto* × *Ugly Duckling*), experimental phase (story × motor game × cognitive game × presentation), gender (boy × girl), and group (1 × 2).

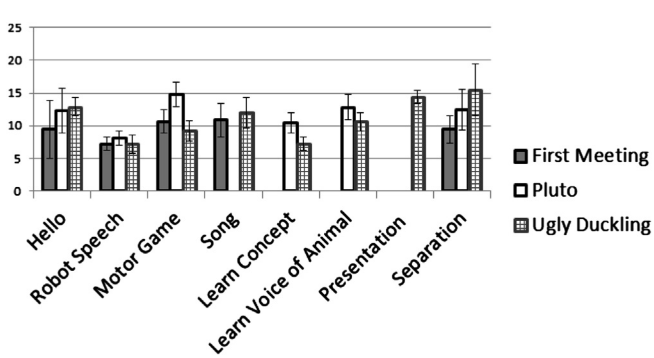

Fig. 6. Child-robot interaction levels during the first meeting and the two storytelling procedures.

2.5.3. Comparison with first meeting procedure

ANOVA was used to compare the interaction level (IL) and children's performance (P) in the first meeting procedure with corresponding experimental phase in the storytelling experimental procedures, with IL and P as main effects, respectively, and procedure (first meeting × *Pluto* × *Ugly Duckling*) as the between-subject effect.

2.5.4. Correlation between children's performance and interaction levels

We measured two types of children's performances: cognitive performance (in sections where the robot teaches the children new knowledge) and motor performance (where children play a motor game with the robot). Pearson product–moment correlations were calculated to determine the relationship between children's IL and P in relation to activity type.

2.5.5. Correlation between emotion in the story text and emotion expressed by the children

The Ugly Duckling story has strong emotional content. We therefore examined whether the robot successfully conveyed appropriate emotion while telling the story. The Pearson product–moment correlation was calculated to determine the relationship between the emotions in the story ("sad" and "happy" sections were defined in advance) and the emotions expressed by the children.

3. Results

3.1. Children's interaction levels with the robot

ANOVA with repeated measures (trials) with a Greenhouse-Geisser correction determined that mean IL scores (Fig. 5) differed significantly between the first meeting procedure and the experimental procedure (F (1, 169) = 3.085; p = 0.85). However, Fisher's least-significant-difference (LSD) post-hoc test revealed borderline significance between trials (p = 0.051; the mean of the second session was only slightly greater than the mean of the first session). Analysis of the between-subject "story" factor revealed significant differences in IL scores for the different stories (F(1, 155) = 4.16; p = 0.043), although LSD comparison showed that IL scores for the Ugly Duckling story were not significantly greater than for the Pluto story (p = 0.1). The experimental phase (tell story × motor game × cognitive game × picture presentation) had a borderline significant effect on IL (F (3,155) = 2.64; p = 0.051). LSD pairwise comparisons revealed only borderline significance between IL in "picture presentation" and in "cognitive game" (p = 0.051). IL was significantly affected by gender (F (1,155) = 9.38; p = 0.003), with ILs higher for girls (Table 3), but not by the group factor (F (1,155) = 1.95; p = 1.64) (Fig. 6).

3.2. Children's performance

ANOVA with repeated measures (trials) with a Greenhouse-Geisser correction revealed no significant differences in mean P scores of cognitive tasks (F (1, 69) = 1.388; p = 0.243). P was not significantly affected by any of the between-subject factors.

3.3. Comparison with first meeting procedure

ANOVA revealed significant differences in IL scores between experimental procedures (F (2,619) = 7.994; p < 0.001). Pairwise LSD comparisons showed that IL for the "first meeting" was smaller than for "Pluto" (p < 0.001) or for "Ugly Duckling" (p = 0.14). With regard to scores for similar motor tasks in "first interaction" and "Pluto," no significant differences were found in IL (F (1, 23) = .003; p = 0.958) or in P (F (1, 23) = 2.329; p = 0.141).

3.4. Correlation between children's performance and interaction levels

Our data revealed no violation of normality, linearity, or homoscedasticity. Children's IL and motor P were positively correlated (r = .218, n = 70; p = 0.035), as were IL and cognitive P (r = .401, n = 98, p < 0 .0001). Both correlations were statistically significant.

3.5. Correlation between emotion in story text and emotions expressed by children

The children's emotional responses, as reflected in their IL scores, were correlated with the emotional content in the text of the stories and the correlations were statistically significant (r = .596, n = 40; p < 0.0001).

4. Discussion

In this study, both methodological and conceptual innovations were used to demonstrate a potential application of humanoid assistive technology to aid the educational staff in the educational process. In contrast to previous studies, in which robots were used mainly as tools in story composition activities (Table 1), we showed here that a robot can assist the teacher in facilitating a process of constructive learning for the children through storytelling and teaching of new concepts and motor skills. Moreover, whereas most of the existing storytelling tools have been aimed at older children and seem to have little or no applicability in preschool education, an additional novelty of the present study is that it was designed for preschoolers in their natural setting, the kindergarten.

The positive interaction levels (Fig. 5) observed throughout the experimental session (except during the sad part of the story) clearly showed that children enjoyed interacting with the robot. The IL results for each procedure further suggest that the children's enjoyment in "playing" with the robot was maintained over time. We should mention that this experiment is part of the research project studying how to incorporate KindSAR in preschool education (Belokopytov & Fridin, 2012; Fridin, Angel, et al., 2011; Fridin, Bar-Haim, et al., 2011; Fridin & Yaakobi, 2011; Keren et al., 2012). KindSAR presented in the kindergarten for mostly whole academic year. During following procedures (e.g. Keren et al., 2012), IL remained high and stable, means that novelty is not a main factor leads children to enjoy playing with the robot.

Table 3
Interaction level and performance scores (means ± SD) in “Pluto” and “Ugly Duckling” procedures, according to gender.

Trial 1							Trial 2			
Interaction level					Performance		Interaction level		Performance	
		Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD
“Pluto”	Motor games	Girls								
		1	15.75	10.481	2.42	0.996	16.00	12.756	2.50	1.000
		2	7.00	1.000	2.67	0.577	8.67	4.933	1.33	1.528
		Boys								
		1	37.00	14.177	2.00	1.732	30.00	10.392	2.00	1.732
		2	11.33	7.681	1.33	1.581	12.67	12.796	1.00	1.500
	Tell story	Girls								
		1	9.56	8.485			10.25	7.029		
		2	3.75	1.500			2.75	2.062		
		Boys								
		1	10.50	19.053			6.75	7.890		
		2	16.67	15.642			19.67	15.175		
	Cognitive game	Girls								
		1	14.50	8.847	1.17	1.030	15.58	13.180	1.58	1.240
		2	6.67	3.055	2.00	.000	8.33	5.859	2.00	1.000
		Boys								
		1	10.33	1.528	1.00	0.000	17.00	17.059	1.33	1.528
		2	9.88	9.311	0.63	1.061	7.38	6.186	1.25	1.488
“Ugly Duckling”	Motor game	Girls								
		1	6.00		2.00		0.00		0.00	
		2	6.00	5.196	2.00	1.732	13.00	3.464	1.67	1.528
		Boys								
		1	13.00	1.732	2.00		6.33	13.868	1.00	1.732
		2	3.00		2.00	1.732	10.00		3.00	
	Tell story	Girls								
		1	13.20	15.375			9.30	6.516		
		2	10.33	7.517			11.11	2.934		
		Boys								
		1	11.14	5.816			12.71	7.966		
		2	4.00	1.732			24.00	13.748		
	Cognitive game	Girls								
		1	2.67	0.577	1.33	1.528	8.67	2.309	2.00	1.732
		2	9.00	6.364	0.56	1.130	2.67	13.620	0.00	0.000
		Boys								
		1	6.67	3.606	0.44	1.014	15.67	5.362	1.56	1.014
		2	5.00	1.732	0.00	0.000	25.00	21.071	1.00	1.732
	Picture presentation	Girls								
		1	11.25	6.652			11.25	2.872		
		2	15.50	6.502			16.08	7.525		
		Boys								
		1	16.00	9.254			11.50	6.502		
		2	11.25	4.500			21.00	10.100		

The significance of affective factors in the learning process is well known (Caine & Caine, 1994), and experiences that arouse emotions have proved to be more memorable than neutral experiences. There is evidence indicating that consolidation of novel tasks is enhanced if the training session includes emotional arousal (Mihelj, Novak, & Munih, 2009). Emotional arousal appears to be important in promoting the significance of an experience to determine how well that experience will be remembered (McGaugh, 2000), probably by activating neurobiological processes that modulate memory consolidation of recent experiences (McGaugh, 2006).

Our results indicate that the storytelling robot successfully promoted children’s emotional involvement in the learning process. The children’s emotional responses, as reflected in their IL scores, were correlated with the emotional content in the text of the stories. Moreover, our data showed that children’s IL scores were greater when they listened to the Ugly Duckling story (considered to be the more emotionally affecting of the two stories) than when they listened to the Pluto story. These results suggest that the robot “showed itself” as a “good” storyteller, which convey successfully the content and dramaturgy of the story.

As might be expected, children’s performances (P scores) were strongly correlated with IL. Children of preschool age enjoy playing motor games (e.g., Goodenough & Brian, 1929). Their performance levels were high and stable through all the experimental procedures, i.e., the first meeting and both storytelling sessions.

Novel robotic technology incorporating graphic displays was tested in the Ugly Duckling parts of the storytelling sessions. Use of this technology supports the principles of constructive learning and was shown in the present study to be an efficient learning tool. Children’s ILs during the graphic displays were higher than in other parts of the study.

A child’s psychological profile, learning style, and social/cognitive developmental stage play essential roles in his/her educational process. The KindSAR robot may be able to achieve what a human teacher cannot, i.e., provide feedback tailored to each child’s psychological profile, learning style, and cognitive and social developmental stage. Pierno, Mari, Lusher, and Castiello (2008) reported that children with autism had superior responses to robotic compared to human coaching, suggesting that that a socially simplified set of coaching stimuli is more effective for such children. In the present study, children’s interaction and performance levels were affected by gender but not by group composition. In future research, we will attempt to characterize children’s profiles and to program the robot’s behavior to fit different types of profiles, i.e., the robot will approach and respond differently according to the profile of each child individually.

5. Conclusion

In most of the studies incorporating robotic systems in the educational process (Benitti, 2012), robots have been used as platforms for the teaching of subjects closely related to the robotics field. In contrast, the KindSAR system, using social interaction as a basis, serves to actively assist teachers in a preschool educational setting.

The proposed technology offers numerous advantages over existing tools that support cognitive development (Cassell, 2002; Druin et al., 2003; Kafai, 1996; Malcolm, 2002). It was suggested that interactions with a real robot generate greater enjoyment than interactions with a virtual agent and provide more natural stealth education (Wainer, Feil-Seifer, Shell, & Matarić, 2006, 2007). KindSAR technology promotes face-to-face social interaction, whereas the social interaction that is promoted by computer-based games is mainly remote. When an embodied robot is used, the educational process can take place in any natural environment for children, such as the schoolyard or a playground, and hence allows for children's mobility.

The goal of the present study was to analyze changes in children's constructive learning following a KindSAR intervention. This novel kind of intervention offers significant advantages, both for research and for preschool education. First, it minimizes the artificial interference and distractions caused when video recordings are used in the natural environment of children's games, since KindSAR has its own built-in video recording system. KindSAR monitors children's progress and concurrently provides both the children and the educational staff with detailed feedback on game/task performance. Thus, KindSAR can regulate and monitor children's cognitive development over time and produce unique data on children's behavior during specific tasks in ordinary situations of playing with a toy in the natural kindergarten environment. Second, productive though it may be for educational (and research) purposes, child–teacher interaction is often limited in view of the large number of children (≈ 35) in Israeli kindergarten classes and the small number of teachers (usually 2) per class. KindSAR can help substantially to overcome this limitation by providing, at relatively low cost, social interactions for educational purposes and promoting children's cognitive development over time. Thus, this innovative technology has realistic potential and practical applications for improving the quality of preschool education and extending the fields of microgenetic research.

It should be noted that although we focused in this study on a particular aspect of children's constructive learning development, the ultimate aim of our ongoing research is to provide kindergarten teams with an assistive robotic tool designed to develop a broad range of cognitive, emotional, and social skills in preschool children. When computer games were first introduced into classroom, it was the initial assumption that computers could replace teachers. It soon became obvious, however, that the use of computers was not sufficient. It has been repeatedly suggested that effective integration of computers in teaching environments depends on the ability of teachers to alter the traditional role of teacher as knowledge provider to teacher as organizer, guide, learning partner, helper, and mediator of computer-assisted learning at all ages, including early childhood (Klein, Nir-Gal, & Darom, 2000). Since our proposed assistive robotics technology is by no means intended to substitute for the kindergarten teacher, there would be no purpose in attempting to compare the robot's performance with the performance of the teacher in conveying the skills and activities specified in a particular experimental situation. The intended purpose of the robot is to help the kindergarten staff, on a daily basis, in their educational tasks. Based on the missions predefined for it by the educational team, the robot is designed to be as friendly and helpful as possible. Once accepted by the children, and under the vigilance of the teacher, the KindSAR robot has the potential to become an important instrument in promoting children's cognitive and social development, and in improving routine educational work in kindergarten settings.

The design, implementation, and deployment of SAR systems pose several ethical challenges that become especially crucial in child care. In our future work we indent to develop ethical guidelines for KindSAR and show how to impellent them in kindergarten setting.

Acknowledgments

We thank the staff of Lior's Kindergarten, Neve-Naaman Tower, Israel, for participating in the study. We thank Y. Yakobi and M. Belokopytov for their assistance with design of the experiment, and the Arial University Center for its support.

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