Computers in Human Behavior 81 (2018) 250–264

Contents lists available at ScienceDirect

Computers in Human Behavior

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

Full length article

Breakdowns in children's interactions with a robotic tutor: A longitudinal study

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ARTICLE INFO

Article history:

Keywords:
Child–robot interaction
Education
Robotic tutor
Breakdowns
Interaction analysis
Thematic analysis

ABSTRACT

In recent years, there has been a growing research interest towards exploring the benefit of Child–Robot Interaction for educational purposes through the use of social robotics. Despite the label, such robots are typically only social within scripted activities. The current study takes a critical look at the case of a robotic tutor which was implemented in an elementary school for 3.5 months, where children repeatedly took turns interacting with the robot individually as well as in pairs. The aim of the study was to explore what caused breakdowns in children's interactions with the robotic tutor. In this qualitative study, over 14 h of video recordings of children's interaction sessions were analyzed in-depth through interaction analysis and thematic analysis. The results comprise four themes to explain why children's interactions with the robotic tutor break down: (1) the robot's inability to evoke initial engagement and identify misunderstandings, (2) confusing scaffolding, (3) lack of consistency and fairness, and finally, (4) controller problems. The implications of these breakdowns for the educational use of robots are discussed, and it is concluded that several challenges need to be rigorously addressed in order for robotic tutors to be able to feature in education.

1. Introduction

In recent years, there has been a growing research interest towards exploring the benefit of Child–Robot Interaction (CRI) for educational purposes through the use of social robotics (Benitti, 2012; Mubin, Stevens, Shahid, Mahmud, & Dong, 2013). As part of this effort, having robots feature as tutors is considered a promising approach (Castellano et al., 2013), argued to offer a number of benefits for education, such as to personalize education to individual children's needs (Leyzberg, Spaulding, & Scassellati, 2014), support learning (Kory Westlund et al., 2017), and alleviate teachers' workload (Movellan, Tanaka, Fortenberry, & Aisaka, 2005). As teachers agree, robots and other educational technologies should not be overbearing in relation to their professional workload (Serholt, Barendregt, et al., 2014), while they also need to be useful, and able to support children's learning (Fridin & Belokopytov, 2014; Kennedy, Lemaignan, & Belpaeme, 2016; Kim, Kim, Lee, Spector, & DeMeester, 2013; Lee, Lee, Kye, & Ko, 2008; Teo, 2011).

As Selwyn (2008) argues, research on educational technology tends to focus on what *should* or *could* happen once technology moves into the classroom (i.e., the *state of the art*), leading to a focus on the positive aspects of educational technology. Yet he argues that research needs to be equally concerned with the *state of the actual*, i.e., "questions concerning what is *actually* taking place when technology meets classroom" (Selwyn, 2008, p. 83). Although robotic tutors can be considered state of the art-technology, they can still be placed as-is in authentic educational settings, where negative aspects of children's interactions with them can be brought to the forefront in the research process. Thus, in order to study how the abovementioned visions for robotic tutors play out in practice, this paper takes a critical look at children's interactions with a robotic tutor in an educational setting. The robotic tutor was developed as part of an interdisciplinary EU-project called EMOTE, and was implemented in a school in Sweden. The robot was designed to tutor students in activities based on the syllabi for geography and social studies for elementary education, seeking to offer educational value to participating schools, in addition to the scientific value of studying CRI (Serholt, Barendregt, et al., 2014).

Robots can be said to present both differences as well as similarities in relation to other educational technologies such as

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Abbreviations: CRI, Child–Robot Interaction; HCI, Human–Computer Interaction; HHI, Human–Human Interaction.

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https://doi.org/10.1016/j.chb.2017.12.030
0747-5632/

computers and tablets. On the one hand, children may have distinctive expectations of robots because of their appearance and behavior (Belpaeme et al., 2013). Robots can share and move about within the same physical world as people, and they can resemble humans in appearance and behavior (Duffy, 2003; Fong, Nourbakhsh, & Dautenhahn, 2003). This entails that robots are more likely to be approached as (humanlike) artifacts to interact *with*, rather than to be used as tools for something else (Höflich, 2013; Zhao, 2006; van Oost & Reed, 2011). Indeed, when the robotic tutor under study was implemented in a set of schools in Europe, it was evident that children were prone to interact with it socially (Serholt & Barendregt, 2016), or to perceive it as a friend (Alves-Oliveira, Sequeira, & Paiva, 2016); findings that have been reported in other CRI studies, as well (Fior, Nugent, Beran, Ramirez-Serrano, & Kuzyk, 2010; Hyun, Yoon, & Son, 2010; Kahn, Friedman, Perez-Granados, & Freier, 2004; Kanda, Hirano, Eaton, & Ishiguro, 2004; Kennedy, Baxter, & Belpaeme, 2015; Tanaka, Cicourel, & Movellan, 2007).

On the other hand, robots are similar to other digital learning applications in the way that such tasks are usually structured. Indeed, although robotic tutors are intended to function in a social context, there are still substantive technical constraints when it comes to robots perceiving the natural (social) world around them (Belpaeme et al., 2013), making it much easier to design a robotic tutor with specific capabilities for one or more structured educational activities. There may be clear trajectories within the actual activities, such as correct versus incorrect answers. Also, there may be a specific way in which the activities can be carried out, both in terms of the social interaction modalities that the robot can perceive and respond to, as well as the ways in which answers can be provided or moves within the activity can be carried out. In the current study, a map reading activity (Hall et al., 2016), as well as a game on sustainable energy consumption (Alves-Oliveira et al., 2016), could be carried out alongside the robot on an interactive touchtable.

A robotic tutor's primary purpose is to instruct and guide children within specific learning activities. If this purpose is jeopardized for whatever reason, problems may arise that lead to breakdowns in interaction (Iacovides, Cox, McAndrew, Aczel, & Scanlon, 2015; Ryan & Siegel, 2009), where children, e.g., grow disengaged or unable to progress in the task (Plurkowski, Chu, & Vinkhuyzen, 2011). The aim of this paper is to explore the challenges that currently exist when moving robotic tutors into actual classrooms by focusing specifically on breakdowns in children's interactions with a robotic tutor at their school. Video recordings of such instances are analyzed in-depth through qualitative methods, guided by the following research question: *What causes breakdowns in children's interactions with a robotic tutor, and what consequences do such breakdowns pose for the educational use of robots?*

2. Related work

In this section, the use of robots in education is presented in brief with a particular focus on social robotics. Then, previous research findings relating to breakdowns in HCI is discussed.

2.1. Social robots in education

Social robots are physical, autonomous artifacts that interact and communicate with humans through human social mechanisms, such as natural speech and social cues (Breazeal, 2003; Edwards, Edwards, Spence, Harris, & Gambino, 2016). As explained by Edwards et al. (2016), “social robots overlap in form and function with human beings to the extent that their locally controlled performances occupy social roles and fulfill relationships that are traditionally held by other humans” (p. 628). There are a number of robot capabilities that are thought to facilitate a positive interaction between children and robots, such as empathy (Castellano et al., 2013), non-verbal immediacy (Kennedy, Baxter, & Belpaeme, 2017), social support (Leite, Castellano, Pereira, Martinho, & Paiva, 2012), personalization (Gordon et al., 2016; Leyzberg et al., 2014), and various levels of social behaviors (Kennedy et al., 2015).

Robots can also take on more instrumental roles in education, in which case social capabilities become less relevant. For instance, following Papert's notion of constructionism (Papert, 1980), robots (or robotic kits) are used as hands-on tools in order to explore their potential for facilitating students' computational thinking and learning of skills in subjects relating to science, technology, engineering and math (STEM). This can be done by, e.g., practicing the actual programming of robots (Nugent, Barker, & Grandgenett, 2012) or through robot assembly (Vandevelde, Wyffels, Ciocci, Vanderborght, & Saldien, 2015). Furthermore, robots can also be used as proxies when joint presence is not possible; e.g., if teachers need to conduct lessons away from actual classrooms, they can control, and thus communicate through a robot remotely (Yun et al., 2011).

Mubin et al. (2013) employ five dimensions to classify research on educational robots. These are: the embodiment or type of robot used, the roles or behaviors of the robot, the pedagogical theories underpinning the research, the location of the learning activity (e.g., formal or informal education), as well as the domain or subject of the learning activity (Mubin et al., 2013). Following the scope of the current study, the embodiments of *social* robots in education typically take some sort of humanoid appearance (such as NAO or Robovie), or zoomorphic form (such as iCat or AIBO). When it comes to roles and behaviors, robots can feature as, e.g., teachable agents (Lemaignan et al., 2016; Tanaka & Matsuzoe, 2012), learning companions (Castellano, Pereira, Leite, Paiva, & McOwan, 2009; Kanda, Sato, Saiwaki, & Ishiguro, 2007), or tutors (Kennedy, Baxter, Senft, & Belpaeme, 2016; Leyzberg et al., 2014). Concerning pedagogical underpinnings, the protégé effect, i.e., the idea that children put more effort into learning for others than for themselves (Chase, Chin, Oppezzo, & Schwartz, 2009), is considered to motivate the use of robots as agents that can be taught, whereas Vygotsky's zone of proximal development (Vygotsky, 1930) and principles of scaffolding (Wood & Wood, 1996) are common underpinnings for robots that can tutor children. Social robots can be used in either formal or informal educational settings, such as classrooms or children's after school venues, but this is typically dependent on the subject content. Subject content and learning activities also vary (e.g., in the current study, the focus is on geography and sustainable development). Yet, as mentioned previously, when robots are designed to feature in tutoring roles, they usually tutor participants in structured activities. Examples of such activities include nonogram puzzles (Leyzberg et al., 2014), chess (Leite, Martinho, Pereira, & Paiva, 2009), prime number identification games (Kennedy et al., 2017), wooden block games aiming to teach children to count in a foreign language (Vogt, de Haas, de Jong, Baxter, & Krahmer, 2017), and foreign word learning games (Gordon et al., 2016).

2.2. Breakdowns

As Bødker (1995) points out, “[a]n artifact works well in our activity if it allows us to focus our attention on the real object and badly if it does not” (p. 148). When something happens that disrupts the flow of the task, there is a risk that the interaction breaks down as a result. In HCI, breakdowns can occur when a person's process of using a computer application becomes interrupted by