Empathic Robotic Tutors for Personalised Learning: A Multidisciplinary Approach

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Abstract. Within any learning process, the formation of a socio-emotional relationship between learner and teacher is paramount to facilitating a good learning experience. The ability to form this relationship may come naturally to an attentive teacher; but how do we endow an unemotional robot with this ability? In this paper, we extend upon insights from the literature to include tools from user-centered design (UCD) and analyses of human-human interaction (HHI) as the basis of a multidisciplinary approach in the development of an empathic robotic tutor. We discuss the lessons learned in respect to design principles with the aim of personalised learning with empathic robotic tutors.

Keywords: Personalisation · Robotic tutor · Human-robot interaction

1 Introduction

Robots that are intended to interact with humans must learn how to become empathic rather than merely smart. Our aim is to design an empathic robotic tutor for personalised learning. Since social connection between tutors and learners has been shown to influence learning positively, a way of making tutoring systems more effective is to include a robot that will no longer just have to be intelligent, useable, and interactive, but will establish and maintain a certain level of social connection [18] and respond empathically to humans. Once such robots can convey the impression that they can understand and respond to the user not just intellectually but also emotionally, their use in domains in which they currently play a minor role, such as teaching, will become far more plausible and successful. Our approach is founded in fundamental psychological theory regarding the human ability to monitor others' emotions, engage in shared attention, and to establish effective socio-emotional bonds with one another. These connections have been shown to motivate learning processes [28].

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The goal of the design process presented here is to perform an iterative UCD process to enable a robot to mimic a sufficient number of key social and empathic abilities of a human tutor to establish a socio-emotional bond with the learner. UCD activities can help ensure that the empathic competencies of our robotic tutor are implemented in an appropriate and believable manner, have real world application in the complex school environment, and meet the needs of both learners and teachers.

There is precedent for HHI studies informing the design of human-robot interaction (HRI) [27] and UCD with robotics [9].

2 Background

Findings from the psychological literature suggest that children's learning processes can be facilitated by the tutor creating a strong empathic bond with the child, and having socio-emotional bonds can further be linked to how learners are able to handle their emotions in a guided learning process [20]. In addition, widely cited second order meta-analyses [12] have shown that key competencies of teachers, such as their ability to establish and maintain trusting teacher-student relationships, are far more important than the number of children in the class. The benefits of these relationships clearly suggest that a robot with the ability to form a socio-emotional bond with a child and to respond to the emotional states of a child empathically should be facilitative for the learning process.

In the field of HRI we see that personalised feedback from a robotic tutor can lead to more successful human-robot interactions with reduced problem solving time and a more motivated learner [19]. There is an increasing amount of work that shows that it is possible for a user to build a social bond with a robot. A review of studies that investigated long term interaction with robots [18], recommends that a robot should be able to display an awareness of and respond to the user's affective state and also adapt to the individual's preferences in order to build a good social interaction. Gaze through eye contact and joint attention is very important for social interaction with a robot and can improve performance in a cooperative human-robot task [4]. The social presence between a user and robot can also be mediated with a touchtable [3], suggesting that the capabilities of the robot may be usefully augmented in this manner. There are however dangers as some types of social behaviour from a robotic tutor may distract from the learning task and reduce the impact of the tutor in the learning process [16].

A review of robots in education [21] raises a number of challenges and open questions that we hope to address in our research, namely understanding the role of the robotic tutor, how to adapt behaviour and curricular to the learner, and how to design a socially acceptable robot. As outlined in the introduction, we argue that these basic insights from the literature need to be critically examined, expanded, and adapted via tools derived from UCD. UCD should be included to better account for the specific context, the experience and overarching teaching aims of teachers, and the personalised needs of the learner. Only then will robotic tutors become more successful in forming substantial social bonds with the aim of assisting learners within relatively open and complex learning scenarios.

3 Design Goals

To develop a robot that is accepted into the school context and that demonstrates an effective human–robot interaction, we believe that the following design goals should be met:

(1) Involve our users (teachers and learners) in the design of the robot. When technology is introduced into the classroom, it becomes part of a complex system of social and pedagogical interactions, involving both teachers and learners [23]. Therefore, it is pertinent to investigate the perspective of the potential users as well as the social and contextual structures inherent in the environment [17].

(2) Identify core empathic and personalised pedagogical strategies from human interactions. Successful personalised tutoring has to attempt to identify those empathic and pedagogical components and strategies that are most effective in establishing, strengthening, and sustaining social bonds. We see that HRI studies that are based on human interactions can be quite successful, for example, adopting human gaze behaviour to increase engagement with the robot [27].

(3) Supplement HHI-based behaviors with additional capabilities. On top of the core components identified with the help of observation and UCD tools, the robot can utilise additional behaviors that might be successful when displayed by a teacher but could tap into the same underlying mechanisms, e.g., the robot could produce robot-appropriate sounds that mimic a teacher's backchanneling efforts. HRI interactions are not routinely based on HHI due to the differences in how interactants perceive robots and humans [8]. It remains important to test interaction using techniques such as Wizard of Oz (WoZ) studies where a robot is controlled by a human wizard [7] to investigate how learners interact with a robot before developing final automated behaviours. We should also prototype and test these capabilities in the robot iteratively and in situ [24].

(4) Tie the robot capabilities on well supported psychological and pedagogical theories. Psychology is a field with many coexisting theories and the development of personalised learning strategies should specifically target those concepts that have been shown to be empirically well supported.

(5) Enable the robot to adapt to individual differences. Personalised learning approaches should, in particular, aim to identify cues that teachers use to personalise their teaching styles.

4 Scenarios and System Overview

The robotic tutor will support 10–15 year olds in the domain of Geography. We have developed two different learning scenarios: an individual map-reading activity and a multi-player collaborative game in which the tutor will provide support for two learners.

We use the torso only version of the NAO robot produced by Aldebaran Robotics[1]. The interaction between the tutor and the learner(s) is mediated by a large touchscreen/table. The robot sits opposite the learner(s) on the long edge of the table. Beneath the robot, built in to the table, we have a number of sensors to enable the robot to perceive facial expressions, gaze direction, head position, body posture, electrodermal activity and the volume of speech.

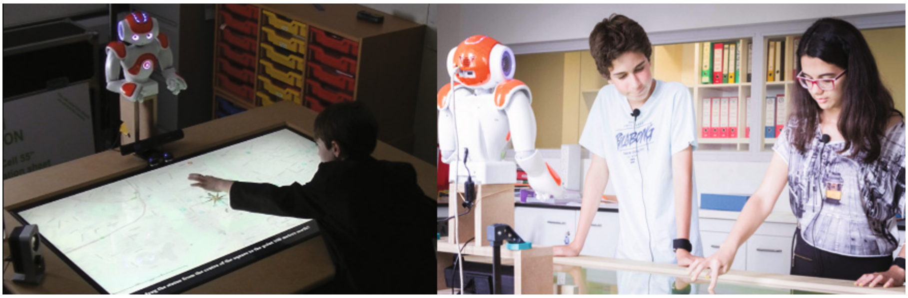

Fig. 1. NAO Robot, Learners, and Learning Scenarios

5 Design Process

The goal of endowing robots with empathic capabilities requires a multidisciplinary effort, in addition to the teachers and learners. Learning, teaching and HHI experts give valuable practical advice for our user centric approach. Psychologists have developed the necessary theoretical framework concerning empathy and emotion, and provide guidelines and feedback on how this framework can be translated into practice.

5.1 Interviews

The primary aims of the interviews, which comprised a series conducted over several months, were to elicit a greater understanding of the context of use and the teachers' [26] and learners' [25] needs. The questions focused on the plausibility of having a robotic tutor in their classes.

We found that it is difficult for teachers to imagine having an autonomous robot in the classroom. More specifically, there are a number of practical and social factors that play an important role when teachers think about robots in school. They have e.g., concerns about managing the availability of a robot to all children and how this will affect their already busy schedule. However, this type of initial resistance towards and mistrust about the intended use of a robot in school was shown to be greatly reduced by involving teachers in the project.

[1] https://www.aldebaran.com/en/humanoid-robot/nao-robot

To aid teachers and learners in imagining a robotic tutor, we have developed a video that gives teachers more information about the capabilities of robots and how their use is envisioned in the project. Together with the interviews, these very first steps in our iterative approach have helped us discuss with teachers in a more concrete way what it could mean to have a robotic tutor in the classroom.

5.2 Participatory Design Workshops

Teachers were provided with a preliminary version of the learning activity and were asked to contribute to the design. The design workshops allow us to understand teachers' ways of approaching the learning task, including their assessment of the difficulty levels of different sub tasks, and how they would personalise their teaching strategy to learners of differing ability.

The teachers' contributions included ideas for technical content and pedagogical strategies. The main finding of these workshops was that there appeared to be a general trend in how directions and instructions are personalised by teachers, in which less capable students are provided with simple and clearly formulated pieces of information, while more capable students are provided with one or several complex pieces of information at a time. However, it was also observed that it is difficult for teachers to provide a description of how they would personalise or adjust to different students' needs from a fictive perspective. Although, generally, this second stage of UCD inspired iterative design approach may not yet provide the finer details, we have found it to be informative in respect to some of the broad strategies to be employed by the robot.

5.3 Mockup Studies with Teachers and Students

We conducted mockup studies involving human teachers and children with varying abilities. The aims of the mockup studies were to understand how and when teachers provide personalised feedback to the students. Earlier studies were paper based, later studies were performed with the touchtable based activity [2].

The findings enabled us to better understand the dynamics between the teacher, task, and learner, as well as examine some of the more detailed pedagogical tactics and strategies employed by the teachers.

5.4 User-Centered Design and Pedagogical Theories

The aforementioned preliminary studies for both learning scenarios have given us insights into the practical requirements needed to create a believable interaction with a robotic tutor in our context. In combining the experience derived from the user-centered pretests with a comprehensive literature review of tactics used by teachers during learning activities, we generated a list of pedagogical tactics that the robotic tutor can use to interact with and motivate students in their learning process.

Pedagogical tactics can be divided in three clusters that serve different learning purposes: the first purpose is to prompt reflection or elicit information from the learner; second, to supply content to the learner; and third, tactics to form a social bond with the learner.

On the basis of recordings made in the earlier studies, we collected over 900 concrete examples of utterances that could be implemented in the robotic tutor. These are spread over 25 pedagogical tactics meaning that the robotic tutor can use the same pedagogical tactic in many different ways, giving it a dynamic and non-repetitive verbal behaviour.

6 Initial Implementation

The specific utterances from the pedagogical tactics from the previous section have been implemented as behaviours for the robot to perform. Each behaviour contains speech and nonverbal behaviour based on observations of teachers.

The robot is able to gaze and gesture at the table and use gestures to explain as it is speaking. Our architecture allows the decision of which social or pedagogical tactic to be taken at a high level as each concrete behaviour already details everything that the robot needs to do in terms of gesturing and gazing at the learner or table [22].

In addition to pedagogical tactics the robot has a set of autonomous behaviors that are continuously running without input from the human wizard. The ability for the robot to perform actions contingent and adapted to the learner is key from the psychological theories and other HRI literature. To achieve this at a low level, the robot makes use of the sensors to track the learner's volume, location and gaze direction. For example, gaze behaviour is based on a mockup study [1], the robot can gaze at the learner when addressing them, follow where the learner is looking or interacting with the activity, and gaze back at the learner when the learner is looking at the robot. These low level contingent behaviours are overridden when the robot is required to perform a behaviour specifically selected by the decision-making component.

7 Wizard of Oz Studies

On the basis of the initial implementation, a number of WoZ studies have been conducted with children at their school. The aim of these studies has been to test the expressive capabilities of the robot in an interaction with the learner and see if it is possible to support the learner in the way that we envisage. Additionally we captured corpora of data to inform the design of the sensing and decision making capabilities of the robotic tutor. The wizards are researchers with teaching experience and had been involved in the development of the WoZ interface with full training in its use.

In a WoZ study the wizard decided which pedagogical tactic to apply via a WoZ Interface. The WoZ interface allows the wizard to observe the learner's activities related to the educational application; view the learner via a webcam and other sensors; and control the robot. The WoZ interface and system architecture allows the wizard to concentrate on high level interaction and not on

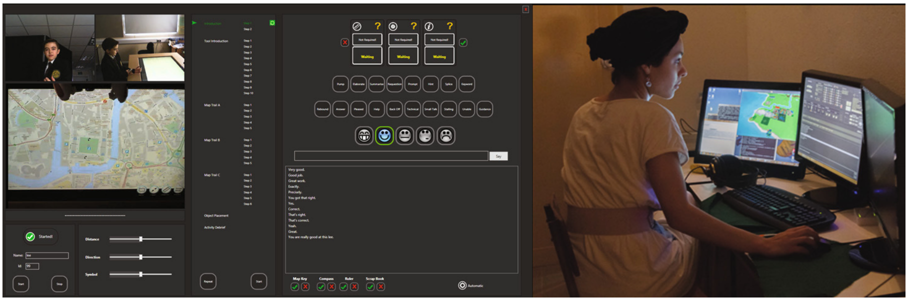

Fig. 2. WoZ Interface

low level coordination of the robot. The robot used concrete behaviours based on the mockup studies but automatically adapted to the situation based on the position of the learner and the state of the task.

In terms of sensing affect, some of our findings were at odds with our initial thoughts on the emotions that we would observe in the learners. We found that expressions of basic emotion were much less frequent than suggested by theory related to learning scenarios. This has led us to adopt a valence and arousal model for the automated system. Our data so far suggests that the smiles exhibited by the children in the WoZ should more cautiously be interpreted as signs of politeness and, perhaps, a readiness to engage in interaction with the robot, rather than any clear indication of enjoyment.

8 Development of Fully Autonomous Behavior

For the robot to work in an autonomous way, we have developed perception capabilities and pedagogical strategies so that the robotic tutor can sense and adapt to the affective states, skills, and difficulties of the learner. The pedagogical strategies comprise of a set of rules that determine which of the pedagogical tactics should be used by the robotic tutor. Some of these rules have been based upon findings from user studies and literature. Other rules were generated using machine learning analysis of the logs of the interactions recorded in the WoZ.

We have also performed supporting studies to develop behaviors not based on human interactions, for example: to create and validate a set of short synthetic sounds that the robot could use as emotional qualifiers to synthetic speech [15]; to investigate how affective feedback is perceived by learners [10]; and to evaluate and train the perceptive abilities of the tutor focusing on the electrodermal activity sensor [14] and the ability for the system to perceive engagement [6].

We are now in the phase of the project where we are running studies with a fully automated robotic tutor.

9 Lessons Learned

A number of lessons can be drawn from our user-centered iterative approach for the purpose of designing robotic tutors:

The involvement of users and UCD-tools may be most effective when implemented throughout the full range of the design process. Including the learners at a very early stage was essential to providing a system that the teachers would welcome in to their classroom and fit into their curriculum. Feedback provided here led to the development of learning aims, the role of the robot and the development of a multiplayer scenario.

Including users at an early stage can be difficult as initially teachers and students were unfamiliar with the capabilities of robots and could not imagine how the robot could fit in the classroom. We used a video and descriptions of possible scenarios to give concrete examples. As development of the activity and robotic tutor progressed we used prototypes as concrete demonstrations.

It can be difficult for teachers to explain in detail how they would adjust to different students' needs on the basis of an abstract description of the task. What is needed in this case is to actually run mockup studies to put the teachers into a situation where the students have different needs and carry out an assessment on that basis.

There is a need to fully take into account personality differences between children. Some children, through high expressivity, make it much easier for the robot to pick up on critical information regarding their emotional state. The challenge is to accommodate these differences and be aware that not all students will indicate their emotional state in the same way. Additionally the learners reactions change over time, so we are required to give each child sufficient time and opportunity to adjust to the presence and unfamiliar nature of the robot. We have tried to address this by making the students familiar with the robot and performing all of our studies in the participant's schools.

As we found that expressions of basic emotion were infrequent we have adopted a valence and arousal model for affect detection.

We have adopted many of the teaching strategies observed in mockup studies. We try to give the student an opportunity to self-regulate their learning process [5]. We match feedback to the abilities of the student, breaking down the task and focusing the student's attention on the areas where they have difficulty. We further personalise the interaction by referring to the learner's previous knowledge and skills.

We suggest too much interaction from the robot could hinder the interaction; frequent or unconvincing praise can adversely affect children's intrinsic motivation [13]. To avoid adverse effects of inhibiting negative emotion [11] and to facilitate a good social bond with the child, our design has aimed for mimicry of context-appropriate affective behavior as a more likely key to a successful learning experience. Care with affective behaviour must also be taken as we have found that it is possible to make the activity seem more difficult with affective feedback [10].

By observing the interactions between teacher and learner we are able to gain a deeper insight into the key tactics used by teachers. We were able to combine the observations with a review of literature to create a set of pedagogical tactics and a set of rules for when it would be appropriate for the robotic tutor to use them. Literature alone would not provide enough detail to formulate such an appropriate, dynamic and non-repetitive behaviour.

10 Conclusion

In this paper, we have presented the design process for the enhancement of off-the-shelf robots aimed at creating a new generation of artificial embodied tutors that are able to engage in empathic interactions with learners. To this aim, we have provided a structure that illustrates how the end users can be actively engaged in the design of an appropriate learning context in which the robot may be enabled to develop the full extent of personalised empathic capabilities.

On the theoretical foundation that has demonstrated the importance of social bonding in education, we show how capabilities in a robot to support social bonding might be developed based on interviews, HHI, and HRI studies in a non trivial, real-world domain. We have developed initial versions of all of the components of the robotic tutor system, including perceptive capabilities, pedagogical strategies, and psychological bonding mechanisms. We are now in the process of evaluating the robotic tutor.

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