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The EASEL Project: Towards Educational Human-Robot Symbiotic Interaction

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Abstract. This paper presents the EU EASEL project, which explores the potential impact and relevance of a robot in educational settings. We present the project objectives and the theorectical background on which the project builds, briefly introduce the EASEL technological developments, and end with a summary of what we have learned from the evaluation studies carried out in the project so far.

Keywords: Synthetic Tutoring Assistant, DAC, Education, Child Robot Interaction, Architecture, Evaluation

1 Introduction

This paper presents the EU EASEL project ("Expessive Agents for Symbiotic Education and Learning"), which explores the potential impact and relevance of a robot in educational settings. EASEL targets Human Robot Symbiotic Interaction (HRSI) in the domain of education and learning. Symbiosis is taken here as the capacity of the robot and the person to mutually influence each other, and alter each other's behaviour over different time-scales (within encounters and across encounters). Based on perception of the social, communicative and

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educational context, the robot responds to the student in order to influence their learning progress.

The impact of EASEL developments crucially depends on the combination of two domains. The field of human robot interaction concerns conversational and social interaction between humans and robots. This involves short term interactions as well as the development of a relation over longer time through repeated interactions [Cameron et al., submitted]. The field of learning and education concerns principles and practices of how a student learns in interaction with other people and learning materials [Charisi et al., 2015]. The theoretical work carried out in EASEL concerns the integration of insights from these two fields.

Clearly, the resulting tutoring assistant(s) need to be evaluated. EASEL achieves this through a combination of lab studies and in-the-wild studies in schools, museums, and daycare centers. The studies carried out in EASEL range across the combination of the two above domains, from studies focusing on the development of a longer term relation between human and robot to studies focusing on the exact effect of certain tasks on the learning process and outcome.

The paper is structured as follows. We introduce the EASEL objectives in Section 2. Section 3 briefly discusses the interplay between the two above mentioned domains of learning and social interaction. Section 4 focuses on the technology developed in EASEL. Section 5 summarizes the EASEL evaluation studies carried out so far, placing them in the framework between HRI and education. Finally, we tie the results together in Section 6, looking at the future directions we need to go to achieve the ultimate aim of EASEL: social robots that are a transformative contribution to the classroom of the future.

2 EASEL Objectives

EASEL aims to deliver a new set of Robotic Based Tutoring Solutions: a Synthetic Tutoring Assistant that incorporates key features of human tutors and other proven approaches capable of instructing a human user and learns from their interactions during large time scales. To this end, new approaches are developed for acquiring social context from sensor data, modeling the student's learning process, and determining the appropriate and most effective strategies for delivering the learning material. The results are incorporated in a social dialog carried out between student and robot, which supports the student in the learning task. The end result of EASEL is a unique and beyond the state of the art social robot based tutoring system that comprises a learning model of the user, a synthetic agent control system for symbiotic interaction establishment, a computational framework of social affordances and a multi modal analysis system for subject's social and affective state analysis. In addition, the project yields guidelines for the design and development of the appropriate robot behaviour toward children in various possible robot roles in the contexts of school and museum environments.

3 Learning, Education, and Robots

The theoretical viewpoint from which we approach learning and education is described by Charisi et al. [2015]. Below, we briefly describe this view and show the potential areas of contribution for social robots.

Vygotsky [1978] describes learning as a socio-cultural process. In this process, the student's learning is mediated in two ways. Firstly, by "physical tools": the learning materials such as books, computers, and other tools. Secondly, learning is mediated by "social tools": other people who participate in the learning situation. Figure 1 shows how learning happens in a triadic interaction between student, materials, and other persons.

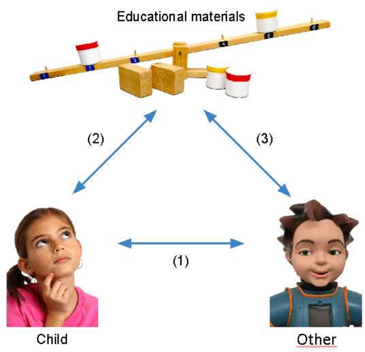

Fig. 1. Learning as a triadic interaction between student, learning materials, and another person (in this case: a robot)

When we look at the interaction between student and learning materials, there is the student interacting directly with the learning materials. We can observe the actions the student takes in the learning task, the utterances and expressions, and the performance in the task. Furthermore, there are the things going on in the mind of the student. These include attitude towards task (is it interesting? is it hard? is it relevant?), self-efficacy with respect to the task (can I do this task? am I doing well right now?), mind set in learning [Dweck, 2012] (e.g., directed at risk avoidance / aversive to failure? directed at growth and learning? willingness to make mistakes? curiosity?), and other factors.

When we look at the role that an "other person" can play in the student's learning process, we see three possibilities. The other can be *more knowledgeable* (e.g., teacher or more advanced fellow student), *differently knowledgeable* (a fellow student doing the task together with, or alongside of, the student, see Dillenbourg [1999]), or even *less knowledgeable*. Things the other person could do in their various roles are, for example, explain to student, be explained to by student, encourage student, praise student in various ways, give good or bad example as fellow student, and many other things. In this way, the other person can influence both the observable behavior and the mental state of the student. The effectiveness of these actions depends to a large extent on the relation between the student and the other: factors such as trust or likability will influence to what extent the student is willing to modify his or her actions or perceptions in response to the other's suggestions and contributions.

Given this context, a robot in class can serve a unique mixed role. It is a computer, and as such it can present learning materials to the student in a smart and adaptive way based on the student's skills and progress: the robot as smart learning material. At the same time, a robot is a social entity, more so than a computer. As such, it can fulfil the role of a more or differently knowledgeable "other person" across the entire spectrum from teacher or more advanced fellow student to less knowledgeable peer being taught to by the student. It is this social role of the robot that we are concerned with here. Like many others, we believe this makes the robot a very powerful tool for learning because learning takes place in a social context [Vygotsky, 1978]. However, the effectiveness of the robot depends among other things on the social believabilty and the quality of the relation between student and robot. This requires us to also look at short and long term affective interactions between student and robot [Cameron et al., submitted].

4 EASEL Technology Developments

The EASEL architecture incorporates the novel technology developments of the project, and is structured in four layers: acquisition, cognitive modules, dialog and behavior planning, and robot behavior realisation. Vouloutsi et al. [in preparation] describe how this architecture is a practical incarnation of the conceptual architecture of the Distributed Adaptive Control (DAC) theory [Verschure, 2012] of the design principles underlying perception, cognition and action. This section briefly introduces the main components developed as part of EASEL.

4.1 Acquisition

The acquisition layer of EASEL consists of various modules integrating audiovisual analysis and acquisition of physiological signals from the user. The speech recognition is based on the open source Kaldi speech recognizer [**?**], with an EASEL specific vocabulary, language model and recognition grammar. Its specific speaker adaptation solution makes it very robust with respect to interfering speech from the robot itself. Audiovisual scene analysis is done using the Scene-Analyzer [**?**], which builds upon several other libraries to deliver quick and robust integrated recognition of multimodal features of the users and their behaviour. Physiological signals can be acquired from the user using non-obtrusive sensor patches that can be integrated in the robot or the learning maerials, which allows signal analysis to take place without sensors worn strapped to arm/head/body of user.

4.2 Cognitive modules

The cognition of the tutoring assistant consists of the memory and decision modules. The memory module stores the current state of the user and the learning task, and has the potential to store longer term memory in repeated interaction, which allows the tutor to build up a user model of a learner from all information in the network. The allostatic control module regulates the tutoring process, learning optimal strategies for delivering the learning content in the right order and at the right dificulty levels, adapted to the student's characteristics and capabilities. The exercise generator, finally, delivers learning exercises of exactly the right nature and difficulty level that is requested by the tutoring models.

4.3 Dialog and behavior planning

The cognitive modules deliver the interaction goals of the tutoring agent. These are then translated by the dialog and behavior planning modules into actual utterances and expressions to be realised by the robot. We use the Flipper dialog manager of ter Maat and Heylen [2011] for managing the dialog, and the BML realizer ASAPRealizer by van Welbergen et al. [2012]. Flipper affers flexible dialog specification via information state and rule based templates to trigger information state changes as well as behaviour requests. ASAPRealizer offers easy, configurable, control of multimodal choreographed behaviours across several robots using the BML language, which abstracts away from specific motor control by exposing more general behaviour specifications to the dialog manager. ASAPRealizer realizes the requested behaviours on robotic embodiments by directly accessing the motion primitives of the embodiments (see below).

4.4 Content presentation and behavior generation

The learning content is presented in two ways: through the EASEL Scope tablets, and through utterances and expressions of the robot. The EASEL Scope offers a mixed reality interface that allows the student to interact with the learning scenario materials. It can be used to present additional information to the child about the learning materials. This allows the system to vary between different ways of scaffolding the learning of the user. The two main robots used in EASEL are the Robokind Zeno R25 and the FACE robot [**?**]. For both robots, contrrollers have been developed that offer acces to the robot's motion control primitives in a comparable way, allowing the system to present the same content through different robots.

The first versions of the complete EASEL architecture have been deployed already in various settings and used in a number of studies; the final year of the project will see several deployments of the system in real life contexts over longer periods of time.

5 EASEL Studies on Robots in Learning

In order to evaluate the integrated solutions developed in EASEL, an ongoing series of experiments is conducted throughout the project. In this section we discuss results we have achieved so far. We looked at the impact of robot behavior and characteristics on the way students *perceive the robot*, the potential for impact on the *longer term (social) relationship* between student and robot, the impact of the robot on the *learning outcome*, and the impact of the robot on the *learning process* that the student goes through. In most experiments these students were children of primary school age since these are the main target group for EASEL. Most studies were conducted with a Robokind Zeno R25 robot; a few were caried out with an iCub.

5.1 Impact of robot behavior and characteristics on perception of robot by student

Regarding direct perception of the robot by the children interacting with it, EASEL studies have looked at the childs affective and social responses related to gender [Cameron et al., 2015b] and age [Cameron et al., 2015c]. Children interacted with a robot during a Simon Says game in two studies. Results of both studies show a clear gender difference: boys respond more positively, showing more smiling and liking, while girls display less smiling with an expressive robot. Furthermore, the second study revealed an age difference: on average older children considered the robot to be significantly more like a machine than the younger children did. In follow-up studies, Cameron et al. [in preparation] looked at the influence of age on perception of animacy and gender of the robot Zeno by boys and girls from different age groups.

Regarding responses of users to the robot during a task, another EASEL study found that children seem to respond differently to the robot depending on whether it seems to be autonomously responsive to speech from the children or its speech understanding is visibly mediated by the experiment controller. In the former case children seem to display more anticipatory gaze awaiting the robot's responses, in contrast to more reactive gaze after the robot started responding [Cameron et al., 2016a]. In several of the studies we saw that children attempted to engage the robot in social interactions, displaying behavior such as conversational turn-taking and socially oriented gaze and spontaneous utterances towards the robot, and they would sometimes modify their speech utterances (following robot errors, participant corrects robot then repeats question more slowly and clearly, emphasizing key words).

5.2 User behavior towards the robot: Potential for longer term relation between robot and student

In the previous section we saw that children seem to be willing to treat the EASEL robot as a social partner, and respond socially to it, depending on its behavior. We are also interested in finding out to what extent the robot's behavior could influence the forming of a longer term relationship.

One EASEL study focused on the impact of robot-stated phrases, relating to its limitations or its intentions, on individuals liking, perceptions of robot competence, and willingness to assist the robot [Cameron et al., 2015a, 2016b]. Results of this study showed that robot behavior can influence the user's willingness to use the robot in the future. This study provides new evidence that strategies used by individuals in interpersonal relationship development can be extended to apply to social robotics HRI.

We also looked at the impact of the *activities* that robot and child share on the potential for longer term relationship. Davison et al. [2016] looked at children who engage in both an educational task and a physical exercise with a peer-like robot, or only in educational tasks. Results, although not significant enough, suggest that sharing an additional physical and extra-curricular activity might promote social perception of the robot.

For future EASEL studies we are planning to focus on the details of relationship development over a longer period of time and in repeated interaction with the system.

5.3 Impact of robot on learning outcome

We looked at the effect on learning performance related to different behavior types of the robot: tutor-like behavior vs peer-like behavior, and various ways of implementing the robot's gaze behavior. The impact was measured on the perception and subjective experience of the user and on task performance and learning outcome [Blancas et al., 2015, Vouloutsi et al., 2015]. Regarding learning outcome, experiments so far indicate that although we can measure improvement in performance successfully with a post-test, the improvement was not yet significantly different between conditions of different robot behavior. We will address this aspect further in longer term studies, since we expect that this effect will depend on longer term interactions.

5.4 Impact of robot on learning process

The final aspect that the EASEL project targets is impact of the robot (behavior) on the learning *process*. In the final EASEL study discussed here, children had to do an inquiry learning task in one of two conditions: with a social robot, or with an interactive tablet. In both conditions the content of the task was the same, including the spoken instructions issued by the robot or tablet. In both conditions, the child was invited to verbally explain their thoughts. Important steps in an inquiry learning task are related to generating explanations. It is well known that explaining learning content to someone else is a powerful source of learning [Bargh and Schul, 1980]; children often gain a deeper understanding of the material when they are asked to verbalize their thoughts and reasoning to others [Coleman et al., 1997, Holmes, 2007].

The main hypothesis for this study was that the social nature of the robot, compared to the tablet, would trigger the child to verbalize their thoughts more easily (faster and/or longer responses). To measure this we looked at both the verbalization by the child, and their perception of the tablet or robot as a social entity.

Results tentatively indicated that children tended to verbalize more and respond faster to questions when working with the robot. It seems that the robot provided a more intuitive context for verbalization than the tablet. The results of the exit interview suggested that the robot was indeed seen as a more social entity compared to a tablet. For example, statements like: “I taught the robot”, or “the robot was curious” were given by the children in the exit interview, and children spontaneously addressed the robot as ‘robot’, asking it its opinion, etcetera.

6 Discussion

We presented the EASEL project, which aims to deliver a new state of the art in Synthetic Tutoring Assistants. The conceptual and technological developments so far have resulted in an integrated system capable of deriving contextual information from audiovisual sensors, modeling students and learning, learn strategies for effective teaching and deliver the teaching material through social dialog.

An important observation in the evaluation studies is the fact that child-robot interaction, be it in learning or in other domains, is challenging to evaluate. So far we have applied a number of novel and traditional methods that gave us sensible results and significant differences between conditions, but not all methods worked equally well (or at all) [Charisi et al., submitted]. The evaluation of child-robot interaction is a topic that we will address in future work. Clearly, we are not alone in this position, as shown by the growing number of workshops, symposia, and panels dedicated to this topic.

Nevertheless, we feel that we managed to start exploring the potential impact of robots in education across the whole spectrum: the perception of the robot by the student, the student’s responses to the behavior and characteristics of the robot; the potential for longer term relationship; the possibility for robot to influence the learning process, and the learning outcome. We see increasing evidence toward the positive effects of the EASEL robots social behavior on how children approach learning tasks as well as on the learning outcome. We are now preparing the final longer term evaluations in which we combine all these aspects in one setup, with the aim of showing how the EASEL robots can be a transformative contribution to the classroom of the future.

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