Using a social robot for different types of feedback during university lectures

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Abstract
In this paper we present a long-term study in which a social robot was used as an embodied feedback channel during a series of university lectures spanning over one academic year. We used a Pepper robot from Softbank Robotics within an enactive didactics framework in order to reinforce the structural coupling between the teacher, the students and the content of the lecture. The robot provided different types of feedback during the lectures. In this paper we will focus on feedback that informed the students of their learning progress and that helped the teacher to understand how the students were able to follow each lecture. At the end of the lecture series we used questionnaires as qualitative measures for how the students perceived the feedback of the robot. Our results show a positive response of the students to the robot. We asked the students also how they thought the robot's feedback affected their learning progress. The vast majority of the students reported that the robot indeed helped them to reflect about their level of understanding of the content of the lecture and facilitated the initiation of interventions to improve their learning.
Keywords: Enactive didactics, Feedback, Social robots, Structural coupling, Robot mediators.

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1. Introduction

1.1 Social robots as mediators in education

The use of robots as mediators in educational settings has moved increasingly into the focus of social robotics research in the last decade due to technological advances in the general field of autonomous robots.

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Consequently, different types of socially evocative robots have been integrated in a plurality of roles in various educational settings (Belpaeme et al., 2018). These robots usually are used as learning supports for children and students, e.g. connecting images and words, or helping to learn a second language. Most of these robots are either humanoid or semi-humanoid (e.g. Robovie R3 (Kanda et al., 2004); Maggie (Gorostiza et al., 2006)). This allows them to use gestures and other non-verbal communication signals, which make the interaction with these robots more intuitive and pleasant. One of the most widely used humanoid robotic platforms in this context is Softbank Robotics' NAO robot (Shamsuddin et al., 2011). However also other robots, like RoboVie (Ishiguro et al., 2001) and Tiro (Han and Kim, 2009), have been successfully deployed and tested, and in the process provided valuable insights into the psychological dynamics characterizing social human-robot interactions in educational settings (Benitti, 2012).

One of the characteristics of the use of social robots as mediators in education is that these interventions typically happen over a longer period of time. These long-term interactions, for example in classrooms, give rise to a variety of issues. One is for example that the novelty effect of using a robot wears off relatively quickly. In order to generate effects that carry over to other learning situations, the robots need not only to provide adequate situational feedback. They also need to provide appropriate emotional feedback. First successful attempts in this direction have been made to support vocabulary learning in primary school students (Ahmad et al., 2019). Specifically Asian countries like Japan, South Korea and Singapore have embraced the use of social robots in pre-schools and middle schools in this way. The majority of these applications are linked to language learning, in which the robots link new words and grammatical concepts to movements and gestures, and in this way help to multimodally anchor the newly constructed knowledge in the memory of the children.

For the topic of this paper – the use of social robots as feedback devices – two recent experimental studies are specifically interesting. In their work Vogt et al. (2017) found that a social robot performs better in educational contexts if it remains within Vygotsky's "Zone of Proximal Development" (Vygotsky, 1978), adapting the difficulty of the learning task to the individual level of the student. This study in particular focuses on the position of social robots in the teaching process. According to the authors, the robots should be located in the area between the biologically determined learning capabilities of an individual student and the limit of learning that can be achieved by the student with the help of social support. In the perspective proposed by the study, this social support can be provided by a social robot in the form of personalized feedback about the learning progress of the student. The results of Senft et al. (2018)

point in a similar direction. They found that a NAO robot improves its tutoring capabilities when it is able to adapt to the learning specificities of each of its users. The idea is that, as teachers ideally know the individual differences of their pupils and adapt their feedback accordingly, social robots should provide not only general, but also personalized feedback for each student. For the use of social robots in education this represents an important finding, particularly relevant in the framework of Enactive didactics.

1.2 Enactive didactics

Our integration of a robot into the educational process, as well as the related applications we created, is grounded in the enactive approach to didactics introduced in (Rossi, 2011), which is inspired by the enactive approach brought forward by Varela et al. (1991) within the cognitive sciences. One of the key points of Varelian enaction can be found in overcoming the traditional distinction between internal and external factors influencing the development of a system in an environment. Varela proposes to overcome this distinction through the concept of structural coupling, which characterizes the dynamic relation between the system and its environment. Indeed, this notion defines a continuous mutual process of co-transformation involving the system's and its environment's patterns of activity. According to the concept of structural coupling, the system and its environment, change not only each other, but also the overall process of interaction. This change happens through their dynamics of self-regulation that maintains or re-establishes their respective dynamical equilibria. In this way, the notion of structural coupling suggests to see the system and its environment as two aspects of the same, global process of (co-)transformation. When this theoretical concept is applied to human (verbal and nonverbal) communication, it implies that the engagement of the social actors in interaction leads them to continuously change each other. Therefore through this ongoing dynamics of co-transformation, to change also the characteristics and context of the interaction.

As shown by Rossi (2011), the development of the enactive approach into didactics structures a specific perspective on the relationship between teacher and student. According to this view, the teacher influences with her/his presence the context of the teaching process, the subject to be taught, and the student, who, in turn, changes the teacher and the context; and the context changes the teacher and the student. This strong emphasis on mutual influences implies a twofold shift in the focus of teaching, which can be conceptualized as a re-focalization from the "What?" to the "How?", from the static content to the dynamic process (*Fig. 1 left* – adapted from (Maturana and Varela, 1987)). Following this line of thought, knowledge has to be seen as a product of an irreducible plurality of factors: the teaching activity, its context, the individual characteristics of the teacher and the students, and the culture in which knowledge itself is developed and expressed (Brown et al., 1989). In this perspective it is no longer possible to distinguish between the content that is to be taught, the way this content is taught, as well as by whom and to whom it is taught.

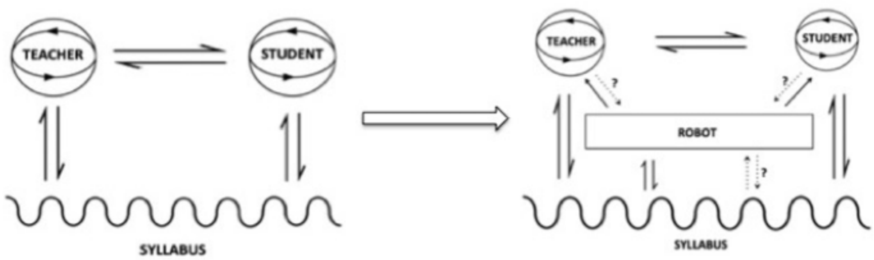

Fig. 1 - Extension of the structural coupling characterising the enactive didactics approach by integrating a social robot and using its embodiment as multimodal social interface (from Lehmann and Rossi, 2020b)

As Rossi (2011) points out, the role of the teacher in the enactive didactics approach is to raise the awareness of a problem in the students. This serves to activate a cognitive conflict in the students that connects the students' experiential knowledge with the new problem and the related new knowledge. Once this cognitive conflict is activated, it then becomes possible for the teacher and the students in a next step to find an answer together. The way in which this answer is constructed is determined by the teacher, who acts as mediator between the world experienced by the student and the knowledge to be co-constructed. In order for this process to be successful it is crucial that the newly constructed knowledge is validated (Rossi, 2011). For this validation feedback about the progress of the learning cycle is very important, since the absence of feedback would create a static system, and therefore hinder the learning progress. Unfortunately one of the limitations of many teaching processes is a lack of space for interaction and feedback. Due to their physical presence in the classroom and their socially evocative interaction behaviors social robots have the potential to augment the frequency of direct feedback. In this role they would represent an additional embodied feedback channel and could become a fundamental support for the reticular structure of learning processes (*Fig. 1 right* – Lehmann & Rossi, *2020*b).

1.3 The role of feedback in teaching and learning processes

The role of feedback for learning has recently been highlighted by different authors and, "based on the idea that the quality of the students' interaction with delivered feedback is as important as the quality of the transmitted message", researchers have begun to re-conceptualize the feedback process (Nicol, 2018).

Hattie and Clark (2018) propose that correct feedback can have a strong influence on successful learning. They identified different elements that allow feedback to be effective: it needs to be clear, propositional, meaningful and compatible with the students' previous knowledge, keeping in mind the cognitive load and the personal zone of proximal development. The most important characteristic of feedback for Hattie and Clark is that it must help the student to build logical connections.

Also Laurillard (2012) emphasizes the importance of feedback as a central element of the interactions between the teacher and her/his students. According to Laurillard, feedback facilitates the alignment between the goals of the teacher and the goals of the learner, clarifies the structure of concepts, and helps to control the learner's actions. Feedback can be related to the concepts processed by the students or to the processes the concepts activate. In addition, there is not only the teacher's feedback about concepts and processes that activate the student, but also the feedback of the students about what they think the teacher does and requires in a lesson is very important for the teacher.

As discussed in (Lehmann, 2020; Lehmann & Rossi, 2020a), the classic feedback is the teacher's response and correction to the questions and actions of the students. This feedback is based on the comparison between the results expected by the teacher, the results achieved by the student, and the ability of the teacher to identify the reason for any potential misalignment. This kind of approach can be sufficient when the result of the assignment is rigidly pre-defined. However, in the case of open results, the comments of the teacher need to be personalized, as they are strictly related to the choices and decisions of the students, and also need to involve the method that was used to arrive at the result (Lehmann, 2020).

More recently feedback is also perceived as being recursive and generative (e.g., Rossi et al., 2018). It is transmitted from the students to the teacher when they explicate their own concepts, and from the teacher to the students when s/he organizes and restructures these concepts. From this perspective it is difficult to arrive at a definitive result, since each concept expressed by the students is, on the one hand, the end point of a process and, on the other, the starting point for the following steps. In this view concepts are always evolving, are fluid and never definitive. This is why feedback, in this process, is seen as being recursive, underlying a didactic cycle and recursively co-built knowledge. Yet the feedback in this case is also generative, as it provides the elements to proceed and the fragments to build the next network of meaning (Rossi et al., 2018).

Some of the most recent reflections on feedback introduce the concept of *feedback loop*, perceived as a triangle between the student, her/his peer group and the teacher. These feedback loops involve alternations of discussions, questions and answers, that activate a cycle that involves both the students and the teacher. This cycle is needed to adjust the actions of the teacher to ensure an impact on the learning of the students (Carless, 2019). Without the information from the students, the teacher is unaware of the consequences of her/his actions and therefore cannot act effectively to improve the quality of learning. This constitutes an interactionist view of feedback (Rossi et al., 2018).

The above examples, of how the role of feedback is perceived and where it is located in current didactic theory, are by no means meant to be exhaustive, but intend to illustrate the central importance that feedback plays in the teaching process.

In order to create meaningful applications for the integration of our robot into university lectures, we chose the concepts above as a general framework for the programs that controlled the robot's behaviors. More specifically, we followed the distinction between general and personal feedback, being aware that this does not do justice to the complexity of the field. We are however perceiving our work as a starting point of more complex applications.

2. Method

2.1 Robotic platform

Most of the educational social robots in use today are implemented in settings with pre-school or school children, and not with university students or in lecture hall contexts. One reason for this might be the less personal format of lecturing at universities. The large group size of university classes makes a one-to-one interaction almost impossible and limits the use of robots to group work involving varying numbers of students. This limitation is more conceptual than due to technical issues. When combining the mediator and feedback functionalities of educational social robots with the ability to display relevant information on a joint screen, we believe it is possible to create applications that prove effective also for university level teaching. The direction of this research trajectory brings us back to the theoretical underpinnings of what role a social robot can play in the process of didactic mediation and where its position in this process is.

We chose Pepper for our project because of its great potential for the easy development of new applications, and the fact that it allows us to focus on the key points of the "Enactive Robot Assisted Didactics" (ERAD) approach that we introduced in (Lehmann & Rossi, 2018; Lehmann, 2020). This is mainly due to the design and construction of Pepper, which was conceptualized as a personal robot capable of expressing emotions and communicating with humans via gestures, body posture and speech (Softbank Robotics, 2018). Smooth motion-generation technology makes Pepper specifically adapted for non-verbal communication, and enhances naturalistic looking dynamics of its movements. It can execute motions that are fluent and "big enough" to draw attention in noisy environments. The semi-humanoid structure of the robot combines two advantages. It's expressive head, arms and hands allow for intuitive and naturalistic human-robot interaction, and it's compact torso and multidirectional wheelbase gives it the stability to navigate in complex environments with moving objects or humans. Overall the capabilities of Pepper allow for the quick proto-typing of complex movement scripts that also involve coordinated head gaze and gestures. The use of such coordinated movements to generate believable and naturalistic looking behaviors, which elicit the human predisposition to anthropomorphize non-human objects (Airenti, 2015; Damiano and Dumouchel, 2018) is an important aspect of the structured approach proposed by Damiano et al. (2015) for the integration of embodied artificial agents in mixed human-robot ecologies.

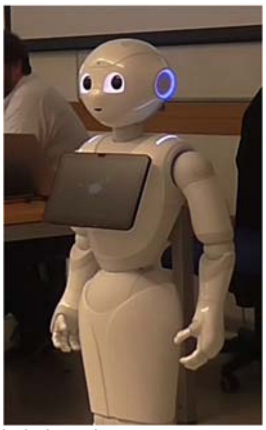

Fig. 2 - Pepper gives general feedback during a lecture

2.2 Robot feedback applications

As illustrated in the first part of this paper, in enactive didactics feedback is considered crucial for successful learning. In order to use a social robot as a feedback device we needed to have the possibility to connect it to data that was entered by the students. We decided to use *Google Forms* as an audience response system (ARS). For each lecture we prepared a questionnaire. These questionnaires consisted typically of five to seven multiple choice questions and two open questions about key concepts of the ongoing lecture. Towards the end of each lecture, the students were given the login information for the specific Google Forms questionnaire prepared for the lecture. The students then had 15 minutes to finish the questionnaire. The answers were analysed in real-time on an excel sheet linked to the Google Forms questionnaire on a dedicated Google Drive account.

We decided to develop applications for different types of feedback following the distinction of general and personal feedback pointed out by Senft et al. (2018). This resulted in three different modes in which the robot provides the students with information about their questionnaire results.

Immediate general feedback:

The robot gave the percentage of correct answers for each question to the entire class directly after the students completed the questionnaire. After the percentage of correct answers for each question, the robot gave the overall percentage of the correct answers for the entire class. This type of feedback provided a quick overview of how well the class has understood the key concepts of the lesson. This is useful for both the teacher and the students. It gives the students a general impression of the importance and difficulty of the different parts of the lesson, and provides the teacher with information where she/he has not been understood by the majority of the class. Since the feedback is given before the end of the lecture, it leaves enough space for the teacher to re-discuss and explain particularly difficult topics.

Personalized feedback:

In order to obtain their individual results, the students had the possibility to approach the robot directly after the lecture and ask it for personalized feedback. This enabled the students to compare their performance with the general performance of the class, and to understand were their personal deficits in the understanding of the material are.

Detailed personalized feedback for open questions with vote and evaluation of teacher:

The third type of feedback provided by the robot differs from the others. It concerns the analysis of the answers to the open questions in the questionnaire. Since open questions cannot be automatically analysed by an artificial system yet, because the content of the answer needs to be understood and interpreted, the professor needs to evaluate after the lesson the content of the answers and, depending on what the student wrote, gives a vote and writes an assessment in a data sheet on the Google Drive dedicated to the robot applications. The students can access the teachers assessments and their vote before or in the breaks of the next lecture via the robot. This form of feedback enables on one hand the professor to understand the students' comprehension of specific topics more deeply, and on the other hand it gives the students a more detailed assessment of their strengths and weaknesses.

The workflow of these different feedback applications can be described as follows. The robot waited for an input signal. If it was used in the immediate general feedback mode this input signal was the finishing of the questionnaire. If the robot was used in either the personalized feedback or the detailed personalized feedback modes this input signal was a touch of the tablet. In these modes the robot would stand idle in front of the class in the lecture hall with the following message displayed on its tablet: "If you want to know how well you did in the last questionnaire, please touch the tablet." After the tablet was touched, the robot would ask the student to input her/his student ID number via the tablet. After the student had inserted the ID number, it was displayed on the tablet and the student was asked if it was correct. If the student pressed "yes" on the tablet, the robot connected to a dedicated laptop. On this laptop a server program was running and waiting for the signal from the robot in order to establish a connection with google forms (i.e. with the excel sheet containing the data of the students). Based on the student ID number the students results were selected from the excel sheet and send back to the server (laptop). The laptop then sent the results to the robot and the robot told the student her/his result (see Fig. 3).

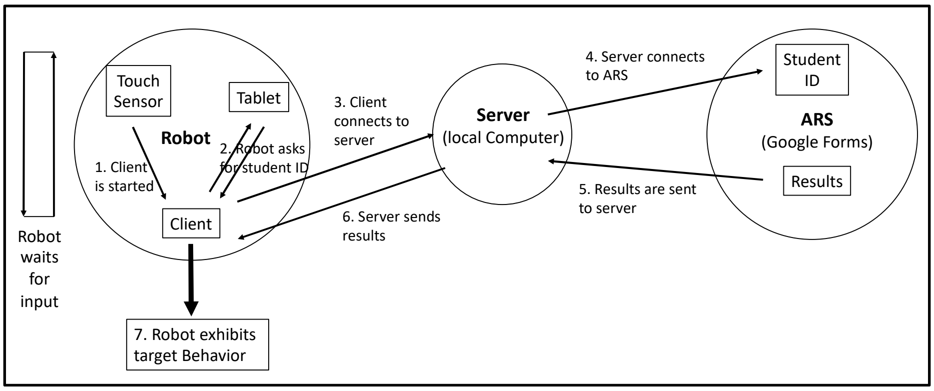

Fig. 2 - Workflow during the personalized feedback application

3. Results

At the end of the lecture series, which lasted 15 individual 3 hours sessions, we administered a questionnaire composed of open questions which allowed the students to freely share their thoughts and opinions about the interventions about the robot. We sent a link to a Google Forms questionnaire and gave the students 30 minutes to answer the questions. From the 163 students to whom the link was sent, we received 155 replies. Of these replies a vast majority of 152 were positive, 2 were productive criticisms and only one was negative. From the 152 positive replies 36 gave a response similar to "I like the robot" without any further information.

We were able to structure the remaining 116 positive answers into different categories. Since the students were allowed to answer freely to the question concerning the usefulness of Pepper's interventions during the lesson, the replies were sometimes relatively long and included various points. We therefore included some answers in more than one category. The categories relevant for the goals of the applications described in this paper are the following:
- Pepper helped me with self-reflection;
- Pepper helped to understand specific concepts better;
- Pepper helped with structuring the lesson.

The answers of the students show that the aim of the feedback provided by Pepper was in broad terms reached. The robot enabled the students to understand where their deficits in understanding the content of the lessons were and to reflect on their weak points. It enabled them also to better understand the structure of the lesson and consequently to focus their efforts on concepts that were not fully understood by them during the lesson directly. Due to the nature of the implementation setup our results are qualitative. To our knowledge, we used a robot for the first time in this way during university lectures. This means we are not able to quantify specifically how much the understanding of the students has improved, since this would require comparative studies with other classes. We have therefore to rely on the answers given by the students in the final questionnaire. This underlines the explorative nature that is, for the moment, characteristic for this research field and this type of robot applications, in which the technology interacts with large groups in relatively open settings.

Besides the questions about their impression of the robot we also ask the students directly what activities they would suggest the robot to do additionally to the already implemented applications. Also for this question we were able to categorize the answers of the students. Most of them suggested that the robot should further structure the lesson, followed by the idea that the robot should collect questions of students during the lesson, which could be discussed together with the teacher at the end of the lesson. Other suggestions involved interactive activities between the robot and the students, and the use of multimedia tools by the robot in order to give examples during the class. The realization of the last two suggestions are rather difficult, since these interventions would prove quite disruptive to the lecture and also would depend highly on the infrastructure available in the lecture hall. The first two suggestions however are very useful and point already towards the next cycle of implementations planned for our robot. At the moment the feedback given by the robot is mainly directed towards the students and provides only indirectly information to the teacher about the learning progress of the class. Implementing the applications that enable the students to get more actively involved into an interaction with the teacher will close the feedback loop involving teacher, students and the content of the lecture and in this way fulfil the interactionist vision on feedback described by Rossi et al. (2018).

4. Discussion

The results show that the majority of the students had in general a very positive impression of the presence of the robot during the course of the class and happily used the feedback provided by the robot. The immediate general feedback from the robot became a fixed point during the lectures. It proved to be useful for a quick overview of the current state of the students' understanding of the topics of the lecture and helped to steer the final discussion of each lecture towards the issues that needed to be re-elaborated most. The personal feedback provided by the robot was usually available to the students during the breaks, and after and before the lecture. It was the responsibility of each student to engage with the readily available Pepper and ask for her/his results. Time limitations and lack of personal interest might have caused some students to use this information more frequently than others.

From our observations during the course of this long term study and based on the final feedback obtained from the students we can infer that the use of the robot had an effect on the teacher as well as on the students. We predict that the future long term applications of social robots that reinforce the reticular structure of the learning process via the provision of feedback will yield benefits as well as create demands for both teachers and students.

The benefits for the teachers are a structured, long term overview of the level of understanding of the students in real time. This overview can be stored and readily available for later analysis, and the resolution of the data depends entirely on the needs of the teacher. Having this information will enable the teacher to have an active discourse with students about relevant problems during the lecture. Furthermore, the presence of the robot catches for the moment the attention of the students and helps them to maintain focus during the lesson, which improves the teaching-learning experience for both the teacher and the students. The demand created for the teacher is a need for structure in the preparation and during the lecture in order to be able to pose meaningful questions in the questionnaire beforehand. However as a consequence of this need for structure the lecture will become more easy to follow for the students and again improves the learning experience.

From our perspective the use of robots during lectures will only be advantageous for the students. Using a robot will help to clarify the roadmap of the lecture. The feedback provided by the robot does not only illustrate to the students their deficits, but also will also make clear which concepts are considered to be important by the teacher. With the applications described above the students have a much better ability to evaluate their own progress and keep a record of their misunderstandings and improvements.

4.1 Limitations

As pointed out above the nature of this research is highly explorative and hence we have to rely on qualitative results in the form of data obtained via questionnaires. This could be seen as a limitation, due to the lack of comparable data. However for the moment we would propose that the relative novelty of the topic merits the reliance on this type of data. In the future more quantifiable setups involving more than one class could provide a more clear picture about the improvements in understanding of the students. From the perspective of gaining an overview of solutions for robotic feedback that are feasible from a practical standpoint in a lecture hall setting, and an insight into the opinion of the students about these solutions, the number of students and lectures involved in this research allows us to be fairly certain about the considerable usefulness and positive effects of robots as feedback devices in education, at least in lecture hall settings.

5. Conclusion

Within the didactic perspective adopted in this article, the ideas of Varelian enaction play a crucial role for the use of social robots in educational processes implemented in schools and universities. The concept of structural coupling has been expressed, within our enactive robot assisted didactic approach and the related theory of reference, in the form of different types of feedback structures. On this basis, the success of teaching is seen here as highly dependent on the success of these feedback structures, conceptualizable as well as a complex dynamic system of interactions between the teacher and the students in which new knowledge is constructed. The complexity of these interactions depends on the strength of the feedback networks, which in turn depends on the information channels available between the different components and actors constituting the overall system. We believe that the above-described applications for a Pepper robot, making of it a device opening new feedback channels, allow a first glimpse at the central role that social robots can play in education.

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