Social Robots as Teaching Assistance System in Higher Education: Conceptual Framework for the Development of Use Cases

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Abstract: This paper provides an overview of the current state of research on social robots in higher education and the existing frameworks to categorize and develop social robot applications. Based on the existing work, we present our own framework to develop use cases for social robots in the education sector. Our framework is based on a heuristic and symbiotic design approach that serves as a guideline for developing use cases and views human-robot interaction as two complementary and mutually reinforcing roles. We illustrate our framework by means of a use case that we have conducted in 2019 during the initial lecture of the large-scale course 'Introduction to academic writing'.

1 INTRODUCTION

Higher education faces a highly dynamic environment. In light of the current technological developments, an extensive substitution of human labor by smart machines (artificial intelligence) may come to the fore (King & Grudin, 2016; Nedelkoska & Quintini, 2018). In this context, Davenport and Kirby (2016) put the focus on mutual complementation and collaboration (augmentation), i.e., "people and computers supported each other in the fulfilment of tasks" (p. 2). According to Jarrahi (2018), augmentation can be conceptualized as a "Human-AI symbiosis" where the collaboration between humans and artificial intelligence (AI) can make both parties smarter over time (p. 583). This kind of symbiosis may change if the communication partner takes on a physical form through social robots. Due to the increasing attention to AI and Human-Computer-Interactions or more specific Human-Robot-Interactions (HRI), the development and use of AI-based robots is recently an emerging field in many areas such as medicine, finance, service industries, and education (Thimm et al., 2019).

Social robots increasingly pervade the daily life. Breazeal (2003) refers to social robots as machines "that people apply a social model to in order to interact with and to understand" (p. 167).

Social robots have the potential to become integral part of the educational infrastructure (Mubin, Stevens, Shahid, Al Mahmud, & Dong, 2013; Belpaeme, Kennedy, Ramachandran, Scassellati, & Tanaka, 2018). However, until now, the implementation of social robots in education has been rather scarce since it is a relatively new emerging research field and requires considerable resources. Instead, studies have often tried to implement pedagogical agents and traditional intelligent tutoring systems in learning scenarios (e.g., Baker, 2014). In contrast to these learning technologies, social robots interact with students in a synchronous way making it possible to react on individual intents with a physical presence. The potential of social robots as assistant systems in education is a rather new phenomenon. In a recent literature review, Belpaeme et al. (2018) summarized the state of the art. Assuming that social robots increasingly pervade future workplaces, students may need training to efficiently collaborate with digital assistants. Since digital assistants might be social robots in the future, students should be able to understand the future today and acquire skills to help shaping the future in terms of using social robots with focus on augmentation and a fruitful symbiotic approach.

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2 DEFINITION OF SOCIAL ROBOTS

Due to the wide variety of different appearances of social robots, it is necessary to classify them. Table 1 elaborates the characteristics of social robots by distinguishing between technical and social dimensions. The first technical dimension to classify a social robot is the physical presence and thus the design of the robot from abstract to human-like (Baraka, Alves-Oliveira, & Ribeiro, 2019). The second technical dimension comprises the degree of autonomy of the robot, ranging from remote-controlled to completely autonomous. The social dimensions (Breazeal, 2003) show on the one hand the development stage of the robot interaction model and on the other hand the social embedding in the environment. The interaction can range from evocative and rather passive to sociable and proactive. The dimension of social embedding adds a broader focus on the social behavior and integration into the environment. It ranges from pure perception and reaction to the social environment to a socially intelligent robot with full social competence (Fong, Nourbakhsh, & Dautenhahn, 2003).

3 RESEARCH GOALS AND METHODS

The aim of the paper at hand is to investigate the potential of social robots for educational purposes in higher education because there is a research gap in terms of pedagogical uses and the robots' social capabilities. In this vein, it may be important to investigate whether the social robot can be useful in the social environment as an autonomous system and how the interaction between human and robot is changing over time. Conceptual frameworks might be useful for designing use cases as an iterative pilot testing. Hence, the paper at hand might act as a stepping stone for coming researchers who might more efficiently uncover further potential of the technology, e.g., type of robot to use, how to adapt it properly to a use case, what kind of architecture the robot system might need, how to achieve the greatest pedagogical value, etc.

In light of the identified research gap, the following overarching research question should be addressed:

How can use cases be designed for social robots as assistance systems in higher education to improve the learning process and enhance learning experiences (e.g., reaching new learning goals) of higher-education students?

The objectives of the paper at hand are therefore twofold:

- Analysis of empirical studies with social robots in order to investigate underlying assumptions, goals, methods and empirical results for designing and evaluating the use cases;
- Development of a conceptual framework as an appropriate methodology to theoretically founded develop use cases for social robots as assistant systems in higher education.

To this end, we lay the foundation for our framework in section 4 by conducting two literature reviews. First, we look at how social robots have been used in higher education. Second, we provide an overview of

Table 1: Characteristics of social robots as socio-technical systems.

	DIMENSIONS	CHARACTERISTICS			
Technical Dim.	Design of physical presence	Iconic, abstract design of robots (e.g. Jibo)	Animal-like robots (e.g. Robear as care robot)	Humanoid robots (e.g. Pepper, Nao)	Android, human-like design (e.g. Sophia)
Technical Dim.	Control and autonomy	Remotely controlled, e.g. telepresence representative	Semi-autonomous: local AI and webservices	Autonomous systems with local AI that allows them to interact independently	
Social Dim.	Interaction model	Socially evocative (e.g. rely on human engagement)	Social interface (e.g. social behavior is modeled)	Socially receptive (e.g. learning skills by imitation)	Sociable (e.g. proactive engagement)
Social Dim.	Social embedding	Socially situated (e.g. perceive and react to social environment)	Socially embedded (e.g. interact with social environment)	Socially intelligent (human cognition and social competence)	

Note: Draws on the work of Breazeal (2003), Duffy (2003), Fong et al. (2003), Belpaeme et al. (2018), and Baraka et al. (2019).

existing frameworks in the field of social robots. Section 5 lays out our own extended framework. Section 6 concludes with some final remarks.

4 LITERATURE REVIEW

4.1 Context: Social Robots in Higher Education

The EBSCOhost database and the IBM Science Summarizer Beta database were searched to find relevant literature focusing on the use of social robots in higher education. The abstracts were searched for terms such as humanoid robots or social robots or higher education and university or college or lecture or post-secondary or postsecondary.

The search procedure yielded a total of 20 relevant papers. The earliest study appeared in 2012, the latest study was published in 2019. Four contributions were literature reviews. A majority of fourteen contributions analyzed the deployment of humanoids in lectures to foster students' learning outcome. The remaining two studies examined specific aspects of the topic, e.g., design of humanoids in higher education.

Clustering the studies according to their subjects revealed that eight studies focused on STEM, one study focused on Business, one study focused on STEM & Business, one study focused on Languages, and five studies did not provide information about the subject.

Four studies focused on undergraduate students, two studies focused on graduates, one study focused on graduates and undergraduates and nine studies did not provide information about the university level.

In terms of the educational setting, the studies differed in the following ways: Eight studies were carried out in a lecture or classroom settings, three in workshops or as part of a group work, two in a laboratory environment and three studies did not provide the necessary information.

The roles that the social robots took in the studies also varied. In five studies the robot acted as a lecturer or tutor, in two studies as a teaching assistant, in two studies as a mediator or partner and in three studies the robot was used as a test platform for the development of applications. One study used the robot as an educational means to teach technology related content (Flynn, 2017). Three studies did not provide the necessary information.

4.2 Design: Frameworks for Social Robot Use Cases

The EBSCO database, the IBM Science Summarizer Beta database and Google Scholar were searched to find journal articles and conference papers focusing on conceptual frameworks in combination with HRI. Search terms were conceptual framework or theoretical framework or reference architecture or use

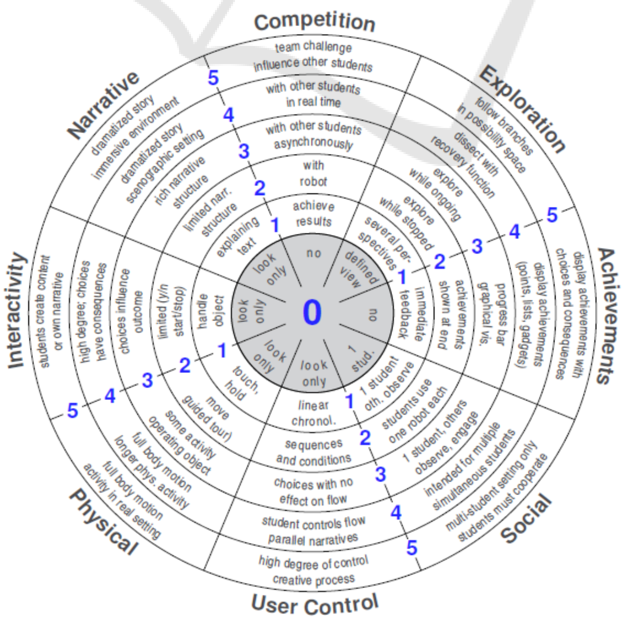


Figure 1: The dimensions of the engagement profile (Cooney & Leister, 2019, p.8).

case and human robot interaction or social robot interaction. Subsequently, the results were manually filtered. Overall, fourteen relevant papers were identified. The earliest study appeared in 2002, whereas the latest study was published in 2020. We split them up into three types.

The first type comprises studies that provide frameworks with robots in automatization processes and industry related contexts. Studies, which regard robots more as a tool than as a social counterpart also belong to this category. Often, they focus on the technical implementation. For examples, see Radanliev, Roure, Nicolescu and Huth (2019) or Cuevas, Fiore, Caldwell and Strater et al. (2007).

The second type consists of studies with frameworks about social robots in their environment. Breazeal et al. (2004) propose an early framework towards robots as partners rather than robots as tools. You and Robert (2018) provide a framework for human-robot teamwork. Their framework describes which characteristics are brought into a work process by which parties (humans, robots) and how this leads to team output.

Belanche, Casaló, Flavián and Schepers (2020) create a theoretical framework for the implementation of service robots. In three categories (robot design, customer features, services encounter characteristics) they identify important factors for a successfull design and implementation of service robots.

Baraka et al. (2019) provide an extended framework for characterizing social robots. Their framework covers along seven dimensions the interaction and the relational role between robot, human and the context. In addition, they outline different approaches for designing human robots: human-centered design, robot-centered design, and symbiotic design (Baraka et al., 2019, pp. 31–33). To develop social robots in a symbiotic design, Baraka et. al. (2019, p. 33) recommend identifying the relative strengths and weaknesses of each party. They refer to the study of Veloso, Biswas, Coltin, and Rosenthal (2015), in which autonomous robots ask humans for help with certain activities, such as pressing the elevator button for them. This little assistance from humans allows the robots to navigate on several floors without the need for any robot hands and makes the implementation of use cases easier and cheaper.

The third type comprises studies with frameworks about social robots in the context of education. Yang and Zhang (2019) develop design guidelines for an intelligent tutoring robot in the tension field between human tutor, student, curriculum, and social milieu. Its scope is relatively narrow, as it only covers the use case of the tutor and no other potential applications in the education sector. Cooney and Leister (2019) provide a more general framework by adapting the engagement profile to the educational context. In an exploratory study at a graduate school, they defined potential useful capabilities to create a prototype for a robotic teaching assistant. Based on this, they weekly tested the robot in a classroom and used the engagement profile to iteratively improve their robot.

Seven contributions were related to type 1, i.e., they provide frameworks for robots from a more technical view in an industry related setting. Five contributions are type 2 studies with a focus on the social interaction between humans and social robots. The remaining two studies were type 3 studies, i.e., they provide frameworks for social robots in education.

5 RESULT: CONCEPTUAL FRAMEWORK

5.1 Structure of the Framework

Based on the available frameworks, summarized in the previous section, this chapter lays out our own extended framework (see Figure 2). Similar to the framework of Baraka et al. (2019) our framework focuses on the overall system behavior of robot, human, and context. While Baraka et al. (2019, p. 3) define the context as “Purpose and application area”, we take a broader view of this notion and add further elements to it.

Knowledge and attitude of the stakeholders towards social robots may be of central importance for the successful implementation of a use case. This applies to both the development team and the users. To represent the requirements and features of the users, we utilize the term customer features from Belanche et al. (2020) who have chosen this element as a key part of their framework.

Belanche et al. (2020) deal in their framework also with technical aspects in the form of robot design. Therefore, we integrate the element technology into our model. Together with financial, legal and ethical constraints, they complete the category context.

Baraka et al. (2019) as well as Cooney and Leister (2019) define the role of social robots by its capabilities. In addition, the role of humans may also be defined by their capabilities. The specific capabilities of both parties (humans and robots) are considered to form the use case. We propose that as an evaluation tool the engagement profile of Cooney and Leister (2019) or various outcome measures (You & Robert, 2018) could be used.

In contrast to the frameworks that we have drawn on, we put educational aspects into focus and at the same time try to keep the model as generic as possible, to cover a broad variety of use cases.

We consider our framework as a design-specification tool to serve as a guideline for the development of own use-cases. In our understanding, the awareness of the complementary roles of humans and robots in interaction with the context may help to avoid pitfalls and to create better use cases.

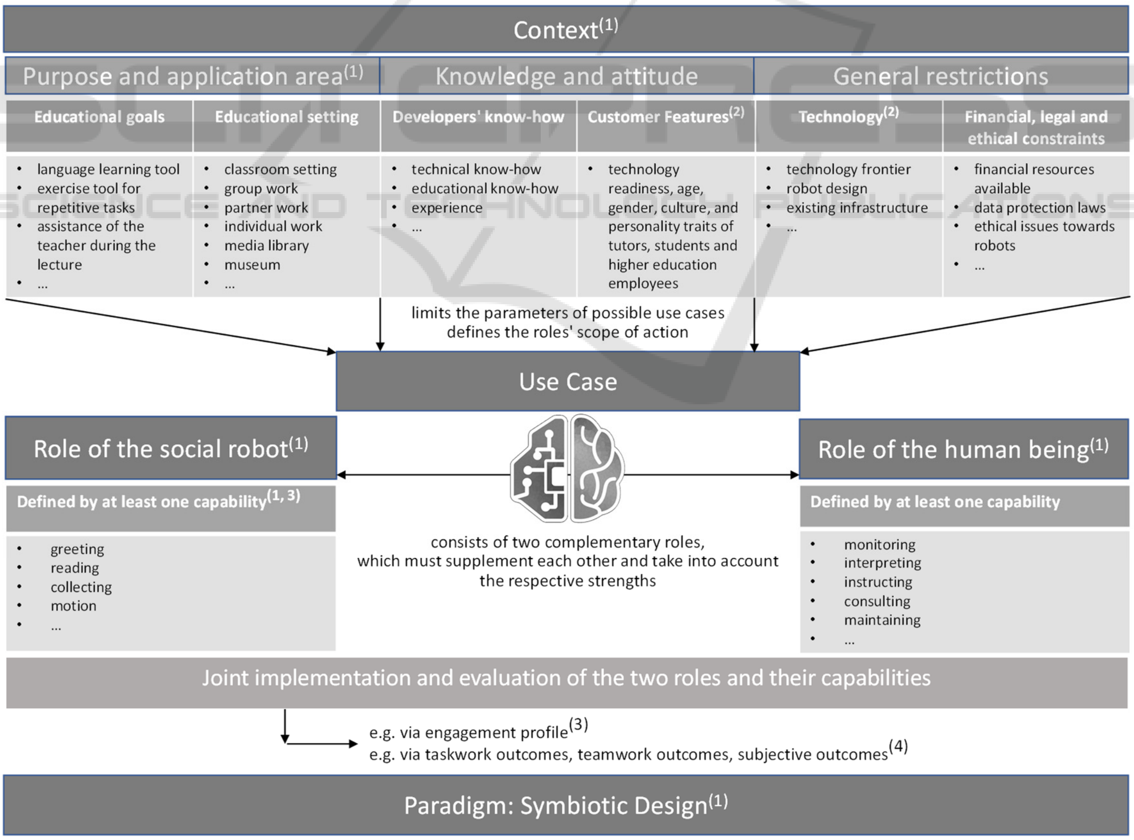
5.2 Paradigm: Symbiotic Design

We follow the symbiotic design approach as outlined by Baraka et al. (2019, pp. 31–33). Not every implementation that is technically possible may also be useful. It is important to consider the relative strengths of humans and social robots and create applications against this background. The purpose of social robots is not to replace humans, but to support humans by extending their capabilities where necessary. Otherwise, social robots will not find social acceptance in the long run. According to our understanding, it is important to view the interaction between humans and robots as two complementary, mutually reinforcing roles.

5.3 Context

In our framework, we follow a heuristic development approach that creates solution-oriented applications for practical use with limited resources. When developing a use case, the development team faces multiple restrictions due to the context. As a first step, the development team should think about the context and record it in writing. The context later implicitly defines the scope of action.

Depending on the educational goal and setting, the project must meet different requirements. The development team has to meet these requirements and at the same time deliberately assess their own know-how and anticipate the know-how and attitude of the future users.



Note. (1) Baraka et al. (2019), (2) Belanche et al. (2020), (3) Cooney and Leister (2019), (4) You and Robert (2018).

Figure 2: Conceptual framework for the development of use cases with social robots.

The existing infrastructure, the available technology and the technology frontier should also be considered. Against this backdrop, the integration and the usage of already existing services (e.g., text-to-speech-services) may be preferable to in-house development, as in-house developments can be very expensive or even impossible.

Finally, each development team must stay within the budget and comply with legal and ethical restrictions (e.g., data protection policies), which influence which use-cases can or cannot be implemented.

In its entirety, the context restricts possible use cases. At the same time, the context also defines the scope of action for the role of humans and robots.

5.4 Roles of Robot and Human Being

In our understanding, a use case consists of two complementary roles: The role of the social robot and the role of the human being. Both roles should supplement each other and take into account the respective strengths. Cooney and Leister (2019) described potential roles for a social robot. The robot could take over the role of a tutor outside class, of an avatar or of a teaching assistant. Many more such roles for socials robot are possible. In our understanding, humans also play such a role when interacting with robots. Depending on the context and the role of the robot, humans could, for example, take on the role of a supervisor, a maintainer or a mediator.

5.5 Capabilities

In a second step, the development team should design the roles of humans and robots and their capabilities. Each role is defined by at least one capability. Cooney and Leister (2019) mention reading, greeting, alerting, remote operation, clarification, and motion as potential capabilities of a robot teaching assistant. Depending on the use case, the role and the associated capabilities will change. To give a second example, the capabilities of a robot concierge in a museum could be greeting, reading, informing and orientating.

5.6 Implementation and Evaluation Measures

Measures for implementation and evaluation are important as a tool to get feedback and iteratively improve the design. One possible approach for implementation might be through the engagement profile.

The engagement profile was originally used for installations and exhibits in science centers and museums (Leister et al., 2017). Cooney and Leister (2019) adapted the engagement profile to the teaching case (see Figure 1). They argue that similar to installations in science centers, a social robot represents an artefact that the students interact with during their studies and classes. Along the eight dimensions of the engagement profile (competition, narrative elements, interaction, physical activity, user control, achievements awareness, exploration possibilities) the capabilities can be defined, measured on a scale and be reevaluated and adjusted in an iterative process.

The engagement profile is a promising approach to measure robot capabilities on scales. However, further research is needed as the dimensions of the model come from the world of museums and science centers and may not always fit into a social robot setting. In addition, the question arises how the engagement profile is to be used to evaluate the team performance of humans and robots together.

At this point, the work of You and Robert (2018) might offer a viable approach. They distinguish between different team outputs (taskwork outcomes, teamwork outcomes, subjective outcomes) of robot-human teams, which could be measured and evaluated.

5.7 Example for an Implementation

The following section illustrates our framework by means of a use case that we conducted in 2019 during the initial lecture of the large-scale course ‘Introduction to academic writing’ (see Figure 3). The course was mandatory for all the 1,552 freshmen at our university who were on average 19.77 years old. The course has an English track (470 students) and a German one (1,082 students). Therefore, the lecture was conducted in both English and German.

Apart from our primary goal of the course to introduce students to academic writing, our educational goal with the robot was to offer the students a representative sample of tasks that a social robot might perform within the context of learning. In the lecture we also wanted to inform about plagiarism and plagiarism software.

For the implementation of our use case we could count on the support of raumCode, a company specialized on humanoid robots and artificial intelligence, as well on the educational know-how from our chair of Business Education. A type Pepper model (SoftBank Robotics) owned by our chair is at our disposal.

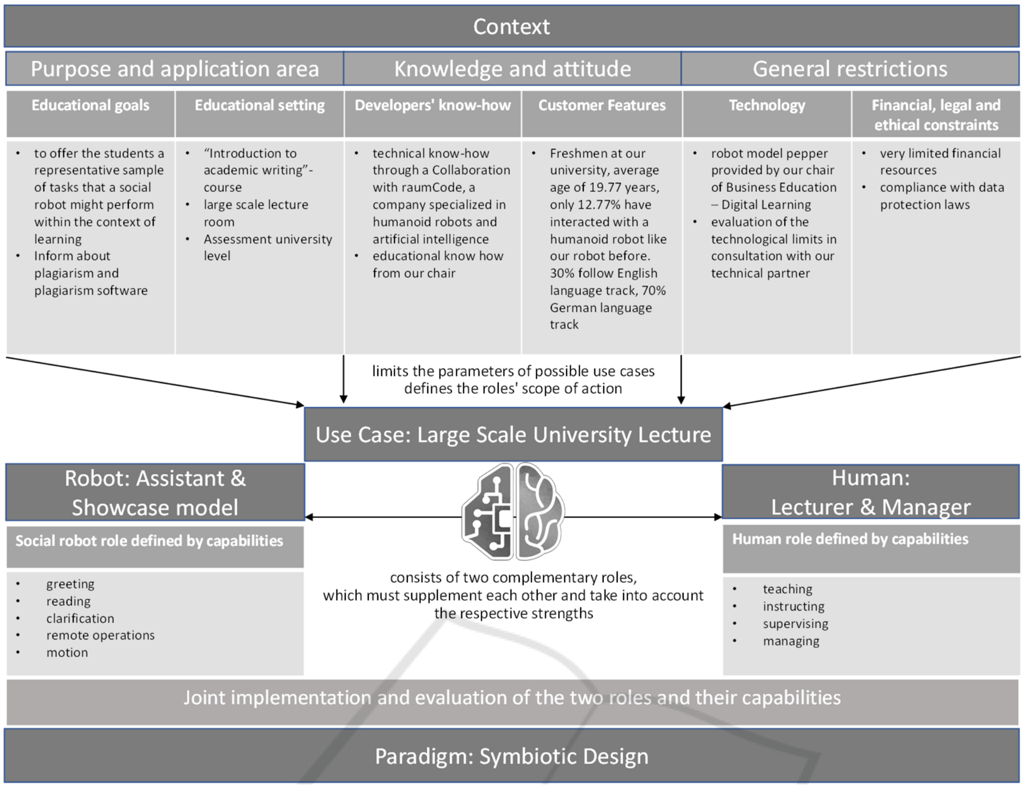


Figure 3: Use case: Social robot Lexi as a teaching assistant in an academic writing course at university.

Based on the given context, we decided to put the robot in a co-role with the lecturer. The robot should support the lecturer during the course as an assistant and showcase model. In return, the lecturer should lead the lesson and supervise the action of the robot.

In the sense of a complementary and symbiotic distribution of roles between humans and robots, we found it appropriate to let the robot do those parts of the lecture that are related to computer science in the broadest sense. In this area, the robot can play its natural strength, because, unlike humans, it can be connected to application programming interfaces (APIs), for example.

Among others, the robot in our course explained plagiarism and its detection by plagiarism software - and searched for the lecturer's sources for "greenwashing" in the database of our university library.

6 DISCUSSION AND OUTLOOK

By means of our literature reviews, we could identify several studies that explore the use of social robots in higher education and beyond. However, a number of challenges for the use of socio-technical systems must also be taken into account. The introduction of these technologies into pedagogical practice involves the solution of technical challenges and requires changes in pedagogical practice. Moreover, ethical concerns have to be addressed (Belpaeme et al., 2018). To what extent it is desirable to delegate education to social robots has to be discussed in-depth. In this discussion criteria that go beyond learning efficiency, i.e., learning outcomes and costs, should be considered.

The main contribution of our paper is the development of a conceptual framework in order to derive theoretically sound use cases for social robots as assistance systems in higher education. We have demonstrated the usefulness of the framework by illustrating our empirical study with the social robot Pepper in an academic writing course.

In several development cycles, innovative practical solutions are to be developed, which at the same time are to produce theories with saturated evidence that can be used as research results. The transferability of the innovation developed is less to be found in the problem solution itself, but rather in the development of transferable theories: "Theory informing practice is at the heart of the approach, and the creation of design principles and guidelines enables research outcomes to be transformed into educational practice" (Reeves, Herrington, & Oliver, 2005, p. 107).

An open question is still how to evaluate the use cases and in particular the human-robot interactions. From a symbiotic research paradigm, the evaluation should focus on the behavior of both partners, human and robot: Does the human adapt to the robot, and the robot adapt to the human, in a way that benefits the interaction? At the current technological state there is much room for improvement in terms of the human-robot relationship. The goal should be that robots act in a way that could be regarded as social in its original sense.

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