Benefits, Challenges and Research Recommendations for Social Robots in Education and Learning: A Meta-Review

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Abstract—Social robots exist in various forms but are still not spreading widely to the societal contexts they are envisioned for, such as educational settings. There appears to be a gap between research and practice: A lot of research already demonstrates promising results for using social robots in various domains, but this promise has yet to be realized in “the real world”. The aim of this paper is to form a systematic understanding of the potential and challenges of social robots in the domain of education and learning, which is an intensively researched application domain for social robots. We conducted a meta-review of recent literature reviews (published in 2018-2022), using the PRISMA method. We analyzed 12 review papers that met the defined inclusion criteria by extracting the potential benefits and challenges presented in these reviews. We identify six benefits, five challenges, and six recommendations for future research on social robots in education and learning. These findings emphasize the potential and developments needed to realize the potential of social robots in educational contexts.

I. INTRODUCTION

The use of social robots in education has been a central theme in the field of Human-Robot Interaction for several decades, with promising results in several contexts. Especially regarding education and learning, social robots have frequently been argued to be an educational technology that may facilitate learning and improve the performance of the learner [15]. Earlier research has examined the use of robots to support the learning of diverse topics that include science [1][7], language [5][12], and arts [21], with learners of varying ages and abilities.

Contemporary progressions in the field of robotics have led to the increased availability of social robots. The incorporation of artificial intelligence techniques has substantially augmented the functionalities of these social robots, thereby enabling the current utilization of such robotic systems for educational purposes. Whereas early research concerned technical feasibility demonstrations or lab studies, gradually researchers have embarked on field deployments in the wild and for sustained periods, e.g., [2][10][16]. Provided sufficient availability and autonomy of robots, they could take over some mundane tasks from teachers, e.g., individual drills and practice, especially for non-text-based content or they can provide an auxiliary interaction channel to traditional screen-based content. By their very nature, social robots suggest possibilities for richer and specifically more embodied forms of interaction than purely screen-based technologies and can potentially be better in affective communication and increasing learner engagement [23].

There have been attempts to take stock of the growing body of work in this field by reviewing related literature [13], with the first systematic review published a decade ago already [15]. With research into the application of social robots for education growing, recent literature surveys focus on specialized aspects of social robotics, specific user groups, and different domains of learning. Because education is one of the most prominent domains of social robotics, it is necessary to synthesize results from these reviews. This synthesis should help establish overarching conclusions regarding the potential, challenges that need to be overcome for these potentials to be realized, and the research directions for the field.

To address this need, we conducted a meta-review, which systematically reviews literature surveys on the use of social robots in education and other forms of learning. We limit our meta-review to the reviews published in a timeframe of 5 years, namely between 2018-2022, a period in which there has been a steep increase in the number of publications on social robots for education (e.g., see [3][14]).

The research questions set for this meta-review study are:

1. What are the potential benefits of social robots in education and learning?
2. What challenges hamper the real-world application of social robots in education and learning?
3. What are the directions for future research in this field?

The meta-review covers both formal education (schools and other educational institutes) and other, less formal learning, for example in people’s homes. In the following sections, we describe the methodology for the meta-review and report the results presenting common themes – potential benefits, challenges, and research recommendations – emerging from the papers reviewed. These findings can help set priorities for future research and developments in the field of social robots in education and learning.

II. THE META-REVIEW PROCESS

For this meta-review, we included reviews and literature surveys about social robots in education or learning published between 2018–2022. We also determined as inclusion criteria...
that the review had to discuss benefits and/or challenges for the real-world use of social robots in the area, and/or propose future research directions.

A search was issued in the Scopus database, on 17 November 2022 using the following search string:

( TITLE-ABS-KEY ( social AND robot OR humanoid ) AND TITLE ( learn* OR teach* OR educat* OR tutor* ) AND TITLE ( review OR survey ) )

The search gave us 38 hits. The second author screened the corresponding records and excluded 14 papers because they did not address human learning (8 papers) or were published prior to 2018 (n = 6). Next, the remaining 24 papers were divided between the authors for independent screening of abstracts and full texts. Final agreement on the inclusion and exclusion of papers was reached through discussion between all authors and where necessary two authors examine the papers. The search and inclusion/exclusion process followed the PRISMA process [17], see Fig. 1.

Finally, 12 papers were included in this meta-review. Table I summarizes the included papers in the order of publication. For each paper, we extracted descriptive information about the period that the papers covered, the number of papers included, and the specific application domain (i.e., language learning). We evaluated the quality check for the papers included in the reviews. Then, we analyzed the papers to identify benefits, challenges, and proposed research directions for social robots in education and learning.

III. RESULTS

We first summarize the rigor and extent of the included review studies and then report the results of the meta-review related to the research questions, i.e., potential benefits, challenges, and research recommendations for social robots in learning and education.

A. Rigor and Extent of the Review Studies

This section will elaborate on whether the papers included in the review studies that are meta-reviewed in the current paper have sufficient rigor. Several systematic reviews have provided criteria for assessing the certainty of evidence in a study, see, for example [24][25][26]. To be classified as "conclusive," studies must satisfy the five criteria listed below: (1) the study used an experimental design (e.g., a group design with random assignment), (2) adequate interobserver agreement and treatment integrity were reported, (3) operational definitions for dependent variables were provided, (4) sufficient details for replication were provided, and (5) the study's design provided some control for alternative explanations for increases in the targeted behavior.

Table I. Review papers included in this meta-review

<table>
<thead>
<tr>
<th>Reference</th>
<th>Shorthand</th>
<th>Period Reviewed</th>
<th># Papers</th>
<th>Scope</th>
<th>Ages</th>
<th>Systematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>[23]</td>
<td>Tuna et al. (2019)</td>
<td>2003-2018</td>
<td>10</td>
<td>GE</td>
<td>All</td>
<td>N</td>
</tr>
<tr>
<td>[5]</td>
<td>van den Berghe (2022)</td>
<td>2011-2021</td>
<td>83</td>
<td>LL</td>
<td>All</td>
<td>Y</td>
</tr>
<tr>
<td>[9]</td>
<td>Chu et al. (2022)</td>
<td>-2021</td>
<td>11</td>
<td>GE</td>
<td>4-33</td>
<td>N</td>
</tr>
</tbody>
</table>

*For the reviews that did not use a starting cut-off year for the review process, the parentheses indicate the earliest publication included in the review.

**LL** = language learning, **GE** = general education, **SE** = special education, **HE** = healthcare.

Figure 1. The search and inclusion/exclusion process
that the technical challenges hamper the current application of game partner, a companion, or a teacher assistant. They note several roles for the robot, such as an interaction partner, a companion, or a teacher assistant. The authors note, however, that studies have deployed social robots in constrained, controlled settings, comparisons between robots and humans are scarce in the literature, and thus there is not yet evidence that robots could serve as equally good tutors as humans.

Cabanillas-Carbonnel et al. [8] examine the use of robots in education for children and infants in a healthcare context. They identify research contributions in various directions including training social and learning skills, especially for children with Autism Spectrum Disorders (ASD), affective responses through gestures and through displaying affective states, learning about disease prevention, and using robotics for health interventions. They note that the evidence from empirical studies is largely positive but do not provide details on measures, the roles of the robots, and the level of evidence found. They note how current technology is such that a human must teleoperate the robot and emphasize the importance of lowering the costs for accessing robotic technology.

Chu et al. [9] present the results of a systematic review of journal articles published in the Web of Science in the educational field. It analyzed research trends, the characteristics of the studies (participants, duration, learning environments, application domain, data analysis, evaluations of learners' performance, learning strategies, and the roles foreseen for robots). They conclude that most studies focus on language or science learning. The studies lasted up to four weeks in a field setting. The most common outcome variable concerned learning performance, followed by the attitudes, opinions of learners or learning perceptions, and learning behavior. They emphasized the need to extend the capabilities of robots to evaluate learning outcomes and call for interdisciplinary research combining robots with learning analytics and studying acceptance of the robot intervention.

Papakostas et al. [19] survey works on the use of educational robots for special needs education. They identify several roles for the robot, such as an interaction partner, a game partner, a companion, or a teacher assistant. They note that the technical challenges hamper the current application of robots, including speech recognition, the distracting noise from the robot motors, the precision and fluency of robot movements especially the hands, etc. Studies in special needs education are characterized by a relatively low number of study participants averaging just over 11. No other quality assessment of the studies was performed.

Tuna et al. [23] do not explicitly evaluate the quality of the reviewed papers but rather provide a scoping survey of the current research on the topic, including the prospects, challenges, and future research directions. The challenges related to education include accommodating complexity in human-robot interactions, including natural language interaction, recognizing everyday objects, but also establishing and maintaining a common ground between children and the robot, and learning through imitation or experience. Similarly, the recommendations for future research are not specific to the domain of education but rather to the design, the behavioral abilities of the robot, and the end-user development.

Rosanda and Starčič [20] conduct a systematic review that discusses various factors that are relevant to studies on robot interventions in education. It does not rate the quality of the revised studies but gives information on the research type (developmental, descriptive, or experimental), the type and number of study participants, their educational level, and the subject area studied. Additionally, it covers the time spent on robot-learner interaction, including the number of interaction sessions and the time dimension. The study found that most papers reviewed did not focus on the analysis of the effectiveness of robot teaching activities or the learning outcomes of students. Instead, the focus was on introducing robots into classrooms and improving robotic technology. Robot learning activities were limited in scope, and the pedagogical aspects of robot teaching activities were not yet fully explored due to technical limitations. The study found that robots had difficulty maintaining long-term interactions with students, leading to a reduction in student interest over time.

The systematic review of Van den Berghe et al. [6] discusses the current evidence on the use of robots for language teaching, including word learning, reading skills, grammar learning, speaking skills, and sign language, focusing on the robot's effect on children's L1 and L2 language-learning gains, the learning motivation and the way robots should behave to maximize the learning outcomes. The reviewed 33 studies describe the method used for the research, the participants, and the outcomes. The review found mixed results with respect to L1 and L2 language learning outcomes. However, participants' learning-related emotions generally were positive, and they enjoyed working with the robot, which could have a motivating effect. Adaptivity and feedback also require more research attention as they play a critical role in successful language education. Finally, the review highlights the importance of carefully considering how to introduce the robot to participants to minimize novelty effects and to study whether the effects found are robust to prolonged exposure or wear off over time.

The systematic mini-review by van den Berghe [5] focuses on second language learning, mainly for immigrant children. Inclusion and exclusion criteria were set based on the level of language learning the studies were addressing. The quality of the reviewed studies was not evaluated, and they were grouped only by the number of language levels learned with the robots.
Tilii et al. [22] present a systematic review in which searches included nine search terms such as “educational robots” and “learners with disabilities”. Activity Theory attributes were used for analyzing the studies. This is among the few reviews where a rigor assessment was conducted of the robot-assisted special education studies using Horner’s Criteria, a widely adopted rubric for case design in special education [26] including items for describing participants, implementation of the intervention and description of comparison and conditions, and outcome measures. The outcome of this paper is a set of recommendations of types of social robot-based learning studies that should be conducted.

Kumar Pandey and Gelin [18] present an overview of humanoid robots in education. The paper suggests a classification of six different roles for humanoid robots in teaching and provides example studies for each role. The authors note that in most studies robots were teleoperated or pre-scripted, and that most studies aimed to assess effects, usefulness, and desired behaviors of robots in education context. However, the review did not follow a systematic review process and does not report the quality of the included studies.

The systematic review by Hein and Roberts [11] focuses on empirical studies in a classroom language learning context from preschool through elementary school. No quality rating of the papers was conducted. The review examined how robots were used in the studies to support student learning, finding that the most common uses were training vocabulary words and increasing oral language skills, while few studies aimed to increase reading comprehension or grammar. The authors note that the social learning relationship merits further research encompassing the broader social dynamics between a robot and students as well as different cultural contexts.

B. Benefits of Social Robots in Education and Learning

The benefits synthesized from the included review papers address social robots’ capabilities to support diversity and personalization, versatile social interaction supporting learning, and social robots’ potential to scaffold motivation and efficiency in learning.

Social robots can provide personalized learning experiences. Social robots can support adaptive learning for people in different skill categories [22] and provide a personalized learning experience [4]. For example, children of different language backgrounds can be positively valued and actively supported in robot-based learning [5]. Furthermore, robots can provide learners with adapted guidance, especially for students with special needs [9]. Social robots can also take different roles that can serve a variety of purposes and experiences [20]. [4] overviews a variety of strategies that have been proposed for personalization which range from simply using the child’s name, to tracking performance and adapting the level of challenge in learning tasks, or even by tailoring to individual learning styles. The report that while there is empirical evidence regarding gains in learning and engagement.

Social robots can support social interactions between diverse children. Social robots can act as a facilitator of positive interactions between diverse children by acting as a mediator in situated interactions [5]. Social robots can also improve social skills for children with ASD [3], and enable them to learn to interact in their everyday lives. However, empirical evidence to demonstrate these benefits is still sparse. While Chu et al [9] argue for the relevance of robots for supporting special needs education, their review did not find any papers that provided empirical support for those benefits.

Social robots have versatile interaction capabilities that can support creativity. Social robots have verbal and nonverbal abilities that can aid learning [11]. Social robots can also support kinesthetic learning activities that can spur creativity [22]. Such multimodal interaction characteristics of robots can also be powerful in supporting learning experiences of people with specific impairments [19].

Social robots can support learning by evoking positive affect. Social robots can induce and adapt to learners’ affect which may lead to improved learning outcomes [3]. The social nature of robots can in itself promote learning [4] and be used to tutor specific skills [4]. With a positive interaction loop, social robots can reduce the fear of making mistakes [11]. However, it is also noted [3] that empirical evidence for learning benefits is mixed, and is also dependent on the application area: Evidence regarding the benefits for STEM learning and acquiring social skills are still lacking compared to areas such as language learning.

Social robots can provide efficiency due to engagement in learning in the classroom context. Robots can provide real-time feedback to students and cost-effective teaching aid for individualized learning [23]. Expressive robots (e.g. using voice and gestures) can furthermore improve learning compared to an inexpressive teacher or robot [11]. Social robots can free teachers’ resources [4] when teachers have adequate operational skills and application knowledge [9]. To provide long-term efficiency, robots should be used in a way that they are a genuine addition to the current classroom practices [5].

Novel and embodied forms of social robots can motivate learners. Social robots are still new in broader use, and this, together with their embodied forms, can motivate learners [18]. Real-life, physical interactions with social robots in and out of the classroom provide versatile learning opportunities [6]. Furthermore, the anthropomorphism of the robot can promote learning [20].

C. Challenges of Social Robots in Education and Learning

The challenges synthesized from the included review papers are related to the insufficient interaction capabilities of social robots, their potential mismatch with the educational context, and acceptance and ethical barriers.

Recognizing human actions and emotions and producing appropriate social robot actions are not yet on a sufficient level. Recognizing the affect of human learners by social robots is not yet reliable, and hence AI-driven robots cannot provide emotional support to students like human teachers can [9]. In specific, emotion and speech recognition are inaccurate albeit central for successful learning experience [23]. Additionally, appropriate timing of verbal and nonverbal output is still difficult for social robots [4], reducing the seamlessness of human-robot interactions.

Social robots have difficulties in holistic interaction requiring complex capabilities. Robots are not able to
understand social context [20], which is a basic requirement for fluent interactions in the learning context. There are technical challenges in correct interpretation of the social environment for the robot to respond appropriately at all times [4]. Furthermore, the motor skills of social robots are not yet sophisticated enough [6].

**Social robots do not support students’ learning processes.** Despite of many successful short-term experiments, long-term engagement with social robots may be difficult. There is evidence that maintaining learners’ interest in robot-based interactions for long periods of time is challenging [9]. One reason for this is that personal development of students is not supported by social robots [20]. Automated decision-making would be needed for which actions to take to scaffold long-term learning [4].

**Social robots may not match the educational setting.** Teachers may be overwhelmed because appropriate interfaces for the teachers to control robots are missing [23]. Hence, content creation for social robots becomes a challenge [20]. Teachers should be enabled to create content via easy-to-use end-user development tools [23]. There may also be logistic challenges in introducing robots into school curricula [4]. The pedagogical aspects of robot teaching activities have not yet been fully explored due to technical limitations [20].

**Acceptance and ethics barriers.** Negative attitudes of teachers may hinder the spreading of robots to education [18]. Some fears exist that the lack of resources to acquire robots may increase the digital divide [18]. Suitability to different cultural contexts has also caused some concerns [11]. It may be also considered ethically questionable to delegate teaching to machines [4]. Robot-assisted learning settings may not adequately fulfill professional and parental expectations of a safe, pleasant, and inclusive learning environment [22].

**D. Recommendations**

The reviewed papers converge on several recommendations for research and development in the field of social robots in education and learning. We summarize these below:

**Inclusive education approaches.** Learning setups with social robots where students with mixed abilities will feel safe should be studied [22]. While the use of robots for special needs education has been considered, a mixed group of learners presents quite complex challenges and is quite demanding for the teacher.

**Social robots’ appearance, behavior, and personalization.** Further investigations are needed to establish the right appearance (e.g., anthropomorphic, zoomorphic) of the social robot, [22], to establish what aspects of human behavior should be emulated by robots [11], and to better understand the role that educational robots should play [18]. The optimal level of social behavior in a robot should be balanced to sustain children's interest without distracting or intimidating them [6].

**Low threshold solutions.** Increasing the access to social robot based learning technology is needed, for which lowering the cost of robot platforms is needed [8] as well as easily programmable, stable programming platforms [23].

**Interaction and educational capabilities.** Social robots’ intelligence needs to be further developed to support personalization [6], extending also to non-verbal behaviors [11], perception of environment and people through speech or visual signal processing [4], and tracking learner needs through learning analytics [9]. Developing the capability to extract high-level attributes for context and situation awareness [18] can pave the way for autonomy of the social robot and individualized robot-supported teaching. Adaptivity and feedback have remained understudied and should have a more central role in future studies [6].

**Extending educational domains.** Social robot research needs to expand to different areas of education, such as critical thinking skills [9], and specific areas of the already supported domain such as grammar in language learning [11]. Importantly, pedagogical guidelines for the utilization of social robots in education need to be developed [23].

**Long-term effectiveness.** Further evidence is needed regarding the claims made for social robots [3], including the long-term effects and acceptance [9]. Such efforts should focus on measuring and sustaining engagement and interest of learners [18] and verifying whether student engagement shown by current research results from the novelty of the system or if it can be sustained [11].

**IV. DISCUSSION AND CONCLUSIONS**

This meta-review summarizes and evaluates the review studies on robots in education or other forms of learning published in the period of 2018–2022. Of the identified 38 reviews, 12 corresponded to our inclusion criteria. Eight of these reviews were systematic, and all the reviews together cover research from the very start of the field of human-robot interaction until 2021. Initially we checked whether the meta-reviewed review studies check for quality and rigor of the papers that were included in the study. We relied on the guidelines for systematic reviews in related studies [24][25][26]. The majority of the review studies we examined did not check for all of the criteria suggested in [24][25][26]. The review studies mainly check the existence of well-defined experimental design, but they did not control for adequate inter-observer agreement and treatment integrity, operational definitions for dependent variables, and whether the study's design provided at least some control for alternative explanations for the effects on the targeted behavior. Instead, quality control was on the methods used, and the number of participants.

We found consistent support across reviews for the benefits of robots in different forms of education and learning in general. The benefits are in providing personalized learning experiences, promoting learning through supporting the social interactions between diverse children, through support kinesthetic and creative learning activities. Also, social robots can support learning outcomes because they bring about positive affect. Similarly, they could provide efficiency because robot expressivity enhances engagement in the learning process. The anthropomorphic presence of the robot can motivate or persuade the learner.

Aside from the outcomes unique to education and pedagogical practice, the reviews noted numerous challenges concerning the improvement of the robot’s interactivity and
autonomy, which will be beneficial to any application domain. It was repeatedly pointed out that the challenges of social robots typically originate in the related domains of robotics and education – the technical difficulties of having reliable real-life speech interaction and emotion recognition; the need for content creation and the difficulties of implementing the robot in the current educational structures because the robots do not work "off the shelf" yet; and some concerns related to acceptance and ethics.

We also identified research and design recommendations for social robots in education that were mentioned in various reviewed studies. The authors of the reviews repeatedly call for more extensive and in-depth research to evaluate the expected benefits of robot-based educational interventions, including interdisciplinary research combining robots with learning analytics. Social interaction capabilities need further development and research, as well as the variety of social robots’ appearance and behavior patterns. The designs and implementations of social robots in the current educational structures, as well as acceptance and ethical concerns, should be investigated further, also in longer-term studies. The definition of a “long-term study” is not well defined and should be revised, it ranges from several sessions to studies conducted for 4 [2,10] or even 6 months per child [16], but rarely the study length is chosen according to how long it usually takes to learn a particular subject or a skill. The presented findings can help set priorities for future research and developments in the field of social robots in education and learning.

Most of the reviews analyzed in this meta-review concern children as learners. Only one review captured by our meta-review covered studies that concerned children with autism [8], which may suggest that either the reviews conducted the context of autism have not specifically focused on education or learning aspects, or the studies for learning social and language skills by children with ASD are labeled as treatment, intervention (see for instance [25]) or training, which is not a chosen by us keyword. As autism is an area with strong potential benefits from the use of social robots [16], another meta-review could be done focusing specifically on benefits and challenges related to learning in this area.

We note how the conclusions we draw are distilled from quite disparate literature surveys, not all of which were systematic. Moreover, these reviews in their turn in their largest part did not evaluate the strength of the evidence of the papers they reviewed, and did not attempt to flag potential methodological limitations in the studies they reviewed. Several reviews were focused on technical challenges that are not specific to education but are needed across domains. Most of the reviewed social robots’ studies mostly do not examine the effectiveness of these as pointed out in [20], while [4] found that most papers reviewed did not focus on the analysis of the effectiveness of robot teaching activities or the learning outcomes of students. also points out that affective outcomes were more commonly reported in the studies than cognitive, but across those studies that reported cognitive outcomes, effect sizes were almost on par with human tutoring.

With these limitations in mind, the presented findings should be triangulated empirically, to examine their adequacy for guiding future research in human-robot interaction in learning and education. Furthermore, findings in other prominent social robot domains beyond education and learning, such as health care and customer service, could be analyzed in meta-reviews to find out about similarities and differences between domains.

REFERENCES


