The use of social robots as teaching assistants in schools: implications for research and practice

El uso de robots sociales como asistentes docentes en las escuelas: implicaciones para la investigación y la práctica

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Abstract
In social robots, AI has been seamlessly integrated to enable them to be programmed to perform a wide range of tasks, from basic movements and interactions to more complex functions, such as assisting in education. This comprehensive review delves into the multifaceted use of social robots in primary and secondary education, addressing key aspects such as trends, theoretical foundations, application domains, and ethical considerations. Guided by four primary research questions, the study reveals notable trends, with the NAO robot emerging prominently in educational settings, particularly among primary school-age children. Application domains explored include language learning, computational thinking, social and emotional development, creativity support, musical instrument practice, and library activities, showcasing the diverse roles social robots play as teaching assistants, peers, and companions. However, ethical concerns and data privacy issues surface, posing risks such as transparency issues, dependency on robots, reduced human interaction, and potential job displacement. The study stresses the need for extensive longitudinal studies and collaborative efforts to responsibly integrate social robots into education, emphasizing the necessity for collaboration among educators, policymakers, developers, and privacy experts to establish clear guidelines prioritizing students' well-being.
Keywords: social robot, education, schools, student robot interaction

Resumen
En los robots sociales, la IA se ha integrado perfectamente para permitirles programarse para realizar una amplia gama de tareas, desde movimientos e interacciones básicos hasta funciones más complejas, como ayudar en la educación. Esta revisión integral profundiza en el uso multifacético de los robots sociales en la educación primaria y secundaria, abordando aspectos clave como tendencias, fundamentos teóricos, dominios de aplicación y consideraciones éticas. Guiado por cuatro preguntas de investigación principales, el estudio revela tendencias notables, en las que el robot NAO emerge de manera destacada en entornos educativos, particularmente entre los niños en edad de escuela primaria. Los dominios de aplicación explorados incluyen el aprendizaje de idiomas, el pensamiento computacional, el desarrollo social y emocional, el apoyo a la creatividad, la práctica de instrumentos musicales y las actividades de la biblioteca, mostrando las diversas funciones que desempeñan los robots sociales como asistentes de enseñanza, pares y acompañantes. Sin embargo, surgen preocupaciones éticas y problemas de privacidad de datos, lo que plantea riesgos como problemas de transparencia, dependencia de robots, interacción humana reducida y posible desplazamiento

laboral. El estudio enfatiza la necesidad de realizar estudios longitudinales extensos y esfuerzos de colaboración para integrar responsablemente los robots sociales en la educación, enfatizando la necesidad de colaboración entre educadores, formuladores de políticas, desarrolladores y expertos en privacidad para establecer pautas claras que prioricen el bienestar de los estudiantes.
Palabras clave: robot social, educación, escuelas, interacción entre estudiantes y robots

1. Introduction

Artificial Intelligence (AI) in education involves the integration of AI systems to enhance learning experiences. AI systems, such as AI robots, are increasingly utilized in educational settings to provide innovative learning opportunities. These AI robots, like the NAO robot, are designed to interact with students and deliver educational content effectively (Iqbal, 2023). Research trends show that AI robots are commonly applied as tutors or tutees, focusing on improving learning performance and behavior in students, particularly those under 13 years old (Karine&Souto, 2023). Additionally, AI applications in education extend to the development of social robots that cater to individuals' physical, cognitive, emotional, and social needs, with a growing emphasis on their role in educational settings (Sayed et al., 2021) .

Robotics stands as a technological facet ingrained across diverse life domains (Kalaitzidou & Pachidis (2023)). In education, social robots denote specially designed robotic systems engaging students to enhance their learning experiences (Belpaeme et al. (2018); Kubilinskiene et al. (2017)). These AI-powered entities are equipped with sensors, perceiving and responding to their surroundings, engaging with students in social and educational realms. Research highlights the profound impact of social robots in diverse educational settings, underscoring their potential in supporting both learners and educators (Donnermann et al. (2020)). Their adaptability tailors interactions to individual student needs, assessing abilities, offering personalized content, feedback, and teaching assistance. For language acquisition, these robots aid in conversations, pronunciation practice, vocabulary building, and immersive language scenarios, boosting motivation (Sisman et al. (2018)). In STEM subjects, they facilitate hands-on learning, guiding experiments and nurturing problem-solving skills. For special education, robots provide crucial support, aiding communication, social skill development, and emotional regulation, particularly benefiting children with autism spectrum disorder. Moreover, as collaborative partners, these robots encourage teamwork, discussions, critical thinking, and creativity, contributing significantly to social development (Ekström & Pareto (2022)). They also offer emotional support by engaging in conversations and providing encouragement, beneficial for students facing stress or loneliness (Escobar-Planas et al. (2022)). Through equipped cameras and remote capabilities, robots enable virtual field trips, enriching understanding in geography, history, or scientific phenomena. Additionally, they serve as educational tools for teaching coding, robotics concepts, and computational thinking.

The utilization of educational robots has experienced exponential growth in recent years, driven by advancements in technology and a growing recognition of their benefits in enhancing learning outcomes. According to a report by Research and Markets (2018), the global educational robotics market is projected to reach $3.8 billion by 2023, with a compound annual growth rate (CAGR) of 16.8% from 2018 to 2023. Similar growth is anticipated in the next few years. This surge in adoption can be attributed to the increasing emphasis on STEM (Science, Technology, Engineering, and Mathematics) education, where educational robots play a crucial role in fostering students' skills in these disciplines. Additionally, a survey conducted by the International Federation of Robotics (IFR) revealed that the number of educational robots used in schools doubled from 2016 to 2019, indicating a significant uptick in their integration into educational curricula globally. As educational institutions continue to prioritize the integration of technology into teaching practices, the growth trajectory of educational robots is expected to remain robust, shaping the future of education worldwide.

The main aim of this paper is to examine the effectiveness of social robots across multiple educational settings, due to the lack of comprehensive reviews in the field. Therefore, this review will assess the support for claims regarding the potential of social robots in primary and secondary education through an analysis of experimental studies and will delve into the applications of social robots in schools and the underlying theoretical frameworks guiding these studies.

Therefore we start with an overview of the current state in the field in relation to using social robots as teaching assistants, followed by a discussion of the methodologies used in existing studies identifying existing theoretical models and main applications of social robots in the classroom, and conclude with implications for practice and suggestions for future research.

1.1. Social robots as teaching assistants

In recent years, the landscape of education has witnessed a transformative shift with the integration of social robots into classrooms. These humanoid or non-humanoid robots are designed to interact and engage with students, providing a myriad of benefits that extend beyond traditional teaching methods. As technology continues to advance, educators and researchers are exploring innovative ways to leverage social robots to enhance the learning experience (Tolksdorf et al. (2021); Zhexenova et al. (2020)). While some schools and educational institutions have embraced the use of social robots in research and pilot programs, it's important to note that the adoption of such technologies can vary widely. Factors such as budget constraints, technological infrastructure, and differing educational philosophies may influence the extent to which schools integrate social robots into their educational practices.

Although scattered, research practice in schools is often focused on areas like:

1. Personalized Learning: One of the key advantages of incorporating social robots in education is the ability to facilitate personalized learning experiences. These robots can adapt to individual learning styles, pace, and preferences, offering tailored content and support. By recognizing and responding to students' unique needs, social robots contribute to a more inclusive and effective learning environment (Chen et al. (2020); Song et al.(2021); Yueh et al. (2020); Konijn & Hoorn (2020); Peura et al. (2023)).
2. Enhanced Engagement: Social robots excel in creating a dynamic and interactive atmosphere within the classroom. Their ability to express emotions, maintain eye contact, and use non-verbal cues fosters a sense of connection with students. This increased engagement is particularly beneficial for students who may struggle with conventional teaching methods or have special educational needs. Social robots can also assist in maintaining a positive and supportive classroom atmosphere (Chen et al. (2020); Sisman, et al. (2018); Arar et al. (2021); (Chalmers et al., 2022)).

3. Language Development: For language learners, social robots offer a valuable tool for honing communication skills. Through conversational interactions, pronunciation feedback, and language games, these robots provide a safe and non-judgmental space for students to practice and improve their language proficiency. This is especially relevant in multicultural classrooms where students may come from diverse linguistic backgrounds (Sisman, et al. (2018); Arar et al. (2021); Chen et al. (2020); Zhexenova et al. (2020)).
4. Social and Emotional Learning (SEL): Recognizing the importance of social and emotional skills in education, social robots play a role in fostering SEL. They can guide students in developing empathy, emotional regulation, and effective communication. Through role-playing scenarios and interactive exercises, social robots contribute to the holistic development of students, preparing them not only academically but also socially for the challenges of the future (Escobar-Planas, et al. (2022); Ahumada-Newhart et al. (2023); Ali et al. (2021); Serholt (2019)).
5. Addressing Educational Gaps: Social robots have the potential to address educational disparities by providing additional support in areas where resources are limited. Whether in remote or underserved communities, these robots can supplement the work of teachers, offering personalized tutoring, assistance with homework, and reinforcement of key concepts. This can help bridge the gap in educational access and quality.

Besides the mentioned areas, ethical considerations must be considered when using social robots in education. Issues related to privacy, data security, and the potential impact on human relationships need careful examination (Boch, et al. (2020); Sibramanian, (2017); Newton & Newton (2019); Wo et al. (2021)). Therefore, it is essential to establish clear guidelines and regulations to ensure the responsible and ethical use of social robots in educational settings.

Overall, the use of social robots in education represents a promising frontier in the ongoing evolution of teaching and learning. As technology continues to advance, educators, researchers, and policymakers should collaborate to harness the full potential of social robots while addressing ethical concerns.

1.2. Previous review studies

As social robots in educational research experience diversification and growth, there is a noticeable emergence of review studies delving into various aspects and focal points within the field. Reviews on the potential of social robots in special needs education (Sannicandro et al. (2022); Lorenzo et al. (2021)), STEM fields (Papadopoulos et al. (2020); Kalaitzidou and Pachidis (2023); Bonaiuti et al. (2022)), language learning (Ao & Yu (2022)), and music education (Martinez-Roig et al. (2023)) have become prominent.

Although previous review studies contribute to the understanding of social robots in education, some limitations need to be reported. The first is the restriction to scientific works published exclusively in Italian journals (Bonaiuti et al. (2022)). As for the available research results, it needs to be noted that Sisman et al. (2018) reported the potential impact of classroom instability on participant attitudes, which may be attributed to environmental factors and lesson design customised for specific language proficiency levels. Next, small sample size is and short-term study duration is also very frequently reported (see for example Chen et al., 2020; Qu & Fok, 2021; Serholt et al., 2021; Yueh et al., 2020; Zhexenova et al., 2020). Besides that, short interaction time with robot was also reported as an issue which needs to be extended in future research (Kim et al., 2023; Osawa et al., 2022). Recommendations therefore suggest longitudinal studies, larger sample sizes, different teaching methods, introduction of control groups, different age range and grades (see for example Chen et al., 2020; Konijn & Hoorn, 2020; Peura et al. 2023; Qu & Fok, 2021; van Straten et al., 2023).

In terms of review studies, several of them have been identified: a study that brings together results from research in special education, computational thinking, and e-health, implying different fields, approaches, goals, participants, and different roles and types of robots (Sannicandro et al. (2022)), a review study involving the application of social and non-social robots such as Lego and mBot (Kalaitzidou & Pachidis (2023)), a study covering human-robot interaction in language teaching, including different robots and roles, participant roles, degrees of human teacher interference, skills being taught, and different learning environments (Ao & Yu (2022)), and a study in which robots took various roles in the classroom as a peer, tutor, teaching assistant, or teacher (Wo et al. (2021)). A small number of review studies have been identified that focus exclusively on primary and secondary education. In previous review studies, a relatively small number of application domains have been covered, and only a few studies address robots as teaching assistants. Additionally, a significant number of studies were identified that conducted short-term experiments, with one session lasting between 15, 20 minutes to one hour.

Lastly, although much recent research with robots in education stresses the importance of considering ethical and privacy issues (see, for example, Sibramanian, (2017); Newton & Newton (2019); Boch et al. (2022); Wo et al. (2021)), previous review studies failed to address these matters.

1.3. Purpose of the study

There are several purposes for this study. The first is to identify trends and gaps among existing research by comprehensively examining how social robots are used in primary and secondary schools, classifying research domains and constructs. The second purpose is to summarise the theoretical models and empirical findings to provide directions for future research. The third purpose is to elicit ethical considerations to be considered when experimenting with robots as teaching assistants.

Accordingly, four research questions were formulated for the review:

RQ1: What are the research trends in terms of the research issues associated with social robots in primary and secondary schools?

RQ2: On which theoretical models are the studies based?

RQ3: What are the application domains in the context of social robots in primary and secondary schools?

RQ4: What ethical and data privacy issues were raised?

2. Method

Systematic Mapping (SM) and Systematic Literature Review (SLR), referred to as secondary research methods, involve examining, categorising, and analysing previous research endeavours. SM entails sorting articles pertinent to the research domain, whereas SLR concentrates on scrutinising specific research inquiries. In an SM study, articles are catalogued according to their subject matter (Wieringa et al., 2005). Conversely, SLR studies amalgamate findings from various studies to address the research questions at hand (Budgen et al., 2018). This research utilised a hybrid approach, combining systematic mapping and systematic review methodologies.

The literature review process was divided into four stages: identification, screening, eligibility, and inclusion, according to Boland et al. (2017) and the complete process is illustrated on Figure 1 with PRISMA flow diagram.

2.1. Research process

The literature review process was conducted using the scientific databases Scopus and Web of Science using the following search strings:

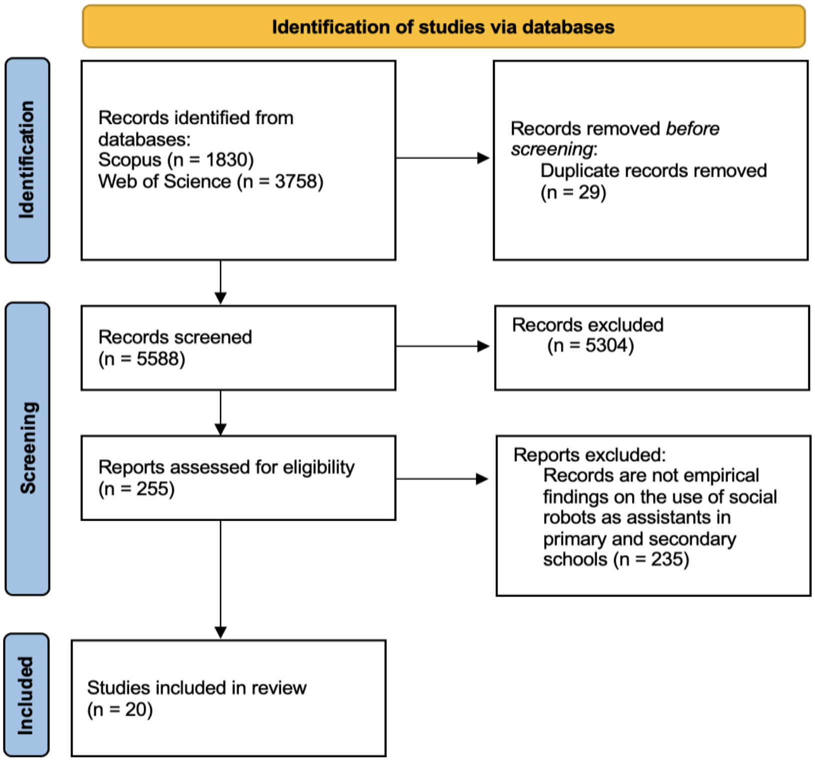
TS = robot AND supported AND learning,

TS = (social OR humanoid) AND robot AND education.

As a result, 3,758 records were identified from the Web of Science, and 1,830 records were identified from Scopus.

Figure 1.

PRISMA flow diagram of the literature review process



2.2. Study selection

For the study selection (Screening) stage, the following additional selection Inclusion Criteria (IC) and Exclusion Criteria (EC) were used:

IC1: Papers published in English.

IC2: Papers published within the time frame 2020-2023, due to rapid developments in robotic technology, especially within the scope of educational (social) robots and AI development

IC3: Document type was an article, published in scientific journals

IC4: Full text was available (Authors had acces to full-text through individual or organisational subscription).

IC5: The subject areas were Computer and Social Science (Scopus) and Educational Research in Education (Web of Science).

EC1: Papers that are not in the Education & Educational Studies category.

EC2: Papers without full-text access.

EC3: Papers dealing only with virtual or remote laboratories.

EC4: Papers intended for review of the literature.

As a result, 162 studies were obtained from Scopus and 122 from Web of Science. 29 duplicates were detected and excluded, and 255 studies were reviewed by titles and abstracts.

In the next stage (Included), the final eligibility criterion was applied – papers should have included empirical findings on the use of social robots as assistants in primary and secondary education. 235 studies were removed because they did not meet the required criteria. Most of these studies did not utilize social robots as assistants, but instead focused on other types of robots, primarily for teaching programming, such as Lego, mBot, etc. Additionally, many of them did not report any empirical findings. Furthermore, studies that dealt with education of children with special needs outside school curriculum were also excluded from further analysis. Finally, a total of 20 studies were included in the final stage of the literature review.

2.3. Coding & analysis

The coding elements were selected based on research questions. When identifying these features, coding schemes employed in prior reviews (Lin and Hwang, 2019; Atman Uslu et al., 2023) were considered. They use 6 or 7 main coding components, and for this research it was decided to use those applicable to social robots in education. As a result, the coding framework comprised five comprehensive components, shaping the analytical foundation for this research. Detailed explanations elucidating the coded features are expounded upon in subsequent sections.

Demographics: The metadata for each paper was subjected to coding, encompassing details such as the publication year, the journal of publication, and the keywords employed in the study.

Participants: Study groups were classified as primary and secondary school students.

Research issues: Classification of research issues was done by taking into account research constructs identified in the papers. The primary author sifted through article sentences pertinent to the study's focus, organizing them in a spreadsheet to form the initial category list, as the initial categories for usage of social robots in education were not found in the existing literature. Subsequently, the entire articles were reviewed to finalize the category list. Collaboratively, all authors reassessed the articles within these categories, achieving consensus on category names and scopes. In total, eight categories of issues were detected: Learning experience and achievements, Perception, 4C skills, Motivation, Enjoyment, Engagement, Behaviour and attitudes, and Coding and computational thinking skills.

Application Domain: Based on the targeted activities with robots as teaching assistants, eight major application domains were detected: Language learning, Computational Thinking and Robotics Education, Children's Social and Emotional Development, Creativity Support, Musical Instrument Practice, Library Activities, and Collaborative Friendship Development.

Ethical and privacy issues: A set of keywords specific to ethical and privacy issues were searched for in the papers to examine if those issues were addressed and in what way: ethics, transparency, data privacy, dependency on robots, reduced human interaction, and potential job displacement.

3. Findings

The overview of the analysed papers is given in Table 1, and it shows the type of robot used, the number of participants and their age, the educational field (languages, STEM, other), and the duration of the educational activity.

Table 1.
Overview of the analysed papers

Author	**Robot**	**Participants**		**Subject**	**Duration**
		Number	Level		
Sisman et al. (2018)	NAO	232	secondary	language	4 months
Escobar-Planas et al. (2022)	Haru	84	primary	problem-solving	1 session
Arar et al. (2021)	Emys	54	primary	language	8 weeks
Yueh et al. (2020)	Julia	36	primary	literacy	1 session
Chen et al. (2020)	Tega	59	primary	language	48 sessions
Konijn & Hoorn (2020)	NAO	86	primary	mathematic	3 sessions
Kim et al. (2023)	Skusie	10	primary	friendship behaviours	2 sessions
Qu & Fok (2021)	KaziEV5	32	secondary	computational thinking	12 sessions
Chalmers et al. (2022)	NAO	96	primary and secondary	computational thinking, coding and language	3 years
Serholt (2019)	NAO	34	primary and secondary	-	3 months
LeTendre & Gray (2023)	Pepper	25	secondary	-	10 weeks
Peura et al. (2023)	NAO	50	primary and secondary	language	2 weeks

van Straten et al. (2023)	NAO	276	primary	science	1 session
Ali et al. (2021)	Jibo	172	primary	creativity	1 year
Song et al. (2021)	SocibotMini	31	secondary	music	1 session
Ahumada-Newhart et al. (2023)	Double2 i VGo Robots	53	primary and secondary	friendship behaviours	-
Zhexenova et al. (2020)	NAO	62	primary	language	1 session
Serholt et al. (2021)	Pepper	10	primary and secondary	mathematic	1 session
Osawa et al. (2022)	NAO	490	secondary	literacy	1 year
de Souza Jeronimo et al. (2022)	NAO, Zenbo	20	primary	music	-

The results show that NAO is one of the most popular social robots in education, used in as many as 9 out of 20 studies. The robot Pepper was used in two studies each, and the robots Jibo, SocibotMini, KaziEV5, Zenbo, Double2, VGo Robots Skusie, Haru, Emys, Julia, and Tega were used in one study each.

The number of participants who actively participated in the research ranges from 10 to as many as 490. Studies are most often conducted among children of primary school age. Five studies were conducted among primary and secondary school age, five among secondary school age, and ten among primary school age.

The use of social robots is most common in teaching languages, as many as six studies have been conducted in this area. Two studies were conducted in each of the areas of literacy, mathematics, computational thinking, music, and friendship behaviors. One study per field was conducted in the areas of problem-solving, science, coding, and creativity. For two studies, the research area was not specified.

Considering the duration of teaching/learning and the use of social robots in the educational process, both short-term and long-term studies were carried out. Nine studies conducted educational activities for a period of two months to two years. The same number of studies conducted educational activities as a one-time activity, while for two studies, the duration of the educational activity was not specified.

3.1. What are the research trends in terms of the research issues with social robots in education?

The papers included in this review were classified according to issues they dealt with and research categories to answer RQ1. Then, eight research categories emerged which are presented in Figure 2.

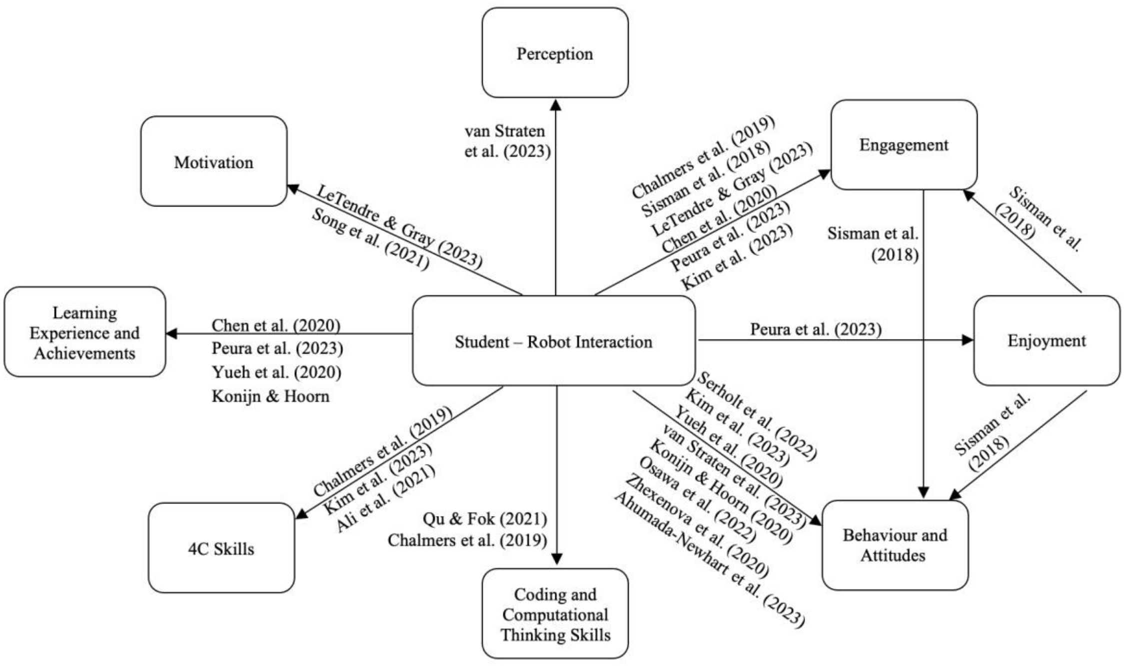
Figure 2.
Research categories, purpose of studies and examples

Category	Purpose of the study	Examples
Learning Experience and Achievements	To investigate how social roots contribute to achievement of learning outcomes and positive learning effect	To examine the impact of a social robot on the learning outcomes (Peura et al. (2023)) To examine whether the robot enhances persistence in learning (Peura et al. (2023)) To identify effect of the social robot on the effectiveness of the educational process and improvement of learning gains (Arar et al. (2021)) To examine learning outcomes, among students who learn with the help of robot (Zhexenova et al. (2020)) To examine the significance of robot student interactions on the achievement of learning outcomes (Chen et al. (2020)) To investigate if robots are capable of creating a positive learning effect (Konijn & Hoorn (2020))
Perception	To examine a variety of ways students perceive a social robot in different settings	To examine what do the children remember from their interaction experiences with the robot tutor (Serholt (2019)) To investigate how children perceive library robots in reading activities (Yueh et al. (2020)) To identify how exposure to a robot affected on student conceptions of robots: classroom impact, awareness of the robot, sociability and interactivity, robot identity in the classrooms (LeTendre &Grey (2023)) To investigate how long-term exposure to a robot in a project-based classroom affected student conceptions of robots (LeTendre &Grey (2023)) To investigate how children perceive and relate to a social robot (van Straten et al. (2023))
4C Skills	To investigate how social robots influence the development of 4C skills	To investigate how the social robot effects on the development of children's creativity (Ali et al. (2021)) To examine perceptions of robot regarding communication and collaboration to interact with the robot (Serholt et al. (2022)) To examine the role of the robot in social roles of children (Osawa et al. (2022)) To identify major design challenges and solutions for developing robot-mediated, collaborative interaction activities (Kim et al. (2023))
Motivation	To determine the ways social robots enhance students' motivation	To examine whether the robot enhances motivation in learning (Peura et al. (2023)) To investigate if children in different learning stages are more motivated with robots with different roles during practising (Song et al. (2021)) To examine the significance of robot student interactions on the motivation and involvement (Chen et al. (2020))
Enjoyment	To examine enjoyment of students when interacting with robots	To examine enjoyment and mood change among students (Zhexenova et al. (2020)) To examine perceptions regarding enjoyment and willingness to interact with the robot (Serholt et al. (2022))
Engagement	To examine the level of engagement of students with social robots	To examine if children interacting with a tutee robot are more expressive and engaged than children with a tutor robot (LeTendre & Grey (2023)) To examine if humanoid robotics technology engages students with their learning (Chalmers et al. (2019))
Behaviour and Attitudes	To examine how social robots influence students' behaviour and attitudes	To investigate whether the designed robot-mediation influenced children's friendship behaviours (Kim et al. (2023)) To develop a valid and reliable attitude scale that could be employed to determine students' attitudes towards the use of humanoid robots in educational settings (Sisman et al. (2018))
Coding and Computational Thinking Skills	Cultivating students' coding and computational thinking skills	To investigate how students worked with the humanoid robot to develop both their coding and computational thinking skills (Chalmers et al. (2019)) To explore how student - robot interactions cultivate students' computational thinking (Qu &Fok (2021))

As seen in Figure 2, papers covered a variety of research categories. However, most of the papers (5) were concentrated on learning experience and achievements, which sought to understand how social robots contribute to the achievement of learning outcomes and experience. Four papers were found to be dealing with perception, focusing on examining how children perceive social robots in different study contexts. The research centred on the examination of four papers investigating the impact of social robots on the cultivation of 4C skills—namely, communication, cooperation, creativity, and critical thinking. Three papers delved into the exploration of motivation, specifically examining how the interaction between students and social robots in educational settings influences student motivation. Two papers focused on assessing students' enjoyment of engaging with robots. Additionally, two papers were dedicated to discerning the mechanisms through which social robots influence student engagement in the learning process. Two papers were dedicated to the investigation of the impact of social robots on students' behaviour and attitudes. Concurrently, another pair of papers focused on the cultivation of students' coding and computational thinking skills.

In addition, the papers were further reviewed to explore the connections between research constructs that were investigated. Figure 3 presents an overview of the confirmed relationships between constructs found in the analysed papers.

Figure 3.
Overview of confirmed relationships between research constructs



Most of the authors dealt with research on student-robot interaction and the influence on students' behaviour and attitudes. A positive correlation has been established in as many as 8 studies (e.g. Kim et al., 2023; Yueh et al., 2020; van Straten et al., 2023; Serholt et al., 2021; Konijn & Hoorn, 2020; Osawa et al., 2022; Zhexenova et al., 2020; Ahumada-Newhart et al., 2023). A noteworthy discovery by Serholt (2019) was that students who had experience with robots exhibited greater critical attitudes toward the concept of emotion recognition in robots compared to their peers without such experience. Yueh et al. (2020) showed that participants perceived the robot companion as more favourable and desirable for reading than a human co-reader. Children exhibited a preference for robotic verbalization over human verbalization. In terms of effect, the robot co-reader prompted more social interaction during the reading sessions. Kim et al.'s (2023) study emphasised that student-robot interaction contributes to the development of positive attitudes and behaviours related to learning. According to the results of the research of van Straten et al. (2023) children engaged with a robot that either provided information about its lack of human psychological capacities and machine status or did not. The disclosure of this information reduced children's feelings of closeness and trust toward the robot. Konijn & Hoorn (2020) showed that the results from the standard school test indicated that pupils significantly improved their performance after learning with assistance of social robots. Ahumada-Newhart et al. (2023) showed that children who feel a high chance of success at operating their robots in the remote school environment and place a high value on self-directed play activities are able to use their robots to support general friendships and also engage in play activities that contribute to self-expression and identity. Findings of the study conducted by Zhexenova et al. (2020) reported that children gained similar knowledge after learning with a social robot as after learning with a teacher or with the help of a tablet. In addition, children’s likeability ratings and positive mood change scores demonstrate significant benefits favouring the robot over a traditional teacher and tablet only approaches. Osawa et al. (2022) validated that the robot could sustain engagement over an extended duration without inducing boredom.

Great interest was shown in the impact of student-robot interaction on student activity in the learning process. In 6 studies, a positive influence between student-robot interaction and student engagement was demonstrated. Chalmers et al. (2019) investigated the effects of humanoid robots on students' learning and engagement. The findings underscored the positive influence of humanoid robotics technology on student engagement in the learning process. LeTendre & Gray (2023), in their study, showed that skilfully designed interventions using social robots have the potential to engage students. The research conducted by Chen et al. (2020) concluded that social robots brought the most benefits to children's affective engagement. Kim et al. (2023) in their research proved that student-robot interaction improves student engagement in the learning process. Results from Peura et al. (2022) demonstrated improvements in learners' pronunciation during the experiment, and active participation by pupils became a natural aspect of the learning process. The participants exhibited persistence and enjoyment in learning with the robot throughout the challenge. Sisman et al. (2018) in their study have proven that engagement emerged as the most influential construct among various factors contributing to attitudes toward the integration of robots into lessons. The notably high correlation between engagement and intention, as well as between enjoyment and intention, highlights the potential effectiveness of enjoyable and engaging practices in robotics-integrated lessons on fostering positive attitudes toward future technology use in the classroom. The significance of enjoyment is emphasised in transforming teaching practices into personalised "edutainment" experiences, thereby influencing students' engagement levels in the lesson.

In addition, 4 authors have proven a positive relationship between student-robot interaction and the learning experience and student achievement. Yueh et al. (2020) showed that the cognitive comparison revealed that human and robot companions facilitated children's reading comprehension in distinct ways, with children performing similarly well with both types of reading companions. Results from Peura et al. (2022) demonstrated improvements in learners' pronunciation during the experiment, and active participation by pupils became a natural aspect of the learning process. Konijn & Hoorn (2020) showed that the results from the standard school test indicated that pupils significantly improved their performance after learning with assistance of social robots.

The research conducted by Chen et al. (2020) concluded that social robots brought the most benefits to children's vocabulary learning.

A positive connection between student-robot interaction and the development of 4C (communication, creativity, cooperation, and critical thinking) has been identified in 3 papers. The results of the research conducted by Chalmers et al. (2019) show that collaborative efforts with humanoid robots enhanced 21st-century skills such as creativity, critical thinking, communication, and collaboration. Ali et al. (2021) found that both creativity demonstration and creativity scaffolding can serve as social mechanisms for eliciting creativity in children using a social robot. Kim et al. (2023) in their investigation revealed that robot mediation made a complementary contribution to the development of friendships among the children.

The existence of a positive effect of student-robot interaction on student motivation and development of computational thinking and programming skills was confirmed by 2 authors. LeTendre & Gray (2023) demonstrated in their study that skilfully designed interventions using social robots have the potential to motivate students. In addition, Song et al. (2021) showed a significant interaction between condition (i.e., alone, evaluative robot, and non evaluative robot) and learning stage groups indicating that children in different learning stage groups had different levels of motivation when practising alone or with an evaluative or non evaluative robot. In a more detailed analysis, novice participants demonstrated increased persistence when engaging with the non evaluative robot. The findings of Qu & Fok (2021) indicated an increase in students' computational thinking skills during a summer camp, and the change in computational thinking skills was positively correlated with the time spent on student-robot interactions. The study conducted by Chalmers et al. (2019) showed improvement in students' computational thinking and coding abilities.

In the end, a positive relationship between perception and enjoyment of student-robot interaction has been proven. van Straten et al. (2023) showed that the tendency to anthropomorphize the robot mediated the effects of transparency on closeness and trust, while the perception of the robot's similarity to themselves only mediated feelings of closeness while Peura et al. (2022) showed that the participants exhibited persistence and enjoyment in learning with the robot throughout the challenge.

3.2. Which theoretical models are the studies based on?

After the detection of the main research issues, the focus shifted to a thorough examination of whether the studies referred to any theoretical models, as indicated in RQ2, and how they employed it. Table 2 presents an overview of papers (12) that employed any theoretical model. It is important to exercise caution when interpreting frequencies in this context, as assessing the theoretical foundations of a study goes beyond a mere reference to theories. Therefore, solely evaluating the papers’ content, while considering how the quoted theory is reflected in the teaching-learning process, is considered a problematic approach. The absence of a reported theoretical model does not necessarily imply a lack of theoretical basis, and even if reported, subjective biases may influence its assessment.

Table 2.
Theoretical model/concept/approach

Author	**Theoretical model/concept/approach**
Ahumada-Newhart et al. (2023)	● Theoretical Model: Expectancy-Value Theory (EVT) ● Framework: Presence and Social Connectedness (PASC) framework, with a focus on three forms of interaction: collocated, cooperating, and collaborating.
Ali et al. (2021)	● Theoretical Model: Boden's framework of creativity ● Assessment Tool: Kahn et al.'s Droodle Task Coding system (for determining creativity of Droodle titles)
Song et al. (2021)	● Theoretical Models: Social Facilitation Theory (Triplett, 1898) and Self-Determination Theory ● Insight: For new and complex tasks, being observed may be detrimental, but for well-trained tasks, observation can have positive effects on performance and motivation.
Sisman et al. (2018)	● Theoretical Model: Total Physical Response theory (Asher, 1969) ● Approach: Integrating kinesthetic movement into English language learning activities using a humanoid robot.
Kim et al. (2023)	● Concept: Child Development Theory ● Interaction Design: Grounded in the idea that children like to engage in fantasy play with peers, conversing and working together to achieve shared goals.
Qu & Fok (2021)	● Theoretical Model: Computational Thinking (CT) framework proposed by ISTE (2011) ● Key Concepts: Formulating problems, abstraction, logical thinking, using algorithms, analyzing and implementing solutions, generalizing and problem transfer.
Chen et al. (2020)	● Theoretical Model: Vygotsky's Zone of Proximal Development theory ● Approach: Using social robots or computer agents as tutors to engage children as more knowledgeable partners, fostering the acquisition of new knowledge and skills.
Peura et al. (2023)	● Concept: Robot Assisted Language Learning (RALL) ● Definition: The use of robots to teach language expression or comprehension skills. ● Insight: Social robots in RALL may have superior pedagogical effects compared to non-RALL conditions, and they might replace other technologies, but less likely to replace human teachers or peers.

Peura et al. (2023) explored the learning of a second language with the help of a social robot as a part of the normal classroom routine without the presence of a human teacher. They used the Robot Assisted Language Learning (RALL) method, defined as “the use of robots to teach people language expression or comprehension skills—such as speaking, writing, reading, or listening”. The findings suggest that the robot serves as a motivating factor, leading to enhanced learning, even in the absence of the novelty effect associated with the robot. Qualitative observations highlight a positive impact on learning when a social robot is involved. Consistent with earlier research, active participation seamlessly integrated into the learning process with the robot.

Sisman et al. (2018) developed the Educational Robot Attitude Scale (ERAS) to measure the attitudes of secondary school students towards the use of humanoid robots in educational settings and successively to identify their potential emotions associated with the use of humanoid robots. The scale developed in this study consists of engagement, enjoyment, intention, and anxiety—psychological constructs regarded as crucial variables for determining the learning experience of students. These attitudinal categories (Entertainment, Acceptance, Emotions) have been recognized in the literature of educational technology as of prominent importance. Among all the factors influencing attitudes toward integrating robots into lessons, engagement emerged as the most impactful construct. The strong correlations observed between engagement and intention, as well as between enjoyment and intention, underscore the potential effectiveness of enjoyable and engaging robotics-integrated lessons in fostering positive attitudes toward future technology use in the classroom. Additionally, it is emphasized that the role of enjoyment is particularly crucial in transforming teaching practices into personalized "edutainment" experiences, which, in turn, can influence the level of student engagement in the lesson.

Kim et al. (2023) explored if a social robot would play a role in facilitating the development of friendship between young children while they engage in playful learning. They established a small triadic interaction community consisting of a robot and two children, wherein the robot facilitated collaborative and equitable interactions between the children. The design of the interaction was based on Child Development Theory, which posits that children enjoy engaging in fantasy play with peers, conversing, and working together to achieve shared goals. The observation of friendship development between the children focused on five behavioral categories: liking, togetherness, parity, agreement, and co-construction. The findings indicated that both conversational and tablet-assisted robot mediation played complementary roles in fostering friendship development among the children.

The study from Qu & Fok (2021) focuses on student–robot interaction in the learning environment of robotics education and attempts to explore how it cultivates students’ computational thinking. In contrast to the exploration of child-robot interactions within the social robot domain, interactions between students and robots predominantly revolve around the interaction process in robotics education settings, specifically involving programmable robot kits. The authors opted for the computational thinking framework proposed by the ISTE (2011) due to its operational nature, widespread citation, and lack of limitations in domain-specific knowledge. The results revealed an increase in students' computational thinking skills, with a positive correlation between the change in their computational thinking skills and the time spent on student-robot interaction. Furthermore, the study identified how three types of student-robot interaction (programming-computing, observational investigation, and participatory investigation) contributed to the cultivation of students' computational thinking.

Chen et al. (2020) researched how young children learn or engage when interacting with different types of pedagogical agents (social robot as a tutor, tutee, or peer) and how we can leverage the benefits of each pedagogical agent paradigm to provide a synergistic impact on young children's learning and engagement. Specifically, the researchers aimed to compare various child-agent interaction paradigms and assess their respective impacts on children's learning and emotional experiences. They introduced an innovative Adaptive Role Switching (ARS) model, allowing the robot to dynamically shift its role in a reciprocal interaction, alternating between teaching and learning from each child. The study revealed that the robot's instructional sessions and knowledge demonstrations positively influenced children's vocabulary acquisition. However, when the robot assumed the role of a tutee, children displayed slightly more pronounced emotions on their faces. The synergistic effect observed between the tutor and tutee roles underscores why the adaptive peer-like agent brought the most benefits to children's vocabulary learning and emotional engagement compared to an agent solely acting as a tutor or tutee for the child.

Ali et al. (2021) explored the impact of a social robotic peer's sociobehavioral patterns on children's creativity. They specifically emphasized two interaction patterns of the robot: 1) creativity demonstration, where the robot exhibits artificial creativity, and 2) creativity scaffolding, where the robot supports and encourages the child's creative thinking through reflective questions, challenges, and positive reinforcements. The researchers utilized Boden's creativity framework and Kahn et al.'s Droodle Task Coding system (for assessing creativity in Droodle titles) as evaluation tools. The findings revealed that both the creativity demonstration and creativity scaffolding provided by the social robot positively influenced children's creativity across verbal, figural, and constructional creativity tasks.

In their study, Ahumada-Newhart et al. (2023) explored how children engaged with school-distributed robots in self-directed play activities. The authors identified two overarching themes that were consistently present in self-reported play scenarios, encompassing physical, verbal, visual, extracurricular, and desired play. The results indicate that children who perceive a high likelihood of success in operating their robots within the remote school setting and prioritize self-directed play activities can utilize the robots to foster overall friendships. Additionally, these children engage in play activities that not only contribute to self-expression but also play a role in shaping their identity.

3.3. What were the main application domains of social robots in schools?

To address RQ3, papers were examined to find out for what purpose social robots have been used in schools. In general, they were commonly used to assist in language learning, foreign language teaching, and other educational activities. They acted as assistants, peers, and reading companions, contributing to improved learning outcomes, engagement, and motivation among students. Figure 4 presents an overview of the main application domains identified according to the research context described in the papers, and a short description of robot's usage is given below:

Figure 4.
Overview of the main application domains

Language Learning	Robots are employed as language learning assistants, demonstrating success in teaching foreign languages to children and adults (Arar et al. (2021); Peura et al. (2022); Sisman et al. (2018); Chen, et al. (2020); Zhexenova et al. (2020); Chalmers et al. (2022))
Computational Thinking and Robotics Education	Robots are utilised in robotics education to cultivate students' computational thinking skills through interactions (Chalmers et al. (2019); LeTendre & Grey (2020); Qu & Fok (2021))
Children's Social and Emotional Development	Social robots play a role in motivating children to engage in various activities, fostering collaborative behaviors, and impacting children's perceptions of friendship and reliability (Konijn & Hoorn (2020); Serholt (2019); Ahumada-Newhart et al. (2023))
Creativity Support	Social robots are employed as creativity support tools for children, promoting high levels of creativity, exploration of unique themes, and generation of creative ideas (Ali et al. (2021))
Musical Instrument Practice	Robots are utilized in supporting roles during musical instrument practice, providing encouragement and feedback to children at different learning stages, influencing their motivation and persistence (Song et al. (2021); de Souza Jeronimo et al. (2022))
Library Activities	Social robots serve as reading companions in libraries, facilitating children's reading participation as alternatives to group storytelling activities (Osawa et al. (2022); Yueh et al. (2020))
Collaborative Friendship Development	Research explores the use of social robotic technology to assist young children with collaborative friendship development, showing positive behaviors in conversational robot mediation (Kim et al. (2023); Escobar-Planas et al. (2022); van den Berghe et al. (2021); van Straten et al. (2023))

Language Learning:

Robots are employed as language learning assistants, demonstrating success in teaching foreign languages to children and adults. Demir-Lira et al. (2020) showed in their research that children successfully learnt a foreign language from a social robot as an assistant, as well as they learnt from a human teacher. Arar et al. (2021) researched the use of social robots in foreign language teaching and found that the use of social robots enhances the effectiveness of the educational process and significantly improves learning outcomes. Furthermore, given the facilities offered by the social robot through its support for foreign language learning to children, the authors recommend the use of social robots for improving the quality of learning outcomes and comfort in the schooling conditions. Sisman et al. (2018) also confirmed positive experience with robots in language learning. They highlighted that a social robot can assume the role of an assistant and the role of a peer. This is in line with Chen, et al. (2020) who found that children who interact with the robot in the role of an assistant learnt more target vocabulary words than children who interact with the robot. Finally, an interesting experience is related to gamified robot-assisted language learning done by Peura et al. (2022). They investigated the impact of a social robot on the learning outcomes and how the robot motivates and enhances persistence in learning. The results showed that learners' knowledge improved during the experiment and that pupils' active participation became a natural part of the learning process. It was also shown that the robot is perceived as a motivating factor producing improved learning in pronunciation, even without the novelty effect of the robot.

Computational Thinking and Robotics Education:

Robots are utilised in robotics education to cultivate students' computational thinking skills through interactions. Chalmers et al. (2019) delved into the effects of humanoid robots on the learning and engagement of students. Their findings underscore the positive influence of humanoid robotics technology on student engagement in the learning process. Through collaborative efforts, students not only honed their 21st-century skills—including creativity, critical thinking, communication, and collaboration—but also advanced their computational thinking and coding abilities. Notably, their curiosity reached new heights when tasked with the challenge of programming the robot to speak. Research on the effects on students and their conception of robots during long-term exposure to a robot in a project-based learning was investigated by LeTendre and Grey (2020). The research revealed both limitations and complexities in using social robots as interactive educational technology for young adolescents. While current technology hinders widespread deployment in public-school classrooms, well-designed interventions with social robots have the potential to motivate and engage students. Qu and Fok (2021) conducted a study aimed at fostering students' computational thinking through interactive experiences with robots in the realm of robotics education. Conducted during a summer camp, the study found a significant improvement in students' computational thinking skills. The duration of social interactions with the robot showed a notable correlation with this positive change, indicating that integrating robots into educational settings can effectively enhance students' cognitive abilities.

Children's Social and Emotional Development:

Social robots motivate children, encouraging engagement in activities, fostering collaboration, and influencing perceptions of friendship and reliability. In self-directed play, robots support friendships, contribute to self-expression, and enhance identity development. Konijn & Hoorn (2020) investigated the impact of a social robot on the learning process and, more specifically, the role of the robot's social behaviour in contributing to this educational impact. Results showed that social robots positively affect learning outcomes. Interestingly, the study found that the robot's more social behavior did not enhance the learning experience. The researchers focused on testing whether amplifying social cues had a beneficial impact on memory retention, rather than delving into relationship intricacies.

Establishing how children use robots for self-directed play activities and investigating the perspective and meaning of salient experiences, identify social structures, and identify processes in order to understand the meaning behind participant behaviour is an area that was investigated by Ahumada-Newhart et al. (2023). Their discovery revealed that children who believe in their ability to operate robots in remote school settings, along with a fondness for self-directed play, can use their robotic companions to foster general friendships. These children actively engage in play activities that contribute to self-expression and play a role in shaping their identity. Serholt (2019) explored children's perceptions of the child–robot relationship in an educational setting. Study showed that students who had interacted with a robot became more critical than their peers. The possibility of developing empathic relationships between robots and children based on affective data gathered about individual children.

Creativity Support:

Social robots are employed as creativity support tools for children, promoting high levels of creativity, exploration of unique themes, and generation of creative ideas. Game-based child-robot interactions are designed to afford creativity, demonstrating positive effects on children's verbal, figural, and constructional creativity tasks. Ali et al. (2021) conducted research in which social robots were presented as creativity support tools for children in collaborative interactions.Their observations showed that individuals engaging with the robot displayed heightened creativity, exploring unique themes and generating more creative ideas. The study demonstrated that the robot's creative display and its supportive structures positively impacted children's creativity in verbal, figural, and constructional tasks. This research contributes significantly to the development of game-based interactions between children and robots, emphasizing creativity facilitation. It also provides compelling evidence for the effectiveness of such interactions and offers valuable guidelines for designing social embodied agents to nurture creativity in young children.

Musical Instrument Practice:

Robots are utilised in supporting roles during musical instrument practice, providing encouragement and feedback to children at different learning stages, influencing their motivation and persistence. Song et al. (2021) investigated the impact of robots in different supporting roles (i.e., evaluative role versus non evaluative role) on children’s motivation in different learning stages in musical instrument practice. The results confirmed that children in different learning stages are more motivated with robots with different roles during practising. Robot roles have an impact on children’s persistence, the encouragement and feedback provided by the robot may reinforce the self-concept of the advanced players, which further improved their motivation.

Library Activities:

Social robots serve as reading companions in libraries, facilitating children's reading participation as alternatives to group storytelling activities. Children perceive robot companions as favourable and desirable reading partners, inducing social interaction during reading sessions. Study conducted by Osawa et al. (2022) was focused on the role of the social robot as a first-time learner in motivating children out of their social roles. Authors observed changes in children’s behaviour, such as spontaneous advertising activities, guidance from upperclassmen to lowerclassmen, collaboration with multiple people, and increased interest in technology.

The social robot as a reading companion to facilitate children’s reading participation, as alternatives to group storytelling activities in libraries, was investigated by Yueh et al. (2020). The outcomes of their study discovered that children held a more favourable and desirable view of reading with a robot companion compared to a human co-reader. The cognitive examination gave intriguing findings, highlighting that human and robot companions each played distinct roles in enhancing the children's language comprehension, with both types of companions yielding similar performance outcomes. Interestingly, on the emotional front, the robot co-reader stood out by eliciting more social interaction during the reading sessions, adding a unique affective dimension to the overall experience.

Collaborative Friendship Development:

Research explores the use of social robotic technology to assist young children with collaborative friendship development, showing positive behaviours in conversational robot mediation. Kim et al. (2023) investigated if social robotic technology could assist young children with collaborative friendship development. The authors found out that children showed liking behaviours in the conversational robot mediation, showed togetherness behaviours and agreement behaviour in the conversational robot mediation. Social robots need to be designed in a way that they are child-centred and collaborative because robot behaviours and collaboration paradigms affect children's perception about the robot. Escobar-Planas et al. (2022) found that cognitive reliability of the robot shapes the helping relationship between the children and the robot, while the robot’s expressivity impacts the perception of the robot's support ability and friendship.

Although the majority of analysed papers fell into one of the categories above, it needs to be highlighted that two papers reported the research in which it was investigated how children perceive robots. van den Berghe et al. (2021) studied child-robot interaction and found that children generally anthropomorphised the robot and a weak but significant correlation was established between children's increased anthropomorphism and their word knowledge. van Straten et al. (2023) conducted research on how children perceive and relate to a social robot that acknowledges its lack of human psychological capacities and machine status. The results of their research show that exposure to this information decreased children's feelings of closeness towards and trust in the robot. Children's tendency to anthropomorphize the robot mediated the effects of transparency on closeness and trust, while their perception of the robot's similarity to themselves only mediated children's feelings of closeness.

3.4. What kind of ethical and data privacy issues were raised?

The use of social robots in education raises several ethical considerations and data privacy concerns. As technology advances and social robots become more prevalent in educational settings, it is essential to address these issues to ensure the responsible and safe use of these devices. However, most of the analyzed papers do not even mention any kind of ethical or privacy issues.

Serholt et al. (2021) indicated ethical constraints that make it questionable whether leaving children alone with robots is a good idea in relation to their physical and emotional safety. They also emphasized the need for further studies on the ethical implications surrounding the child–robot relationship that could develop, i.e., the potential psychological implications for children who commit to helping a robot. Chen et al. (2020) also arguec it is important to develop best practices and ethical guidelines for the use of intelligent pedagogical agents for young children to help ensure they contribute positively to children’s developmental needs. However, they do not explicitly mention nor target any of them. In a study from LeTendre & Gray (2023) they want to answer how far do we want the education of our children to be delegated to machines, and social robots in particular? They argue that these concerns are largely derived from data with young children. How young adolescents react to, or form emotional attachments to robots, remains unclear. Therefore educators should carefully consider the ethical ramifications of exposing students to social robots when considering the educational objectives of robotics education.

In the end Serholt (2019) demonstrated that students who had interacted with a robot became more critical than their peers towards functions that are often argued to hold most potential in the field, i.e. the possibility of developing empathic relationships between robots and children based on affective data gathered about individual children. Taking these concerns seriously, it may be wise to proceed with caution in the endeavor to introduce emotion perceptive social robots in education on a wider scale, as some teacheres raised concerns about the emotional harm that could follow as children grow older and realize that their school holds emotional profiles on them.

4. Discussion

The study identified several key trends in the research landscape, emphasising the prevalence of the NAO robot in the context of primary and secondary schools. Here it should be noted that NAO is also very popular social robot in the context of preschool and in higher education (e.g. Tolksdorf et al. (2021), Connolly et al. (2022), Demir-Lira et al. (2020), van den Berghe et al. (2021), Velentza et al. (2021), etc.)

The range of participants varied widely, and the predominant focus was on primary school-age children. The common application domains included language learning, computational thinking, social and emotional development, creativity support, musical instrument practice, and library activities. Here it should be noted that language learning is also very frequently reported in the preschool environment (eg. Tolksdorf et al. (2021), Demir-Liraet al.(2020), van den Bergheet al.(2021), Kim et al.(2021), etc.)

In terms of research issues and constructs, the centre of interest for researchers was student-robot interaction and its connection with other constructs such as engagement, behaviour, and attitudes, learning experience and achievements, and 4C skills. Many papers (8) confirmed the relationship between student-robot interaction and behaviour and attitudes which is in line with studies in other fields of education. For example, Guggemos et al. (2020) investigated the acceptance of social robots by higher education students in the field of social sciences. The perceived characteristics of the social robot: trustworthiness, adaptiveness, social presence, and appearance, indirectly predict the intention to use a social robot for learning purposes. Kim et al. (2021) investigated the use of a social robot to moderate interactions among culturally and linguistically diverse children, with a focus on design challenges and solutions to facilitate positive peer interactions. They proved that children could benefit from their design principles of using social robots for flexible children's exploration, friend-like communication, tasks relying on familiar experiences while stimulating imagination, and use of children's native languages.

In terms of main findings, it should be noted that most of the research had relatively small samples, which means that some results should be confirmed by others. However, we can note that even 6 papers point out the relationship between student-robot interaction and engagement. Such a relationship was also noted in other educational fields. Connolly et al. (2022) researched using social robots in digital health for patient education and reported high levels of acceptance and engagement with this method of intervention. Findings from Chalmers et al. (2022) also showed that the robot could be used to enhance the curriculum, from introducing robotics, coding, and computational thinking to using the robot to engage students with foreign language and mathematics.

Confirmed relationship between enjoyment and student-robot interaction was also studied and confirmed outside the field of education by Demir-Lira et al. (2020) who showed in their research that preschool children expressed great excitement and enjoyment due to the social robot acting as an assistant, which is associated with the novelty and the anthropomorphic tendencies of the robot. Velentza et al. (2021) found that the social robot in the role of assistant increases the student's enjoyment. In their research, students had statistically significant higher scores in the enjoyment questionnaire in comparison with the human - teacher condition.

In the end, the relationship between student-robot interaction with motivation was also confirmed by Ekström & Pareto (2022) who explored teachers' perceptions of a learning activity based on learning-by-teaching where the robot was designed to act as a didactic tool and a social actor in preschool. They found that robot-based learning activities can contribute to learning, develop skills, increase children's metacognitive awareness, and especially can increase children's interest, motivation, and participation.

As it can be noted, there are commonalities between research interests in the context of primary and secondary schools and other educational levels. However, even though integration of social robots into educational settings presents promising opportunities, it also raises significant ethical and data privacy challenges. The main issue that should be underlined is that neither of the analyzed papers deal with those questions, although some of them highlight their importance. It was also noted in the review of educational robots conducted by Woo et al. (2021) who highlighted the insufficient consideration given to the considerable safety and privacy concerns affecting students and teachers. None of the studies they examined addressed potential threats posed by robots. Despite the lack of such research within our targeted domain, it can be noted that this topic has been of interest in other fields where social robots were used and can therefore provide guidelines for tackling those issue in the domain of primary and secondary education. For example, Boch et al. (2020) outlined that risks such as lack of transparency, data privacy issues, dependency on robots, reduced human interaction, and potential job displacement need careful consideration. These challenges underscore the necessity for responsible and safe use of social robots in education. Also, data privacy is a central concern, as articulated by Boch et al. (2020). Clear protocols must be established for data collection, processing, storage, and informed consent. Newton & Newton (2019) point out the need for a collective evaluation of the appropriateness of assumptions, values, and beliefs embedded in the robot's instructional approach. The management and secure disposal of collected data, whether by robots or human teachers, become critical elements in ensuring the privacy and safety of students and educators. The creation of specific regulations addressing new technological features that enable enhanced data collection further underscores the need for ongoing policy development. All the above issues raise the question of regulations and public policy formulations for social robots, which will be an important subject of study and research in the near future (Subramanian, 2017). Collaboration among educators, policymakers, developers, and privacy experts is crucial to establish clear guidelines and policies that prioritise students' well-being and rights (Boch et al., 2020).

5. Implications for researchers

Drawing from commonalities identified in the analysed papers, several points could be noted to assist researchers in shaping the future directions of research involving social robots in education. Here it needs to be mentioned that we also took into account the results from other research that were oriented towards usage of educational robots, but were excluded as they were identified as review papers.

First, some researchers underlined **limitations** of previous studies. In their review, Ao & Yu (2022) highlighted the primary limitation of their study on interactive behaviors and emphasized the need for considering unexplored factors. These unexplored factors encompass variations in robots, diverse roles performed by a robot, differences in participants, varying degrees of human teacher interference, distinct skills being taught, and variations in learning environments. Bonaiuti et al. (2022) emphasized the necessity for more extensive longitudinal studies in educational robotics and discuss limitations in the integration of robotics into school curricula. They found that only three articles reported experiences lasting beyond one year, with two targeting adults, school teachers, and computer science undergraduates, and one investigating a primary school class throughout a complete 5-year cycle. It is crucial to note that despite general institutional encouragement and increasing teacher interest, the integration of robotics into school curricula has not been systematically realized.

Next, Papadopoulos et al. (2020) stress the importance of comprehensive evidence to evaluate the potential of socially assistive robots, particularly in mathematics and science, and the need for further research to explore acceptance, feasibility, and ethical considerations.

Challenges and opportunities in Social Robotics are underlined by Wo et al. (2021) who underscore the necessity for "in the wild" studies to examine the legal, social, and moral implications of social robots on children, teachers, parents, and stakeholders. Their review noted a gap between ethics literature and real-world robot deployments. Despite a growing literature on the ethics of using social robots in education, they appeared to be disconnected with research deploying robots in real-world settings. The limited number of studies meeting the ideal conditions of allowing robots to interact with students "in the wild" also highlights the current generation of commercially available robots, such as NAO or Pepper, lacking sufficient programming for seamless integration into classrooms without substantial support and resource mobilization. Allocating resources for this integration may compromise support in other critical areas, introducing significant ethical considerations for administrators deciding whether to adopt this technology. Allocating resources for this integration may compromise support in other critical areas, introducing significant ethical considerations for administrators deciding whether to adopt this technology. Martinez-Roig et al. (2023) discuss limitations in their study on social robots in music teaching and provide insights into using social robotics, suggesting future research directions that could involve implementing social robots across various educational levels, providing diverse perspectives. Additionally, exploring students' experiences and perspectives with social robots could be a valuable avenue for further investigation.

Chou et al. (2023) in their systematic review identified **barriers and facilitators of robot-assisted education** in higher education, highlighting the potential benefits in engaging students effectively. They emphasize the need to address technological challenges and conduct randomized controlled trials in other learning environments using rigorous methodologies, to improve credibility and understand the barriers and facilitators better.

Finally, for future research, Sannicandro et al. (2022) recommend the establishing the link in teaching strategies between computational thinking and disciplines such as Learning Analytics or Instructional Design, which share interdisciplinary approaches and skills, along with the decomposition of complex tasks into simple actions; implementing interventions that involve collaboration among kindergarten and primary school children, secondary school students, and Digital Education degree candidates who act as guides and scaffolders.

6. Conclusion

This comprehensive review aimed to address various aspects of the use of social robots in primary and secondary education. Four primary research questions guided the investigation, focusing on trends, theoretical foundations, application domains, and ethical considerations. The findings shed light on the current landscape and implications for future research in the field of social robots in education.

The study identified several key trends in the research landscape, emphasizing the prevalence of the NAO robot in education. The range of participants varied widely, and the predominant focus was on primary school-age children. The common application domains included language learning, computational thinking, social and emotional development, creativity support, musical instrument practice, and library activities. These domains showcased the versatility of social robots as teaching assistants, peers, and companions, contributing to improved learning outcomes, engagement, and motivation among students. Both short-term and long-term studies were conducted, highlighting the diverse duration of educational activities involving social robots.

Ethical considerations and data privacy concerns associated with the use of social robots in education identified risks such as lack of transparency, data privacy issues, dependency on robots, reduced human interaction, and potential job displacement. Collaboration among educators, policymakers, developers, and privacy experts is therefore needed to establish clear guidelines and policies prioritizing students' well-being and rights.

Despite the progress in the field, certain limitations were acknowledged, such as sample size constraints, technological challenges, and the necessity for more extensive longitudinal studies. The collaborative efforts of researchers, educators, policymakers, and industry professionals were emphasized to address these limitations and propel the responsible and effective integration of social robots into educational environments.

In conclusion, this review provided a comprehensive overview of the current state of social robots in primary and secondary education, offering valuable insights for researchers, educators, and policymakers to navigate this evolving field responsibly and ethically.

The multifaceted nature of the findings sets the stage for further exploration and innovation in the intersection of technology and education, highlighting the need for longitudinal studies to explore the impact of interactive behaviors on learning performance, since researchers often use 'wizard of oz' techniques for short-term research to make robots appear more interactive than their current programming allows (see for example LeTendre & Gray, 2023). Such exploration should particularly consider how these behaviors are influenced by various factors, such as students' prior knowledge and age, teachers' experience and motivation, the type of robot used, as well as other technical and organizational factors. In addition, a series of investigations should be carried out (see for example Ko'kiyev Boburmirzo Baxodir o'g'li, 2023) throughout at least 8-10 weeks to properly investigate the preferences and engagement levels of children with different forms of robots and the influence of the above mentioned factors in child-robot interactions.

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