A Systematic Review of Socially Assistive Robots in

Pre-tertiary Education

Abstract

With rapid advances in Artificial Intelligence (AI) over the last decade, schools have increasingly employed innovative tools, intelligent applications and methods that are changing the education system with the aim of improving both user experience and learning gain in the classrooms. Even though the use of AI to education is not new, it has not unleashed its full potential yet. Much of the available research looks at educational robotics and at non-intelligent robots in education. Only recently, research has sought to assess the potential of Socially Assistive Robots (SARs), including humanoids, within the domain of classroom learning, particularly in relation to learning languages. Yet, the use of this form of AI in the field of mathematics and science constitutes a notable gap in this field. This study aims to critically review the research on the use of SARs in the pre-tertiary classroom teaching of mathematics and science. Further aim is to identify the benefits and disadvantages of such technology. Databases' search conducted between January and April 2018 yielded twenty-one studies meeting the set inclusion criteria for our systematic review. Findings were grouped into four major categories synthesising current evidence of the contribution of SARs in pre-tertiary education: learning gain, user experience, attitude, and usability of SARs within classroom settings. Overall, the use of SARs in pre-tertiary education is promising, but studies focussing on mathematics and science are significantly under-represented. Further evidence is also required around SARs' specific contributions to learning more broadly, as well as enabling/impeding factors, such as SAR's personalisation and appearance, or the role of families and ethical considerations. Finally, SARs potential to enhance accessibility and inclusivity of multi-cultural pre-tertiary classroom is almost unexplored.

Keywords: Early years education; Elementary education; Secondary education; Improving classroom teaching; Socially assistive robots

1. Introduction

The use of Artificial Intelligence (AI) as a new emerging technology is infiltrating our lives, and governments around the world are setting initiatives that will address the appropriate harnessing of AI and its impact on training, lifelong learning, and education more broadly (Aoun 2017; Baker, Smith, and Anissa 2019; Tuomi 2018; UK Government 2018). From as early as the late 20th century, educational theorists, such as Papert (1980), acknowledged the potential benefit of including technology in classroom teaching. In fact, Papert's learning theory of constructionism – along with the models of active learning, learning by design and hands-on experiential learning (e.g. building and programming a robot) – has established itself as the main pedagogical theory in the field of robotics in education (Alimisis 2013). Furthermore, Vygotsky's kindred theory of social constructivism, with its stress on cooperative learning based on interaction (Mevarech and Kramarski 1993), is similarly widespread as robotic applications go beyond the growing robot-based learning activities (Karim, Lemaignan, and Mondada 2015; Pachidis et al. 2019) and take the form of tutors in classrooms, tools, or peer learning companions (Mubin et al. 2013). Increasingly, innovative tools, intelligent applications and methods are changing the education system with the aim of improving both user experience and learning gain in the classrooms. Even though the use of AI to education is not new (e.g. use of virtual reality into learning), it has not unleashed its full potential yet (Luckin et al. 2016).

A form of AI in education is the use of social robots. There is a clear distinction between Socially Assistive Robots (SARs)/Socially Assistive Humanoid Robots (SAHRs) and robots. The term 'robots' captures any type of robotic kits, programmable robots, and robotic platforms used in education: from kits that can only be used to describe and teach a single function (e.g. reaction to sound) to robotic kits that students can build and program or to LEGO Mindstroms (Karim et al. 2015). In general, the term refers to any machine that is

programmable by a computer and can carry out automatically a series of actions. In contrast, SARs/ SAHRs are robots embodied as pets, toys, or humans, and are programmed to interact with users through engaging in social interaction, with the involvement of gestures, speech, emotional expression, and other actions. SAHRs can be considered as SARs which in addition adopt the appearance of humans (Feil-Seifer and Mataric 2005; Erich, Hirokawa, and Suzuki 2017). The use of SARs sits within a growing acknowledgement of the promise of technology in the education of young people, and several governments have highlighted the potential benefits of it (Reuters 2018; Siddique 2018). In the UK, a £10 million backed strategy for the use of technology in education has set several aims, including reducing teachers' marking workload and improving their training opportunities to promoting use of innovative technology for students with additional needs and learning disabilities (Department of Education 2019). Further recognised benefits of the use of technology in education include providing support in teaching practices, lifelong learning, and administration processes (Department of Education 2019).

Some evidence is available in relation to the use of robots in education. Benitti (2012) and Toh and colleagues (2016) found that the use of robots as an educational tool can have positive outcomes in the areas of mathematics and science learning. For example, the use of robots can lead to an improvement in knowledge regarding mathematical concepts such as multiplication, increase student's interest for engineering or develop their ability to understand scientific processes (Cristoforis et al. 2013; Highfield 2010; McDonald and Howell 2012; Toh et al. 2016; Varney et al. 2012). Similarly, Whittier and Robinson (2007) reported that non-English speaking students had improved their comprehension of scientific concepts as a result of using a robot and the knowledge of physics-related topics was found to been enhanced by the use of robots (Mathers et al. 2012). More broadly, the use of robots in education has demonstrated positive influence on the behaviour and development of students,

especially in the areas of problem solving skills (Barak and Zadok 2009), teamwork practice (Varney et al. 2012), and collaboration (Hong, Yu, and Chen 2011), increased motivation to learn (Kubilinskiene et al. 2017), and in enhancement of participation (Rusk et al. 2008).

Less solid is the evidence base around the use of SARs in education, due to this form of technology being emergent. A recent review focused on learning a first or second language, and found that SARs have a positive impact on students' learning gain (van den Berghe et al. 2019). Another recent review focused on young children up to the age of eight years and found that very few studies focused on early language and literacy learning. The limited available evidence showed the positive support that social robots can have on early language learning, but the author urged for more research in the field (Neumann 2020). Similarly, there is a major gap of evidence in the use of SARs/SAHRs in the areas of maths, science and STEM with no available reviews on this topic. For this reason, this systematic review is timely and necessary in as much as it aims to map and assess the existing research about the knowledge around utility and conditions for implementation of SARs in pre-tertiary education as well as the gaps in research that may inform, motivate, and inspire future projects to address them. This study arises also from conversations that the authors had with pre-tertiary schoolteachers, administrators, and inclusion specialists in England about their interest in deploying artificially intelligent robots, such as SARs/SAHRs, in their schools, specifically for their mathematics and science classes. In fact, evidence indicates that early mathematics skills is a better predictor of math and literacy attainment in later years than early literacy skills: the Early Childhood STEM working group, for example, is advocating for the inclusion of STEM skills in early childhood education since 2016 (Bowman et al. 2017). Finally, another trigger for this study has been the current evidence on the shortages of teachers that increases the need to consider different AI solutions in classrooms (Edwards and Cheok 2018; Sibieta 2020).

The distinct focus of the present review is the use of SARs, including SAHRs, in the pre-tertiary classroom teaching of mathematics and science. A broader aim of the review is to investigate the current state of knowledge and evidence on the contribution of SARs in pre-tertiary education and hopefully stimulate further discussion. Specific research questions include: 1. What is the current state of knowledge and evidence on the contribution of SARs to learning and teaching in pre-tertiary education? 2. How are SARs being utilized and deployed in pre-tertiary education to support learning in mathematics and science? 3. What specific contribution has/can SARs make to learning in mathematics and science? 4. What can the use of SARs contribute to the accessibility and inclusivity of students from diverse backgrounds in pre-tertiary education?

2. Material and methods

2.1 Search Strategy

A structured search strategy was created for use on various bibliographic databases with key words used according to each database's specific requirements. Databases were searched between January and April 2018. Specific key words were included: "socially assistive robots", "humanoid robots", "pre-tertiary education", "widening participation", inclusiv*, divers*, cultur*, accept*,access*, engag*, motivat*, interest*, learn*, teach*, Math*, Scien*, "SAHR" and "SAR". These were used in combination with Boolean expressions "AND" and "OR". The electronic bibliographic databases searched were: Education Research Complete via EBSCO host; Education Journals Collection (Taylor and Francis); Social Sciences Citation Index; 2017 MEDLINE via OVID; Embase via OVID; Science Citation Index; IEEE Xplore digital library; PsycINFO; Google Scholar; European Commission and Eurobarometer. Additional searches were also conducted: ACM Digital Library, Computer Source Lecture Notes in Computer Science; Science Direct. The

references of eligible reports and key review articles were examined for any additional relevant studies. The search was limited to the previous 15 years since the field of social robotics emerged in the beginning of the century.

All records were uploaded into RAYYAN software (Ouzzani et al. 2016), which was used by two researchers for the process of de-duplicating, and independently screening, and selecting the studies based on pre-specified inclusion criteria. Disagreements and uncertainties about eligibility of studies were discussed with a third researcher when necessary and a final decision was based on consensus. Fig. A.1 summarizes the selection of studies in accordance with PRISMA guidelines (Moher et al. 2009).

2.2 Selection Criteria

In view of the likely paucity of potentially eligible studies related to this specific topic, we considered experimental designs (randomised controlled trials) and other study designs (non-randomised trials, observational, cohort, case-control, and qualitative). Editorials, conference abstracts, opinion pieces, studies not published in English and studies in settings outside of pre-tertiary education were excluded. The target population included the stakeholders who were part of the procedure of implementation of SARs in pre-tertiary education (e.g. students, staff and parents). Due to the lack of a uniform definition of SAR, any study which used a social robot that assisted users in tasks through engaging in some type of social interaction was included in the study, irrespective of the appearance of the robot. Although this review has a focus on Mathematics and Science, studies looking at other subject areas such as languages were also included to address the question of the current knowledge and evidence regarding the use of SARs in pre-tertiary education. We opted for a specific search strategy (Gough and Richardson 2018) focusing on studies that used social robots in pre-tertiary education whilst not excluding studies based on methodology.

2.3 Assessment of Risk of Bias and Quality of Included Studies

The quality of all included studies was assessed using the Cochrane Collaboration's tool for assessing risk of bias (Higgins et al. 2011) and the critical appraisal for public health (Heller et al. 2008). According to Newman and Gough (2020), there are different ways in assessing quality of studies in educational research and we opted for two well established and widely used tools. Both tools were completed for each study by one researcher (Table B.1). The research team decided that two additional researchers assessed bias and quality of two studies independently in order to ensure the validity and reliability of this process. Inconsistencies were discussed and consensus decisions reached.

2.4 Data Extraction and Synthesis of Results

After an agreement between two researchers on the data extraction form, study details and outcome data were extracted by one researcher. This process was further validated through data extraction of four of the included studies by additional two researchers independently. Data extraction included the type of study/design, date of publication, main objectives, country and specific setting (i.e. primary schools), intervention (i.e. type of SAR), sample and characteristics of participants, outcome measures, primary (i.e. educational progress in mathematics and science) and secondary (i.e. learners' engagement, learners and teachers' satisfaction, accessibility and inclusivity) outcomes of the review.

The heterogeneity of the studies included in this review did not enable a standard quantitative synthesis (i.e. meta-analysis) to be performed. Instead, an inductive narrative synthesis of the results was conducted and presented in the form of a summary table (Table B.2) and figure (Figure A.2). Based on the extraction forms and the summary table, studies' results were critically discussed and weighted by three researchers following a meta-aggregative approach with the aim of identifying descriptive categories, and sub-categories,

to which results could be assigned based on evident similarity (Munn, Tufanaru, and Aromataris 2014). Any uncertainties were resolved via a consensus-based decision.

The protocol for this systematic review has been registered and published on Research Registry (ID: reviewregistry544, date of registration June 8, 2018). Ethics approval was not required for this review.

3. Results

3.1 Search Results and Characteristics of Included Studies

The data extraction table presents the characteristics and outcomes of all of the included studies (Table B.2). The dominant theoretical and conceptual backgrounds of included studies (n=9, 43%) appear to be social interactionism and constructivism, where collaborative, active, and personalised learning are often quoted, in some cases explicitly referring to a Vygotskian framework (Study 1, 3, 4, 5, 6, 8, 9, 18, and 21 in Table B.1). Eight studies (38%) do not make explicit their theoretical framework (Study 2, 10, 11, 12, 16, 17, 19, and 20), while the remaining 4 studies adopt other specific approaches to learning (Study 7, 13, 14 and 15 in Table B.2). Post-experimental data were collected and analysed from a total of 1333 participants, most of which were students (99%, $N = 1320$) and the remaining few, 1%, were teachers ($N = 13$). Not all studies detailed the gender of participants but of the 14 studies that did, a total of 237 participants were male and 351 were female. The nationality of the total sample is as follows: 432 Japanese; 402 Taiwanese; 190 Spanish; 92 Iranian; 83 UK; 79 USA; 38 Israeli; 10 Italian; 6 Swedish. Overall mean age of participants was 8.1 years. All studies took place in a learning classroom within the respective educational institutes (i.e., kindergarten, elementary school etc.).

3.2 Quality of studies.

Studies graded as low quality with many studies exposed to biases associated with quasi-experimental and cross-sectional designs (Table B.1). Major issues included the lack of

a comparator group and /or the lack of baseline measures (e.g., Study 4, 5, 6, 8, 9, 10, 14,15, 19 and 20 in Table B.1). Small sample sizes (e.g., Study 6, 8, 9, 15, & 18 in Table B.1 and B.2) with fewer than 20 participants and not reporting ethics information, the study protocol or fidelity checks were additional identified issues.

3.3 Narrative Synthesis

Largely reflecting on the primary and secondary outcomes, the evidence reviewed in this systematic review has been meta-aggregated and synthesised along the four categories of learning gain, user experience, attitude, and usability. We also found that these categories are encompassed by a transversal factor in the use of SARs in education, which is personalisation. Thirteen sub-categories have been identified and presented below under each category. Sub-categories are either highlighted in bold in the text or provided in sub-headings. For further synthesis, results of this study are visually represented as a circle made of four elements corresponding to the four categories, and relative sub-categories (Fig. A.2). The circular shape is to emphasise that categories are interconnected and mutually reinforcing, and to show how they all have the potential to be significantly and positively enhanced the more the SAR can offer personalised, tailored interaction and feedback during learning activities (Fig. A.2). Many of the studies reviewed below covered more than one, if not all, the four categories of gain, experience, attitude, and usability. Equally, sub-categories may cross one or more studies.

3.3.1 Learning gain.

Learning gain in mathematics and science. The impact of SARs on learning gain has been explored within 10 of the 21 studies included in this review (Study 1, 3, 11, 12, 13, 14, 15, 16, 17 & 18 in Table B.2). Only 2 of these 10 studies however, considered learning gain in the domain of mathematical related concepts. Keren & Fridin (2014) reported an improvement in geometric thinking and metacognitive tasks whilst kindergarten children

interacted with KindSAR, who guided them to complete some screen-supported tasks. This study suggests the positive impact of a complex, **multi-sensorial interaction** provided by the SAR. A similar combination of screen- and SAR-supported tasks is used in Baxter, Ashurst, Read, Kennedy, & Belpaeme, (2017) who found learning gain in the domain of mathematics, regardless of personalisation of the SAR. Only 1 of the 10 studies explored learning gain in relation to scientific topics. Jones and Castellano (2018) specifically looked at the subject of physical geography and reported evidence of learning gain, regardless of personalised support, with the SAR which introduced tasks, provided domain tutoring, and performed motions throughout the session, pointing to the importance of **verbal and non-verbal communication.**

   Learning gain in language ability. Learning gain in the domain of language ability was the focus for 7 of these 10 studies. The majority of studies focused on learning English and only one study on learning Mandarin, but in general the results were positive. To learn Mandarin, a group of preschool children were supported by the iRobiQ – which provided a **multi-sensorial experience of verbal and non-verbal communication** by broadcasting sounds, expressing human-like emotions and providing a touch screen. The intervention group improved to a greater degree in the specific areas of word recognition and story retelling ability compared to children who were supported by the tablet alone (Hsiao et al. 2015). Studies that examined learning English as a second or first language found consistent results. Mazzoni & Benvenuti (2015) reported improvement in the learning of English among preschool children and this was greater for children who interacted with the robot which provided **verbal and non-verbal guidance**. Similarly, Kory-Westlund, Jeong, et al. (2017) demonstrated learning gain in the form of word learning supported by as SAR offering **multi-sensorial, non-judgmental support**. Minoo Alemi, Meghdari, & Ghazisaedy (2014) also reported results that strongly supported the effectiveness of using SARs to assist in the

teaching of English words as a second language, as the robot group learned and retained more words whilst also learning faster. In addition, children who interacted with a SAR performed better in the specific domain of English reading compared to those who were assigned to the control group (human teaching assistant), suggesting that the **non-judgmental** presence of the robot help dis-inhibit children's expression (Hong et al. 2016). Less convincing results were found in a study that examined the effect of Robovie robot which was put into student classrooms (Kanda et al. 2004). Results revealed that learning gains were modest and that children with a higher baseline of English knowledge were more successful. Another important finding was that most children reduced their interaction time with the robot within the first week, and learning gain was associated with those who maintained interaction with the robot during the second week. A study by Kory-Westlund, Dickens, et al. (2017) investigated if children's attention to **non-verbal social cues** such as gaze would be influenced by the type of interlocutor (human or robot) during a word learning task. Results highlighted the impact on performance by the spatial distinctiveness of **non-verbal orientation cues**.

3.3.2 User experience.

Abundance of literature has demonstrated how enjoyment leads to greater motivation and engagement in learning (Chen, Chen, and Liu 2010; Kirikkaya, Iseri, and Vurkaya 2010). The use of SARs as learning companions can increase the enjoyability of learning activities via novel and fun modalities of interaction. Thirteen (62%) of the studies included in this review reported findings related to the experience of interacting with a SAR during learning activities (Study 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 17 & 21 in Table B.2). Overall, the evidence gathered indicates that pre-tertiary students enjoy the interaction with the robot, and this enjoyment in turn positively impacts on their motivation to learn.

User experience and motivation. 'Motivation' is here conceived in a broad way as to encompass a number of elements that many of the studies in this review have considered, such as engagement, attention, concentration, participation, and interest. Almost the totality of studies referred to this domain, more or less explicitly, since motivation is a crucial element in learning. Evidently, in a way, fun, curiosity and connection feed into motivation, for which four studies have been found particularly relevant.

Jones & Castellano (2018) examined whether an adaptive self-regulated learning offered by a SAR, together with a domain scaffolding, would lead to an increase in self-report of motivation. Findings suggested that both control and experimental groups significantly improved their self-regulated learning skills attitudes with no significant difference between the two groups. However, in the experimental condition (SAR) the less able students had a more significant increase than in the control. Albeit the authors of this work do not discuss in detail this finding, this seems to indicate that SAR can be particularly useful in engaging students with lower levels of learning performances. Students' engagement was enhanced with the use of SAR and especially their interest in the science class (Hashimoto, Kato, and Kobayashi 2011), but age-dependent differences in interest, motivation, and concentration between elementary school and university students in their twenties were found. Elementary students showed greater levels of concentration and participation than their older counterpart. The younger children declared to have had a good time in the class, with a significantly different score from their older counterpart, and to want to participate again. Younger children felt also more familiar with the robot, albeit perceiving it less uncanny than the university students. Similarly, children's learning behaviours which are indicative of motivation and engagement, such as gazing, bidirectional interaction, reading or singing, and replying to questions, were significantly more frequent in the group interacting with a SAR compared to those children working on a tablet-PC (Hsiao et al.

2015). In addition, Fridin (2014a) reported positive interaction levels by young children as measured by eye contact and an emotional factor based on facial, bodily, and vocal expressions of emotions in response to the robot's very first appearance. The only negative experience occurred when the robot fell down and the children felt fearful. This finding is consistent with existing evidence where it is established that SARs' technical problems are an important barrier to their implementation (Anonymous 2020). In Fridin (2014a), a correlation was found between child's personality, and interaction and performance measures. For example, high scores on child's activity levels and interpersonal communication, the higher the scores on level of interaction with the robot and completion of motor and cognitive tasks. These results speak, among others, to the importance of personalisation in the child-robot interaction in learning, and to the relevance of designing personalised motivation strategies tailored onto different types of personalities and in support of diverse learning styles.

User experience and fun. Fun – intended as playfulness, joyfulness, enjoyment, and pleasure – is particularly explored in four studies. Wei, Hung, Lee, & Chen (2011) focused on the dimension of fun, articulated in terms of joyfulness and hedonic learning atmosphere and found that almost 92% of the students felt happy, and "overall learning atmosphere was hedonic" in 100% of participants. They concluded that, along with the hands-on practicing and the appropriate feedback, joyful learning with a SAR had a positive influence on learning motivation. Friendliness was crucial to the personalised mode of the SAR in the study Baxter et al. (2017) which showed that children learnt better on certain tasks when interacting with a personalised robot. The robot's deployed friendliness with the children added an element of pleasantness and comfort to the interaction during the learning activities. Examples of verbal interaction in personalised condition consisted in greeting the student by name, welcoming them back, providing friendly encouragement and correction. Instances of non-verbal features in the personalised condition included a socially responsive gaze, anticipatory reaction, and

touchscreen-oriented movements together with life-like posture movement of head and arms. Furthermore, the robot's pleasantness resulted in playful interactions that reduced student's anxiety while learning (Alemi, Meghdari, and Ghazisaedy 2015). The robot-student interaction was perceived as non-judgmental, and therefore reduced the fear to make mistakes. Furthermore, in this study, the SAR precisely played the role of a student who can make mistakes, and this triggered – the authors argued – empathic feeling contributing to "inhibit affective filters" when learning a foreign language in classroom (Alemi et al. 2015). Only one study presented mixed results in regard to joyfulness (Chang and Chen 2010) where self-reported joy showed a decrease in the SAR group, but the video analysis contradicted this finding with students increasing smiling (as indicative of enjoyment) in the same group.

User experience and connection. Connection is a subtle process, difficult to observe and measure in general, and even more in children. M. Alemi et al. (2015) argued that their positive results were due to an empathetic response to the robot. Three studies elaborated further about connection and looked into children's emotional engagement (Chen, Quadir, and Teng 2011; Fridin 2014b; Kory-Westlund, Jeong, et al. 2017). Fridin (2014b) found that children's emotional responses were significantly correlated with the emotional content in the text of the stories as well as greater when listening to the more emotionally affecting narration. This suggests that the storytelling robot successfully promoted children's emotional involvement in the learning process. The humanoid robot told the story, expressing emotions both verbally and bodily, and simulating a human-like shift of attention to different children. In addition, the human-like features of the robot in the study by (Chen et al. 2011) that mimicked real life interactions contributed to having the students feeling familiar and comfortable, and progressively confident to speak in English. Kory-Westlund, Jeong, et al. (2017) looked into children's concentration, engagement, surprise, and attention during a storytelling task. In the expressive storytelling, the robot's actively read and interacted with

the children using a voice characterised by a wide range of intonation and emotion. Differently from the other two studies around storytelling (Fridin 2014b; Hsiao et al. 2015), in this work the SAR is not humanoid, rather a teddy-like robot designed for educational activities with children. Children's facial expressions were recorded and analysed, and it was found that children in the expressive conditions showed significantly higher mean levels of concentration, engagement, and surprise, than children in the non-expressive condition and displayed more facial expressiveness throughout the whole session. The authors concluded that the children could identify more with the expressive robot.

User experience and curiosity. Curiosity and fascination are naturally higher in children, and this can be particularly evident when placing a SAR in a classroom of pre-tertiary children. Young students seem to be attracted by a learning companion who is not fully alive, and which stands midway between being an alter ego of the teacher and a funny peer. Even though the concept of curiosity was not specifically investigated, researchers in two studies especially commented on curiosity. Chang, Lee, Chao, Wang, & Chen (2010) argued that better learning occurs because humanoid SARs ignite greater engagement and motivation because they are a source of curiosity and fantasy; facilitate comprehension due to their mimic faculties and because they can support conversation in ways perceived as non-judgmental by the children. Z.-W. Hong et al. (2016) utilised a specific tool to measure post-intervention learning motivation in their study, and of relevance is that the attention sub-scale emphasizes that an instructional material in a class must gain and sustain a learner's curiosity, enthusiasm and interest.

3.3.3 Attitude.

Very few studies have explored children's attitudes towards robots. The already covered study by M. Alemi et al. (2015) tested the use of robots in teaching English among Iranian girls, and reported the students' positive attitudes towards the use of robot as a

teaching assistant. In addition, students expressed less classroom anxiety when a robot was used in the language teaching compared to usual practice (corroborating the positive effect of a **non-judgmental presence** highlighted above). The students' general attitudes were measured by a modified questionnaire originally developed by Vandewaetere & Desmet (2009), which focused on attitudes related to the effectiveness of the robot, the added value of having the robot in the classroom, and the degree of inhibition/exhibition towards the robot. The majority of students strongly agreed with the statement that they liked learning English with the help of the robot and 70% of student strongly agreed with the statement that learning with the help of the robot improved their English greatly. Hsiao et al. (2015) captured children's attitudes towards the use of the robot on reading. Children reported that they liked more reading books with the robot (73%) than reading e-books (27%). Fernández-Llamas, Conde, Rodríguez-Lera, Rodríguez-Sedano, & García (2018) used two questionnaires to assess students' attitudes towards robots. Firstly, they found that the majority of students did not feel nervous or strange standing next to a robot or talking to a robot, and they were not worried of the future role that robots could play in the society. However, they found differences according to **children's age** (i.e. primary and secondary students). A higher percentage of secondary school students said 'yes' to the questions: 'I would hate the idea that the robots could think' or 'I feel that if I depend on robot too much something bad might happen'. In addition, fewer secondary students said 'yes' when asked if they felt relaxed talking with robots compared to a higher number of younger primary students. Regarding attitudes towards communicating with the robot overall students do not seem to worry about the behaviour of the robots during interaction, but again age differences were observed with younger students worrying more than older students. Similarly, Hashimoto et al. (2011) reported **age differences** on robot acceptance. They found that younger students (elementary vs university) were feeling more familiar to the robot and less spookiness around. Finally,

students' perceptions were tested after having a humanoid robot available in their science class, and a positive relationship was found between their perceptions of the robot's pleasantness and the amount of questions they asked the robot. The higher the level of perceived **pleasant characteristics**, the higher the interaction with the robot with perceived likability having the stronger relationship compared to perceived enjoyment, and perceived friend-likeness of the robot (Shiomi et al. 2015).

3.3.4. Usability.

Usability refers to the practical and logistical elements of implementing the use of a SAR within a classroom. The level of usefulness can be subjectively determined, whilst objective factors, such as **cost** and **safety**, can also act as barriers or enablers to usability. Of the 21 studies included in this review, 5 addressed the usability of SARs in pre-tertiary education (Study 4, 5, 6, 19, 21 in Table B.2). Wei et al. (2011) reported that children found the robotic system both useful, in terms of facilitating learning, and easy to use. In contrast, the remaining 4 studies that commented on usability of SARs addressed barriers as opposed to the positive factors. Chang & Chen, 2010 showed that whilst effectiveness, efficiency, ease of learning, memorability, and interest were rated positively, there were concerns in the domains of usability and safety. Concerns surrounding usability were because the robot's price was considered **too expensive** for elementary education budgets, and safety concerns were based around fears over the **robot's resistance**, in term of children potentially damaging it, rather than the other way around. Another study that expressed concerns over the **cost** of implementing a SAR for English learning examined the integration of a robot with a computer and a book to create a pleasant learning environment (Chen et al. 2011). Findings suggested that this integrated system was easy to use. However, both the English teacher and principal expressed apprehension over the **cost** of implementing the SAR integrated system. The former also noted that the novelty of the system would decrease over time. The cost of

the robot was highlighted again by a study that explored the optimal use of a SAR for promoting the teaching of language (Chang et al. 2010). Results revealed that teachers had concerns about the **cost** of the robots and the complexity of using them. Moreover, teachers commented on limitations of the robot which could be improved including; movement, voice variety, and lack of emotion. Despite these concerns, teachers maintained high expectations for using robots in class. Finally, one study focused entirely on the usability of a SAR in pre-tertiary education by examining a specific barrier to the implementation of SARs – breakdown in interactions between child and SAR (Serholt 2018). Results revealed four potential causes for breakdown in interaction: (a) difficulties around the robot's initial engagement and adapting to misunderstandings; (b) robot's use of unclear and irrelevant scaffolding; (c) lack of consistency and fairness; and (d) technical problems with the controller. Hence, this study showed that there are a number of factors that need to be considered when implementing the use of SARs within a classroom.

4. Discussion

Findings from our review were grouped into four major categories synthesising current evidence of the contribution of SARs in pre-tertiary education: learning gain, user experience, attitude, and usability of SARs within classroom settings. Overall, the use of SARs in pre-tertiary education is promising, but studies focussing on mathematics and science are significantly under-represented. Further evidence is also required around SARs' specific contributions to learning more broadly, as well as enabling/impeding factors, such as SAR's personalisation and appearance, or the role of families and ethical considerations. Finally, SARs potential to enhance accessibility and inclusivity of multi-cultural pre-tertiary classroom is nearly unexplored. Below further discussion in relation to our findings is outlined

Our review revealed that studies focussing on mathematics and science are significantly under-represented among the SAR literature. Instead, language related learning gain, primarily English, encompassed most of the studies looking at learning gain in this review. Furthermore, the only study that looked at science concepts focused on Earth sciences rather than the common science topics of physics, biology, and chemistry. This is particularly surprising considering the vast amount of previous research that has shown the positive effects of the use of machine-like robots on mathematics and science learning (Cristoforis et al. 2013; Highfield 2010; Mathers et al. 2012; McDonald and Howell 2012; Varney et al. 2012; Whittier and Robinson 2007). Moreover, in the same field of non-socially assistive robots, a review by Benitti (2012) found that 80% of the studies related to topics of mathematics or physics. Thus, there appears to be a discrepancy in the focus of subjects learnt between studies using SARs and studies using traditional, machine-like robots. From a functional perspective, this may make sense as the non-socially interactive robots may be more suited for the learning of mathematics and science, whilst social interaction and engagement may be considered more suitable for subjects such as English and humanities. For example, a SAR can influence the development of English language skills by saying and acting out particular words and commands (Chang et al., 2010). However, we suggest that the lack of studies exploring the use of SARs in terms of mathematics and science learning gain is not evidence against using SARs for this purpose. Rather it could be argued that the interactive nature of SARs could enhance the learning of mathematics and science.

Personalisation of the robot's interaction to the user, in this case the child's individual learning style and/or psychological profile, has been found important for maintaining child's engagement, except in two studies (Study 3 and 13, Table B.2). Fridin (2014b) argued that it is possible for a robot to achieve what potentially is very difficult for a human, that is to provide tailored feedback to each child's profile and learning style. There is evidence that the

higher the personalisation, the higher the chances to keep students engaged (González, Toledo, and Muñoz 2016; Tsiakas, Abujelala, and Makedon 2018). Furthermore, sophisticated personalization of more and more autonomous self-learning SARs could assist in contrasting the natural decay of children attention as well as of the novelty effect. The effect of novelty of SARs in a classroom makes children curious and attracted by the robot in the first place, but tends to decline with familiarisation with its presence (Ahmad, Mubin, and Orlando 2017; Oh and Kim 2010). However, high level of personalisation requires that robots have sophisticated skills (e.g., autonomy, self-learning, complex facial and voice recognition systems, etc.). Therefore, the more AI technology progresses, the more research will be needed around tailored educational interaction responding to different personalities, special needs, and, crucially cultural backgrounds of students, all of which can address the issue of inclusivity. Significantly, the students' cultural background was not considered nor discussed in any of the studies we reviewed.

Roboticists have acknowledged the importance of culture and essential work is being conducted in order to better understand how culture influences the human-robot interaction (Blanchard and Allard 1AD; Endrass et al. 2013). In a recent review of the literature on humanoid robots in healthcare, evidence was found to suggest that a person's cultural background influences many behaviours towards robots (Anonymous 2018). Culture influences the acceptance levels of robotic technology, and it also influences the user's preferences towards robots, including the appearance of a robot (Broadbent, Stafford, and MacDonald 2009). In addition, culture has an impact on general attitudes towards the use and application of robots, and the robot's appropriate cultural capabilities of verbal and non-verbal communication are always positively received by users (Trovato et al. 2013). Cultural differences in human-robot interaction have also been reported in studies conducted with children. Pakistani and Italian children have been found to be more expressive and sitting in

close proximity when interacting with a robot compared to Dutch children who chose to sit further away from the robot (Neerincx et al. 2016; Shahid et al. 2011). Brown, Schreiber, & Barbarin (2018), in their recent chapter, highlighted the importance of teaching mathematics in a culturally appropriate way in order to engage ethnic minority children and especially African American children. They also spoke for the inclusion of the family and for viewing the child as the centre of different interconnecting systems. The influence of culture is crucial when considering the use of SARs in student classrooms and their involvement in teaching. This is reflected onto the fact that culture is increasingly considered when designing robotic technology, AI technology, and educational interventions (Cramer and Bennett 2015; Fallon, O'Keeffe, and Sugai 2012; Woolf et al. 2013).

Human-robot interaction is influenced by the robots' characteristics for example its appearance (eyes, arms, etc), but also the way it acts. Issues of the appearance of the robot have been identified with research suggesting, for example, a preference towards anthropomorphic humanoid robots for teaching (Belpaeme et al. 2018; Ryu, Kwak, and Kim 2007). A preference for anthropomorphism appears consistent with the dominant educational theoretical framework of the use of SARs in education (i.e. social constructivism and constructionism which are based on social interactions and collaborative, active, and personalised learning) that we found across the studies, and that others have also showed (Neumann 2020). It has been argued that children learn better in particular due to the fact that SARs: ignite greater engagement and motivation, thanks to playful interaction; are a source of curiosity and fantasy; facilitate comprehension due to their mimic faculties; and can support conversation in ways perceived at the same time as non-judgmental and lifelike (involving both verbal and bodily communication). Arguably, one of the values of SARs is that, on the one hand, they are 'human enough' to trigger familiarity, identification and empathy; whereas on the other hand, they are not 'too human' and keep an uncanny allure in

a way that children know that they are machines who cannot 'judge'. In other words, SARs' non-humanness is less intimidating and reduces the fear of making mistakes. This leads to the hypothesis that children's greater naivety and fantasy enhances SARs' 'magic effect', which is made of a combination of fear and attraction. More research is needed to probe into these aspects revolving around the question as to whether children are the best placed to make the most out of SARs in learning.

The role of the family, in particular, the parents/carers of children and their perceptions on using SARs in education is of great importance, yet largely overlooked in the SARs literature. The consequences of parental disapproval of using SARs in education may limit the use of SARs within classrooms, if not completely abolish their use altogether. Despite the possibility of involving parents/carers in research looking at learning gain, usability and perception in relation to using SARs in education, this was not observed in any of the 21 studies in this review. Instead, all 21 studies focused on the perspective of students, 4 of which (study 4, 5, 6 and 11 in Table B.2) explored the perspective of a small number of teachers (N = 13). Whilst it may be argued that teachers adopt the role of the parent as they are obliged to promote the wellbeing of children as a sensible parent would (Toh et al. 2016), this should not void the opinion of parents it may differ from that of the teachers. Rather, it could be reasoned that future research has a responsibility to allow parents/carers to express their opinions on the development and the use of SARs in education, with many factors, such as digital literacy of parents (Romero 2014) potentially impacting on their perspectives. The concept of digital literacy links to one of the few studies investigating the perception of parents and carers towards using robots in education which found mixed opinions (Lin, Liu, and Huang 2012). Parents held the view that educational robots could be beneficial for students but were not confident in using the robots themselves. This demonstrates the complexity of parental perceptions and warrants further attention from research in this field.

Finally, only two studies included in the review discussed the ethical issues of implementing SARs in schools (Fridin 2014a, 2014b), despite literature identifying a range of potential ethical considerations. For example, it is via the development of emotional attachments with SARs, as research has shown, that it is possible to develop meaningful relationships with robots despite identifying them as technology (Melson et al. 2009; Stanton et al. 2008; Tanaka, Cicourel, and Movellan 2007). Fridin (2014b) offered a solution to emotional attachment by using a SAR that was programmed to express its non-human character (i.e., regularly stating that it is a robot). Sharkey (2016) discussed the ethical concerns around robot teachers in detail with a focus on privacy, attachment, and power. Privacy is of great concern, especially in the climate of the General Data Protection Regulation in Europe, and even more so when handling the data of vulnerable individuals such as school children. Thus, SARs that record and store personal information of children (Kanda, Sato, Saiwaki, & Ishiguro, 2007) come with the complication of managing this data sensitively as a means of protection. In terms of attachment, advances in technology which allow robots to recognise facial expressions, make eye contact, and respond to different levels of attention, enhanced the quality of interaction between SAR and child which could make it easier to form attachments to such devices (van den Berghe et al. 2019). However, the development of SARs that appear and behave like humans (Yamaoka et al. 2007) raises another ethical concern around the deception of portraying a robot as animate. Sharkey (2016) also noted a loss of human interaction and contact which has the potential to have negative effects on children's relationship skills. For example, it has been noted that some children abused the SARs (Brscić et al. 2015) which did not respond to them. This could result in children learning that, being unpleasant, holds no consequence, thus reinforcing the behaviour in other human interactions. Lastly, the issue of authority and power has been discussed in terms of how much power a robot can exert responsibly and within which

domains (i.e., learning and disciplinary). This immediately flags concerns around safety and whether an increase in SARs' authority would also increase risk to children. In sum, there are a number of ethical issues to be considered when implementing SARs in education, which many of the studies in this review have not acknowledged. It is important that future research considers how SARs can be carefully implemented within ethical boundaries in order to enable the use of this technology in mainstream education.

4.1 Limitations

All study participants in this review belonged to high-income countries, except for Iran, which is an upper middle-income country, therefore the generalisability of the results is limited to these socio-cultural contexts. In addition, the relatively young average age of participating students (8.1 years) limits the application of the results to younger children among the pre-tertiary population. More studies are needed among older age children. The heterogeneity of research designs and the use of mixed-method, or quasi-experimental designs, combining the administration of scales, tests, with interviews and analysis of video footages reflects the methodological challenges that the field is presenting and the creativity that is needed to study the use of human-social robots interactions in education (Dautenhahn 2007).

5. Conclusion

The number of children using technology is growing worldwide and several governments are increasingly recognising and supporting the use of technology in education. Available evidence indicates that the use of personal computers, tablets, as well as machine-like and socially assistive robots is promising, albeit concerns exist among education professionals in terms of job security, usability, and children's development. This review has gone beyond the only other reviews our searches identified by providing an extensive overview of the current evidence on the contribution of SARs to learning and teaching in pre-

tertiary education. The few studies identified and reviewed, and their general low quality, make knowledge claims necessarily preliminary and speculative. However, our study yielded positive results with respect to attitudes and benefits of using SARs with young children. The distinct focus of this review has been the specific contribution of SARs in learning mathematics and science. Results showed that the use of SARs in mathematics and science is very limited, possibly due to the assumption that SARs, by virtue of their lifelike interactional skills, are more apt in language learning. Such studies devoted greater attention to the affective dimension and the user experience, rather than the learning gain with SARs. Unfortunately, our research question around the accessibility and inclusivity of students from diverse backgrounds produced no findings, if only in terms of the benefits of a personalised child-robot interaction. SARs' revolutionary potential for a complex tailored approach onto different learning types, special needs, and cultural backgrounds of children requires investigation. In conclusion, rigorous evidence is needed to assess SARs' promise in mathematics and science inclusive teaching and learning. Equally, more research is also necessary around SARs' acceptance, feasibility, and ethics to identify barriers to implementation, and overcome them. Ultimately, our findings are meant to contribute to new theories of education, beyond the state-of-the-art captured, based on the impact of AI on learning.

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