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Review article

Educational Robotics for children with neurodevelopmental disorders: A systematic review

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ABSTRACT

This paper aims to provide a critical review of the studies dealing with Educational Robotics for children with Neurodevelopmental Disorders. We aimed to investigate whether in the literature there is a sound evidence that activities with robots improve the abilities and performances of children with special needs. This paper explores the methodological aspects as well as the outcomes of the selected studies to provide a clear picture of the state-of-the-art on this topic. After a systematic search in the online database via keyword searches, 15 scientific papers were included in this review. We applied strict selection criteria limiting our review only to papers reporting educational robotics activities with children (from 3 up to 19 years old) with a diagnosis of neurodevelopmental disorders, in which the children had the opportunity to somehow program the behaviours of real robots. The majority of experiences showed improvements in the participants' performance or abilities, their engagement and involvement, communication/interaction with peers, during robotics sessions. Some studies reported mixed results, calling for the need to carefully design the objective and the related activities of each experience.

1. Introduction

Rapid progress in social robotics offers promising prospects for innovation in intervention with *children with special needs (CSN)*. Social robotics is the branch of robotics that studies the interaction between robots and humans. One of the branches of social robotics is Educational Robotics (ER). ER studies how interaction with the robots can foster and support learning processes in humans (from young children to adults). Traditionally, the approaches to ER have been divided into “Learning *about* Robots” and “Learning *with* Robots”, in other words, between “*Education in Robotics*” and “*Robotics for Education*”. The former approach concerns technical, robotics-oriented education, while the latter implies teaching different subjects (technical and non-technical) through robotics (Alimisis, 2013; Zawieska and Duffy, 2015). The use of ER could be either intra-curricular or extra-curricular. Intra-curricular activities are those that are included in school curriculum and are an official part of the syllabus. Extra-curricular activities take place after school hours as workshops under the supervision of instructors, at home under the guidance of parents or in other locations, such as public places and events (Mubin et al., 2013). In this review, we do not make a distinction between ER realized inside or outside a school environment.

In this paper, we are interested in understanding whether there is any clear evidence in the literature that robots can be effectively used to support the learning process in *children with special needs (CSN)*. For this purpose, it is of paramount importance to distinguish between “*robots used for CSN*” and “*robot used by CSN*”. The former implies the use of robots to entertain and stimulate the attention of special needs children, but it does not involve any active design of the robot's behaviour by the children. For instance, by *robot used for CSN* we mean robots used to enhance the attention of special needs children during diagnosis and/or therapy. In this case, robots are only the ancillary tools to intervene on CSN as much as any other technological device (see Boucenna et al., 2014). On the other hand, by *robots used by CSN* we consider robots as tools used for teaching (and learning) curricular subjects (or even specific subjects) leveraging on computational thinking-oriented activities to promote active learning (e.g. Bargagna et al., 2019). In the remainder of the paper, we will use the term Educational Robotics (ER) as the use of robots for the education of children with special needs (CSN).

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By the term "*educational robot*" (ER) we mean any kind of robot interacting with children for educational purposes. In this context, children are meant to give instructions to the robot (or to create a program for it) to accomplish a specific task. This can be realized in many different ways, but the important thing is that the pupil should be engaged in an activity aimed at planning, designing, or implementing an algorithm to control the robot's behaviour. The *programming* could also be realized by pressing the buttons of a BEEBOT, or lining up the pieces of a Cubetto, or more broadly as making a NAO move on the floor by showing it a series of commands displayed on flashcards (e.g. Hedgecock et al., 2014).

However, we consider fundamental that the children should be involved in some sort of *programming* to call an activity an ER activity. For instance, the following activities do not involve any programming and we do not consider them as ER: drawing a robot, making dresses for a robot, building a robot with recycled materials, sketching a robot to solve the environmental problems of the planet, playing or interacting with robots programmed by others or even remote control them (e.g. Cook et al., 2011; Robins et al., 2005). In the same way, a humanoid robot teaching physics to high school children, does not involve any sort of programming and it is not considered as ER (Ferrarelli et al., 2017; Shiomi et al., 2015).

Some previous analysis of the literature on ER are the reviews of Benitti (2012), Mubin et al. (2013), and Xia and Zhong (2018). These surveys were aimed at investigating the benefits and efficiency of robotics in teaching and learning for standard school pupils. These reviews document that most of the papers reported that robotics can be valuable in technical education (e.g., the activity of building robot) and non-technical education (e.g., science and language), but they also highlight how many studies appear inconclusive about the role the robots plays in education. For instance, in their systematic review, Benitti (2012) found learning improvement to be linked with the use of robotics in several studies, mainly concentrated in two aspects: (a) contributions to the learning of concepts/subjects in specific STEM concept areas; and (b) skills development such as thinking skills (observation, estimation and manipulation), science process skills/problem-solving approaches and social interaction/teamwork skills.

In a similar way, this article aims to provide a critical review of the state of the art of studies dealing with ER with CSN. Specifically, the review focuses on children with neurodevelopmental disorders. Neurodevelopmental disorders (ND) denote delays in a broad variety of areas of development (e.g., in the domains of motor, social, language, and cognition) that begin during infancy or childhood, are strongly related to biological maturation of the central nervous system, and produce impairments of personal, social, academic, or occupational functioning (DSM-5, 2013; ICD-10, 2004; see also Thapar and Rutter, 2015). Although these disorders tend to diminish with age, deficits largely continue into adult life (Clegg et al., 2013). According to DSM-5 (2013), ND involve 1) Intellectual Disability (ID; replacing the outmoded term Mental Retardation), 2) Communication Disorders (CD; encompassing language disorder, speech sound disorder, childhood-onset fluency disorder (stuttering), and social pragmatic communication disorder), 3) Autism Spectrum Disorder (ASD), 4) Attention Deficit/Hyperactivity Disorder (ADHD), 5) Specific Learning Disorder (SLD; combining reading disorder, mathematics disorder, disorder of written expression and learning disorder not otherwise specified), 6) Motor Disorders (MD including coordination disorder, stereotypical movement disorder, Tourette's disorder, motor or vocal tic disorder).

According to Bishop (2010) the term neurodevelopmental disorder is used in two main ways. The first indicates all conditions affecting children's neurological development with known genetic or acquired aetiology (e.g., Fragile X Syndrome, Rett's syndrome, Down Syndrome - DS, Cerebral Palsy – CP). The second way refers to conditions of multifactorial aetiology in which certain aspects of neurodevelopment are selectively impaired (e.g., ASD, CD, ADHD). Only the second type of conditions were included in this systematic review. Furthermore, we also compared these ND definitions with the ICD-10 system of medical classification listed by the World Health Organization (WHO; ICD-10, 1992)[1].

In this review, given the impairments of children with ND, we considered programming and coding in their broader meaning. For instance, given children with CP present major motor and cognitive disabilities, we consider very simple coding/programming activities (e.g., pupils lifting flashcards to make the robot perform the specific activity displayed in the flashcard) as effective examples of ER activities (Hedgecock et al., 2014).

2. Method

This study aims to:

- document the experiences of ER with children with ND involving some sort of basic and straightforward programming; the complexity of programming experiences can be tailored to the specific conditions of the involved children;
- critically review the concrete field experiences of ER with children with ND focusing on outcome evaluation, that is the measurement of the improvement/worsening of involved children skills after taking part in the experiences;
- provide possible readers of the review, that is teachers, engineers, psychologists, educators and all those who work for the promotion of the well-being of children with ND, with a ready-to-use reasoned synthesis of the relevant literature about what has worked, using which robot, among children with which disorder;
- make a list of recommendations available to those researchers aiming to design and perform an outcome evaluation study on ER with children with ND.

2.1. Inclusion criteria

The inclusion criteria were as the follows: 1) studies must be focused on the use of ER with children and young (from 3 up to 19 years old) with a diagnosis of ND; 2) studies must test the efficacy of the use of one or more robot kits in the educational curriculum of those kids; 3) studies - regardless of their methodology, including qualitative, quantitative, and regardless of the positive or negative nature of their results - must include at least one case or a group of participants and must involve them in robot programming activities; 4) studies must report data collected among children and/or their parents and/or their teachers; 5) studies must be published and available in full-text in peer-reviewed journals or conference proceedings or study reports must be available via the common scientific databases (i.e. Scopus, Pubmed, and Google Scholar); 5) the studies must be published in English language.

2.2. Exclusion criteria

The exclusion criteria were as the follows: 1) studies should not include robots meant to be used only for the therapy of ND (e.g., Cook et al., 2011; Desideri, 2017); 2) studies should not test the use of ER

[1] In ICD-10, code range from F70 to F79 describes Mental Retardation, code range from F80 up to F89 describes Disorders of psychological development (including Specific developmental disorders of speech and language, Specific developmental disorders of scholastic skills, Specific developmental disorder of motor function, Mixed specific developmental disorders, Pervasive developmental disorders, Other and Unspecified disorders of psychological development), and code range from F90 up to F98 reports Behavioral and Emotional Disorders with onset usually occurring in childhood and adolescence (including ADHD, Conduct disorders, Mixed disorders of conduct and emotions, Emotional disorders, Disorders of social functioning, Tic disorders, Other behavioural and emotional disorders with onset usually occurring in childhood and adolescence).

among those younger than 3 years of age or aged 20 or older and among undergraduates students (e.g. Bilotta et al., 2009); 3) studies that test the use of ER with SNC or disadvantages children or children with disabilities other than ND are excluded (e.g., Alfieri et al., 2015; Howland et al., 2013; Mills et al., 2013); 4) studies that use educational or assistive technologies that are not robotic kits (e.g., computers, tablets, videogames, virtual reality, etc.) or studies that present a design, development or improvement of a single component of a robot (e.g., algorithm, piece of hardware) are excluded (e.g., Saiano et al., 2015); 5) studies that do not provide exhaustive information about the results obtained or that only have insufficient preliminary results are also excluded (e.g., Andruseac et al., 2015; Strawhacker et al., 2013); 6) unpublished material is excluded; 7) articles dealing with narrative reviews, meta-analysis, and other types of literature review are excluded on the basis of the fact that no outcome measures are reported; 8) studies in which participants do not engage in the programming phase of robotic activities are also excluded (e.g., Özdemir and Karaman, 2017); 9) studies published before 2006 are excluded; 10) all the studies that do not describe the functions of one or more robot kits for the educational goals or that focus exclusively on the design and the technological descriptions of the robot are also excluded from this review.

2.3. Information sources and search strategy

At first, we performed a careful search to identify the existence of systematic reviews involving the application of ER with ND. No specific research on this topic was found, although there were systematic reviews involving the use of robotics in education in general (e.g., Benitti, 2012; Kubilinskiene et al., 2017), concerning teaching and learning robotics content knowledge in K-12 (e.g., Xia and Zhong, 2018) or, more specifically, reviews focused on the state of the art of robots used for the rehabilitation and education of children and young people with the CP and ASD syndromes (e.g., Cruz et al., 2017; Pennisi et al., 2016).

The studies were identified by searching electronic databases. A series of searches were performed including the term "Educational Robotic(s)" and each one of the many terms related to ND in all text-search fields (i.e. title, abstract, keywords, full text, and bibliography), in the following three databases: Scopus, Pubmed, and Google Scholar (see Table, 1). Papers were extracted using combinations of logical operators of "AND" and "OR". The search took place from the beginning of January 2019 until the end of May 2019.

The selection of terms to be searched was based on the classification of ND and relating terms of the major currently used diagnostic classification systems for mental and behaviour disorders, as in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5, 2013) published by the American Psychiatric Association. It was also compared with the terms used in the ICD-10 Classification of Mental and Behavioural Disorders (1992) published by the World Health Organization, considering some alternative terms indicating the same or similar disorders of DMS-5[2]. Each classification describes the neurodevelopmental disorders as affecting coordination, speech, language, and specific academic learning; and in addition, autism, attention-deficit–hyperactivity disorder, tics and Tourette disorder, stereotyped movements, and intellectual disability (see Table 1).

[2] "Mental Retardation", "Specific Developmental Disorder of Speech and Language", "Speech Articulation Disorder", "Expressive Language Disorder", "Dysphasia", "Aphasia", "Receptive Language Disorder", "Unspecified Communication Disorder", "Specific Language Impairment", "Spelling Disorder", "Specific Disorder of Arithmetic Skills", "Mixed Disorder of Scholastic Skills", "Developmental Disorders of Scholastic Skills", "Developmental Coordination Disorder", "Specific Developmental Disorder of Motor Function". Conduct and emotional disorders were not considered because they are not included in the ND classification of DSM-5.

Table 1. The specific terms searched in each database.

Neurodevelopmental Disorder(s) (NDD) *"Neurodevelopmental Disorder(s) (NDD)", "Other Neurodevelopmental Disorder(s)", "Other Specified Neurodevelopmental Disorder(s)", "Unspecified Neurodevelopmental Disorder(s)"*
"Intellectual Disabilities (ID)", *"Intellectual Disability Disorder", "Intellectual Developmental Disorder"", "Global Developmental Delay (GDD)", "Mental Retardation (MR)", "Unspecified Intellectual Disability", "Learning Disabilities (LD)".*
"Communication Disorder(s)", *"Language Disorder(s)", "Speech Sound Disorder", "Social – Pragmatic – Communication Disorder", "Childhood Onset Fluency Disorder (Stuttering)", "Specific Developmental Disorder of Speech and Language", "Speech Articulation Disorder", "Expressive Language Disorder", "Dysphasia", "Aphasia", "Receptive Language Disorder", "Unspecified Communication Disorder", "Specific Language Impairment".*
"Motor Disorder(s)", *"Developmental Coordination Disorder", "Stereotypic Movement Disorder", "Tic Disorders", "Tourette's Disorder", "Persistent (Chronic) Motor or Vocal Tic Disorder", "Provisional Tic Disorder", "Other Specified Tic Disorder", "Unspecified Tic Disorder", "Developmental Coordination Disorder", "Specific Developmental Disorder of Motor Function".*
"Autism Spectrum Disorders (ASD)", *"Autistic Disorder", "Asperger's Disorder", "Childhood Disintegrative Disorder", "Pervasive Developmental Disorder", "Pervasive Developmental Disorder-Not Otherwise Specified".*
"Attention Deficit/Hyperactivity Disorder (ADHD)", *"Other Specified Attention-Deficit/ Hyperactivity Disorder", "Unspecified Attention-Deficit/Hyperactivity Disorder"*
"Specific Learning Disorders (SLD)", *"Learning Disabilities (LD)", "Developmental Dyslexia", "Reading Disorder", "Mathematic Disorder", "Written Expression Disorder", "Developmental Dyscalculia", "Learning Disorder- Not Otherwise Specified", "Spelling Disorder", "Specific Disorder of Arithmetic Skills", "Mixed Disorder of Scholastic Skills", "Other Developmental Disorders Of Scholastic Skills".*
"Down Syndrome (DS)", "Cerebral Palsy (CP)"

During the database search, we came across a number of studies dealing with ER and Down Syndrome (DS) and Cerebral Palsy (CP), terms that we did not search in the beginning of data collection. Considering their frequent occurrence among the ER studies, we decided to exceptionally search for the DS and the CP as well (e.g. Adams and Cook, 2013).

The category of Intellectual Disability (ID) can pose problems of conceptualization (Bishop, 2010) because it is recognized as both a symptom of a known disorder, and a non-syndrome condition of unknown aetiology. Moreover, in the UK, the term 'learning disability' (LD) is used to refer to intellectual disability or, even, for specific problems in a child of normal IQ. We searched for both ID and LD. Finally, in the DSM-V (2013), ASD is proposed as a new overarching incorporating autistic disorder, Asperger's disorder, childhood disintegrative disorder and pervasive developmental disorder (see Table 1).

2.3.1. Selection of studies

The search databases provided a total of 157 citations (see Figure 1). After adjusting for duplicates, a total of 131 studies remained. Of these, 31 studies were discarded, because after reviewing the abstracts and titles these papers clearly did not meet the inclusion criteria. The full texts of the remaining 100 citations were examined in more detail. Firstly, two pairs of Authors independently evaluated the remaining articles and compared them with the inclusion and exclusion criteria. They reconciled any differences through discussion. If there was any disagreement on the suitability of a paper, it was included in a second phase. Secondly, all Authors reviewed the full-texts of the selected papers and came to an agreement about the inclusion/exclusion of each paper in the review. We found that 85 studies did not meet the inclusion criteria. Fifteen studies were finally included in this review.

3. Results

3.1. Process evaluation

In this section, we describe the fifteen included papers. The bibliometric indicators of each publication, that is metric index of SCImago Journal Rank (2018 SJR indicator), and the type of publication (i.e.,

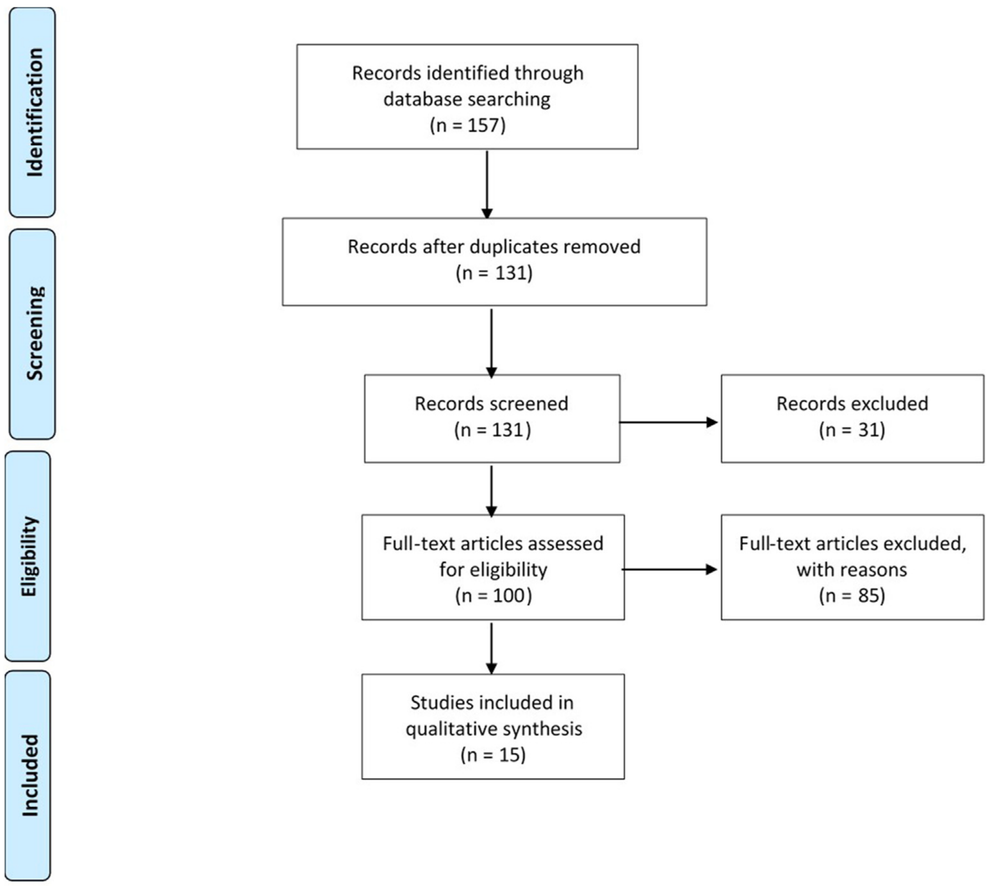

Figure 1. Paper selection flow diagram of our literature review (following PRISMA 2009).

journal paper, conference paper, report) were inspected. Of the 15 studies included,

- 61.66% (10/15) were journal papers,
- 26.67% (4/15) were conference papers,
- and one study is a final report of an Australian association that provide practical solutions for governments, service providers, education and health professionals, families and people with autism (Hinchliffe et al., 2016). No bibliometric indicators are available for the latter report, for two papers published in the same journal (i.e., Taylor et al., 2017; Yuen et al., 2014), and for three conference papers (i.e., Aslanoglou et al., 2018; González-González et al., 2018; Standen et al., 2014). All the other studies were characterized by a 2018 SJR of $M = 0.44$.

As shown in Table 2, each study was coded in terms of child diagnosis (the articles dealing with more than one disorder were included in different categories), the name of robot kits used, participants' characteristics (i.e., sample size and age). Six papers included children with ASD, seven included children with CP and motor disabilities, six included children with DS and one paper included children with ID. As for the type of robot, the majority of papers choose Lego Mindstorm (6 papers) and NAO robot (3 papers), followed by KIBO (2 papers), Lego WeDo (2 papers), one paper used integrated augmentative manipulation and communication assistive technologies (IAMCATs), one used Beebot and one DashRobot[3].

As for the size of the children sample, this ranged from one to 18 pupils. Generally, the experiences involved approximately 10–15 participants, with one paper including 18 participants and two papers reporting one single-case study each.

As for participants' age, it ranged from three to 19 years old[4]. However, given that the ND generally involve a delay in the development, involved children might not be at the same academic level as their age-matched peers in the regular-stream classroom. Their program might include some integrated classes with differentiated instruction via a personal educational assistant (EA). Bearing that in mind, we have chosen to report the school level of participants in Table 3. In general, the studies reporting ER experiences mostly involved children from primary education (12 studies) and from lower secondary education (9 studies). Few studies involved children from upper secondary education (3 studies) and from kindergarten (4 studies).

3.2. Outcome evaluation

We performed a critical evaluation of selected studies in terms of outcome measures. Table 4 describes the main characteristics of the selected studies concerning the type of robot used and the dimensions to be developed within the ER project (Physical development, Cognitive development, Emotional development, Social Development, STEAM).

[3] One ER experience involved both NAO robot and Lego Mindstorms. For this reason, the sum counts 16 rather than 15 studies.

[4] One participant from the study by Standen et al. (2014) was aged 20 years old, falling outside the inclusion criteria considering participants aged 3–19. However, as the study sample goes from 5 to 20 and this is the only participant aged older than 19 in the 15 selected studies, we considered that the inclusion criteria had been met and selected this study.

Table 2. Type of disability, type of robot and sample description.

Type of disability	Article	Robot	Participants	Age
ASD (Autism Spectrum Disorder)	Albo-Canals et al. (2018)	KIBO Robot	12 students	from 6 to 14 years old
	Hedgecock et al. (2014)	NAO NextGen Robot	6 students (4 males, 2 females); 5 teachers	from 9 to 17 years old
	Hinchliffe et al. (2016)	Lego MINDSTORMS® Education EV3	School A: 10 students with ASD; 10 parents; 2 teachers School B: 8 children with ASD; 8 parents; 2 teachers	from 12 to 13 years old
	Lindsay and Hounsell (2017)	Lego MINDSTORMS WeDo®	18 Students: 4 female, 14 male; 12 parents; 11 key informants	from 6 to 13 years old
	Standen et al. (2014)	NAO NextGen Robot	2 female, 9 male (two pupils with this disorder in this study)	one 7 and one 11 years old
	Yuen et al. (2014)	Lego MINDSTORMS® NXT	10 students (data available for two students only)	from 12 to 14 years old
Celebral PALSY (CP) + motor disabilities	Adams and Cook (2013)	Lego MINDSTORMS	1 female student	12 years old
	Adams and Cook (2014)	Lego MINDSTORMS	2 female, 1 male student	from 10 to 14 years old
	Cook et al. (2011)	Lego Robotics Inventions System	10 students	from 4 to 10 years old
	Encarnação et al. (2016)	Integrated augmentative manipulation and communication assistive technologies (IAMCATs)	5 students in the 2013/2014 academic year: 3 female, 2 male; 5 students in the 2014/2015 academic year: 1 female, 4 male	from 5 to 6 years old from 3 to 6 years old
	Hedgecock et al. (2014)	NAO NextGen Robot	6 students (4 males, 2 females); 5 teachers	Students from 9 to 17 years old
	Lindsay and Hounsell (2017)	Lego MINDSTORMS® WeDo®	18 Students: 4 female, 14 male; 12 parents; 11 key informants	from 6 to 13 years old
	Standen et al. (2014)	NAO NextGen Robot	2 female, 9 male (4 pupils with this disorder in this study)	from 12 to 20 years old
Down syndrome (DS)	Aslanoglou et al. (2018)	Lego Wedo 2.0 kit	1 female students	from 7 to 8 years old
	Aslam et al. (2016)	NAO robot LEGO Mindstrom	1 female, 3 male (one male and one female with this disorder in this study)	from 10 to 16 years old
	Bargagna et al. (2019)	Bee-Bot robot	9 students (data available for two students only)	from 5 to 12 years old
	González-González et al. (2018)	KIBO robot	3 female, 4 male students	from 7 to 19 years old
	Standen et al. (2014)	NAO NextGen Robot	2 female, 9 male (one male pupil with this disorder in this study)	5 years old
	Taylor et al. (2017)	Coding blocks Dash Robot	1 male, 2 female	from 6 to 8 years old
Intellectual disabilities (ID)	Standen et al. (2014)	NAO NextGen Robot	2 female, 9 male (four pupils with this disorder in this study)	from 7 to 18 years old

Table 5 describes 1) targets of the evaluation, that is the description of those participants evaluated before or after the ER activities (e.g., children, parents, teachers, educators, educational assistants etc); we excluded those participants involved in the activities, but not evaluated in any way; 2) research design, that is the methodological approach chosen in the study, for instance involving a repeated measure design or a pretest/post-test design or a post-test design etc. Finally, in the last two columns, study strengths and weaknesses are summarised. A larger Table including also 3) the type of outcome measures and the instruments used, that is the qualitative or quantitative nature of the instrument used (e.g., questionnaires, interviews, video-recording, observation etc) and 4) a summary of the main findings of the study is provided as supplementary material.

As for the dimensions being developed within the ER activities, the majority of studies (n = 14) aimed to develop cognitive dimensions such as writing a simple program with support, or learning about "simple cause and effect" and to develop and execute a plan (see Table 4). The second main objective of the studies (n = 8) was to improve the social skills of participants, especially for children with ASD. For instance, some studies measured the duration of student's social interaction with peers before and after the ER activity or asked parents to fill in a questionnaire about their perceptions of the role the robot played in helping students with social skills. Few studies (n = 4) considered the development of STEM as one of their objectives. For instance, one study proposed to children to exercise in four math measurement lessons about comparing, sorting, and arranging objects. Another study compared the student's engagement during STEM robotics and non-robotics activities. All 15 studies involved some sort of programming or coding (as requested by the inclusion criteria). Thus, every study aimed to develop this particular STEM skill in participants.

Only four studies aimed to foster the emotional dimensions. This could be due to the restrictive inclusion criteria used in this review, pointing to the programming as a necessary condition for being selected and discarding those studies involving robots as an "emotional medium" for children. Moreover, psychosocial studies on the social perception of the robot found that it is generally perceived as "cold" on a semantic differential from 1 = cold to 5 = warm, and unsuited to emotional reactions by nature (Agatolio et al., 2017; Beraldo et al., 2018; Sarrica et al., 2019). In this sense, the robot could have not been considered by researchers as suitable to foster the emotional dimension.

Only two studies aimed to develop the participants' physical dimension. This could be related to the characteristics of the selected population, involving cognitive and/or physically impaired children and the specific aims of ER, that is by definition an attempt to foster the development of the children via some kind of programming activities. In this sense, the physical development of children does not pertain to the scope of ER (Benitti, 2012).

When relating the type of robot with the dimensions to be developed, it emerged that Lego Mindstorms and NAO robot were mainly used to develop cognitive and social skills. KIBO seemed very flexible in that it allowed children to pursue cognitive, emotional and social objectives at the same time. To develop STEAM, the Lego Mindstorms was used in three cases out of four.

Table 3. Pupils' school level.

	Number of participants for paper	Pre-primary Education Ages from 3 to 5	Primary Education Ages from 6 to 10	Lower Secondary Education Ages from 11 to 13	Upper Secondary Education Ages from 14 to 20
Adams and Cook (2013)	1			1	
Adams and Cook (2014)	3		1	2	
Albo-Canals et al. (2018)	12		between 6 and 14 years of age		
Aslam et al. (2016)	4	between 3 and 19 years			
Aslanoglou et al. (2018)	1		1		
Bargagna et al. (2019)	2		1	1	
Cook et al. (2011)	10	2	8		
Encarnação et al. (2016)	10	6	4		
González-González et al. (2018)	7		2	3	2
Hedgecock et al. (2014)	5		2	2	1
Hinchliffe et al. (2016)	18			18	
Lindsay and Hounsell (2017)	18		12	6	
Standen et al. (2014)	11	1	2	4	4
Taylor et al. (2017)	3		3		
Yuen et al. (2014)	2			2	

Table 4. Type of robot and dimensions to be developed.

Authors	Type of robot	Physical develop.	Cognitive develop.	Emotional develop.	Social Develop.	STEAM
1. Adams and Cook (2013)	Lego Mindstorms		X			
2. Adams and Cook (2014)	Lego Mindstorms		X			X
3. Albo-Canals et al. (2018)	KIBO	X	X	X	X	
4. Aslam et al. (2016)	NAO + Lego Mindstorms		X			
5. Aslanoglou et al. (2018)	Lego WEDO		X			
6. Bargagna et al. (2019)	Bee-bot		X		X	
7. Cook et al. (2011)	Lego Robot		X			
8. Encarnação et al. (2016)	IAMCAT		X		X	
9. González-González et al. (2018)	KIBO		X	X	X	
10. Hedgecock et al. (2014)	NAO		X		X	
11. Hinchliffe et al. (2016)	Lego Mindstorms		X		X	
12. Lindsay and Hounsell (2017)	Lego Mindstorms		X		X	X
13. Standen et al. (2014)	NAO	X	X	X		
14. Taylor et al. (2017)	Code block + Dashrobot		X			X
15. Yuen et al. (2014)	Lego Mindstorms				X	X

As for the targets of the evaluation, the sample size was small considering whether the students, the parents, or the teachers (see Table 5). Approximately half of the considered studies (n = 8) involved only children in the measurement of outcome of the activity. Seven studies involved teachers to collect interview data for instance about their satisfaction/appreciation about the project, the project results, their perception about the feasibility of the project. Teachers' points of view are valuable in that experienced teachers could provide valuable comments about the impact of the ER projects on children and the feasibility of integrating ER in regular classes. Parents were involved in four studies, mainly questioned about their experiences in the program and the adaptions needed. The parents were interviewed about their perception of the usability of ER sessions, their perception of assistive technology and their comments on the robot's role in learning process.

As for research design (e.g. Campbell and Stanley, 1963; Creswell and Creswell, 2017; Schweigert, 1994), the selected studies fall into three categories: six studies were classified as one-shot case design, five studies as one-group pre-test post-test design and four studies repeated-measure design. While single-case design and one-group pre-test were considered as pre-experimental, repeated-measure design (or within subject design) where each participant receives each level of the independent variable (control conditions), whether it be being treated and untreated or performing two training sessions with robot A and then two more training sessions with robot B, provides more sound evidences as causal estimates can be obtained by examining how individual behaviour changed as the circumstances of the experiment changed.

The column "Type of Outcome Measure" classified the instrument used for measuring/collecting data on outcome in terms of quantitative or qualitative instruments. Face-to-face interviews were coded as qualitative methods, whereas questionnaires, standardized scales were coded as quantitative methods. The method of observation was classified as a quantitative method as it involved the use of a coding scheme shared among researcher to correctly codify completed steps, or it involved the measurement of the duration of engagement or social interaction. Eight out of fifteen papers involved both qualitative and quantitative measures. For instance, one study collected both quantitative measures, such as observation of the percentage errors extracted from the video and qualitative measures such as interviews with teachers. Qualitative data from interviews were, in some cases, analysed via specific software for the content analysis (e.g., Atlas.Ti), enabling the researcher to build categories and subcategories according to which to categorize the textual data. Six papers involved only quantitative studies. For instance, one study performed observation of engagement, administered standardized measures of engagement and measured the frequency of goals attained.

The "strengths" and the "weaknesses" columns report a critical evaluation of the methodology involved in the study and in the reporting of participants' conditions, data collection and data analysis. As for the strengths, some studies reported in details the evaluations from students,

Table 5. Outcome evaluation.

	Targets of the evaluation	Research design	Type of Outcome Measure	Strengths	Weaknesses
1. Adams and Cook (2013)	1 girl.	One-shot case study	Quantitative and qualitative	1) Detailed reporting and analysis of the collected data; 2) The use of Goal Attainment Scale to quantitatively evaluate children's performance	1) Small convenience sample; 2) No control group; 3) No pre-test
2. Adams and Cook (2014)	3 children, 3 mothers, 2 educational assistants (EA), 1 assistive technology (AT) team (the same occupational therapist, speech language pathologist, and teacher for all three participants)	One-shot case study	Quantitative and qualitative	1) Detailed reporting and analysis of the collected data; 2) Evaluations from children, EA, AT team and parents; 3) Sample was homogeneous: the same diagnosis of CP for every child; 4) Software NVivo was used for marking and describing the manipulation events.	1) Small convenience sample; 2) No control group; 3) No pre-test; 4) different settings; 5) Low inter-rater reliability between the teacher and the external teacher.
3. Albo-Canals et al. (2018)	12 children with ASD (a detailed quantitative and qualitative analysis only for two participants)	One-shot case study	Quantitative and qualitative	1) Children have the same diagnosis of ASD;	1) Small convenience sample. 2) Most students missed one or more days of school during the week of the study. Only two subjects completed 80% or more of the sessions, meeting criteria for detailed analysis. 3) No pre-test. 4) No control group
4. Aslam et al. (2016)	4 students; 2 teachers	Repeated-measure design	Quantitative and Qualitative	1) The study aims to compare the efficacy of two different robots	1) Small convenience sample. 2) No pre-test. 3) Results are mainly focused on the comparison between two kinds of robots; 4) No reporting of collected interview data
5. Aslanoglou et al. (2018)	1 student	One-group pre-test post-test design	Quantitative	1) Presence of a pre-test, a post-test and follow up	1) Small sample (single case); 2) No control group.
6. Bargagna et al. (2019)	Eight children with DS. Only two cases were reported.	One-group pre-test post-test design	Quantitative	1) Pre and post test	1) Small sample (Single case). 2) Most students' results are missing; 3) It does not describe how data on acceptability of activities were collected; 4) No control group
7. Cook et al. (2011)	Ten children. Teachers	One-shot case study	Quantitative and Qualitative	1) Evaluations collected from children and teachers	1) Small convenience sample. 2) No pre-test; 3) No control group; 4) Most students' scores are missed; 5) No quantification of how many teachers were interviewed;
8. Encarnação et al. (2016)	Ten children with disabilities, nine regular and nine special education teachers	One-group pre-test post-test design	Qualitative and quantitative content analysis	1) Detailed reporting and analysis of the collected data; 2) Use of ATLAS.ti software to analyse the qualitative data	1) Only teachers' opinions on the systems were collected. 2) Each participant used ER only in a small number of classroom sessions. 3) Small convenience sample, 5) The heterogeneity of participants. 6) No control group
9. González-González et al. (2018)	7 children	One-group pre-test post-test design	Quantitative and qualitative	1) Collection of both data on learning objective and engagement; 2) Relatively large sample; 3) Detailed participants description; 4) Homogeneous sample	1) Brief analysis of quantitative data; 2) No reporting of collected qualitative data; 3) No control group.
10. Hedgecock et al. (2014)	5 children and 5 teachers	Repeated-measure design	Quantitative	1) Quantitative data analysis, despite the small sample; 2) Engagement was compared in classroom settings and during robot session	1) Small sample
11. Hinchliffe et al. (2016)	School A: 10 students with ASD 10 parents 2 teachers School B: 8 children with ASD 8 parents 2 teachers	One-group pre-test post-test design	Quantitative and qualitative	1) Detailed reporting and analysis of the collected data; 2) Dse of standardized measures; 3) Use of statistical inferential analysis, when appropriate; 4) Large sample from 2 schools; 5) Evaluation collected from children, teachers and parents	1) No control-group; 2) No description of the cognitive improvement after the clubs
12. Lindsay and Hounsell (2017)	18 children, 12 parents, 11 staff/ volunteers	One-shot case study	Quantitative and qualitative	1) Detailed description of the robotic program; 2) Evaluation from children, parents and staff	1) Focuses more on student and parents satisfaction and on the description of needed adaptations

(continued on next page)

Table 5 (*continued*)

	Targets of the evaluation	Research design	Type of Outcome Measure	Strengths	Weaknesses
				members were collected; 3) Relatively large sample	than on outcome evaluation of the student learning; 2) No control group
13. Standen et al. (2014)	11 children	Repeated-measure design	Quantitative	1) Detailed reporting of the children disability, 2) Pre-test measurement, 3) Use of standardized measure of engagement, 4) Relatively large sample	1) Poor reporting of the duration of assistance from staff and of frequency of goals attained; 2) No control group
14. Taylor et al. (2017)	3 children	One-shot case study	Quantitative	1) Detailed reporting and analysis of the collected data;	1) Small sample; 2) No control group; 3) No pre-test; 4) Does not present the collected data on participants and parents' questionnaires on satisfaction.
15. Yuen et al. (2014)	2 children	Repeated-measure design	Quantitative	1) Clear description of the duration of social interaction of children; 2) Quantitative measurement of social interaction; 3) An alternating treatment design (instruction of non-robotics activities) used to compare the duration of social interaction between instruction types; 4) Homogeneous sample, 5) Control condition	1) Small sample; 2) No pre-test

teachers and parents as to provide a comprehensive evaluation of the experience from the three points of view, respectively. In some cases, the sample was homogeneous as for the children's diagnosis, meaning that the results could be more easily generalized. The presence of a pre-test and a post-test and, whenever possible, of a control group (designed to achieve the same learning goal without the robot) provide stronger evidence than post-test only design. Large samples are recommended as well as the use of repeated measure design. The use of standardized/validated tools to measure engagement or social responsiveness made the data collected stronger than the use of ad-hoc measures. As for qualitative interview material, in a few cases the data were analysed via software for the quantitative analysis of textual data, introducing more sophisticated data analysis. Finally, as many studies lasted only a few days, we advise implementing longer studies where pupils are involved in ER for many weeks, to better study the possible effects of ER on the expected domain(s).

As for the weaknesses, many studies involved case studies or small samples. Small convenience sample and the lack of many participants' results made it hard to generalize the conclusions. No study involved a control group. Four studies were repeated-measure design, allowing us to compare experiences involving two different robots and the level of engagement and social interaction in a classroom setting and during robot session, among the same sample. Given that the participants were pupils with SN, in many studies only teachers' opinions were collected.

Poor or no reporting of qualitative interview data was frequent. For instance, some papers reported that interviews with teachers/parents were run but the results of those interviews were not described in the paper. We believe that qualitative data on teachers'/parents' voices could be precious when participants with SN were unable to report their personal experiences. Poor reporting of qualitative data collection procedures and data analysis were detected in four cases. For instance, one paper did not report how many teachers were recruited and interviewed.

Concerning the quantitative data analysis, in five studies the dependent variables, analyses and results were not clearly reported. For instance, one study involved eight children but data relating to only two children were reported in the paper. In some cases, the description of data analysis and data analysis itself were superficial and meagre, resulting in unclear outcome data. One study met the inclusion criteria for outcome evaluation but focused more on the participants' satisfaction about the experience than on the outcome evaluation. It was conceptualized more as a feasibility study on the possible use of ER for special needs children than as an outcome evaluation study.

The main findings were content analysed according to the following four categories: attainment of learning objectives, improved engagement, improved communication/interaction with peers, teachers' and parents' evaluation of the project (see Table 6). As for the learning objectives, nine studies out of thirteen reported an improvement in the participants' performance in accordance with the aims of the study. For instance, one study reported that all three participants were able to learn and apply basic computer programming skills, which allowed them to create code for a robot. Four studies reported mixed results with improved skills in one domain and not adequate evaluation in another domain. As for engagement, nine studies out of eleven reported improvement in the engagement of participants during robotics sessions. For instance, one study reported engagement as significantly higher during the robotic session than in the classroom. Two studies reported mixed results, with one study referring a significant heterogeneity in the acceptability of proposed experiences. As for communication/interaction with peers, six studies out of seven were able to document improved interaction with peers. For instance, one case study reported that the participant was able to accept a play-group setting at the end of ER Lab. One study provided mixed results, showing evidence of increased interactions with adults, but not of increased peer interactions. The five studies collecting data on teachers' point of view all reported a positive evaluation of the experiences, describing how most children enjoyed using the robots and provided valuable adaptations to the robotics program to enhance children's participation. As for the parents' point of view, all the studies collecting parents' voice (n = 3) reported

Table 6. Overview of the main findings: number of studies for each dimension evaluated.

	Learning objectives	Improved Engagement	Improved Communication/ Interaction with peers	Teachers' Views	Parents' views
YES	9	9	6	5	3
NO	0	0	0	0	0
YES/ NO	4	2	1	0	0

a positive evaluation of the experience, feeling that it was both important and appropriate to involve children in the ER activities.

4. Discussion

In this review, we have documented the experiences of ER with children with ND, in terms of outcome evaluation, involving any sort of basic programming/coding. Starting from the definition of ND based on DSM-5V and ICD-10, we have selected 15 papers, involving either qualitative or quantitative data or both. The outcome was evaluated in terms of the improvement/worsening of involved children's skill after taking part to the experiences. Also, given the specific conditions of participants, positive outcome was considered an increased engagement of the pupils and increased social interaction with peers and/or with the teachers during the robot session. This way, we hope to have provided (pre-service) teachers, engineers, psychologists, educators and all those who work for the promotion of the wellbeing of children with ND with a critical synthesis of the experiences of ER with children with ND.

4.1. Novelties of the study

At the beginning of the paper, we provide clear definitions of educational robots used *for* children with SN and educational robots used *by* children with SN, the latter involving robots in teaching/learning specific subjects and for general educational purposes through computational thinking-oriented activities. Only experiences of ER with children with SN were included in this review. Whereas reviews generally discuss ER for “average” pupils in K-12 (e.g. Kubilinskiene et al., 2017; Xia and Zhong, 2018; Toh et al., 2016), our paper specifically focuses on children with ND. Moreover, some reviews look at one or a couple of disorders at a time. For instance, Pennisi et al. (2016) focuses only on ASD, and Cruz et al. (2017) on CP and ASD. Our paper takes into consideration a larger spectrum of aforementioned ND, based on DSM-5 and ICD-10 classifications. Some reviews explore the use of robotics in therapy and health care context (e.g. Dawe et al., 2019; Istenic Starcic and Bagon, 2014). Differently, our review focuses on the evaluation of outcome of ER, as defined above. Also, in the literature review papers are available focusing on specific technology such as Lego Robotics (Souza et al., 2018) or motion sensor (Bratitsis and Kandroudi, 2014) in education. Our review is characterised by a broader scope, by taking into consideration any kind of robot used in ER. Finally, we performed a critical evaluation of the methodological aspects as well as the outcome data of the selected studies, to provide a clearer picture of the state-of-the-art on the issue.

4.2. Study limitations

This study has several limitations. First of all, although we used a thorough search strategy, some empirical studies on the use of ER by children with ND may not have been identified for this systematic review (e.g., gray literature, such as unpublished documents and reports). The selection of studies has a direct relationship with the search engine of the virtual libraries/databases because each one has specific characteristics. In this way, the search performed in the databases may not have returned all relevant records.

Secondly, most of the studies taken into account has methodological weaknesses, affecting the possibility to draw strong evidence about the effectiveness of the ER experience, starting from results of the selected papers. For instance, eleven studies do not have a control group. The remaining 4 studies involved a repeated-measure design, where the same sample was tested more than one time, being each participant the control condition for him/herself. Other studies included children with different ND, such as ASD, CP and DS in the same sample, parcelling out the already small sample and making it difficult to say what is working (or not) with which kind of disability.

Moreover, because of the small number of participants for each selected study, the results of this review can be considered as provisional, waiting for future larger studies on the subject. Due to these limitations, we were only able to evaluate the quality of each study considering its methodological robustness and counting up the number of studies reporting positive results. This procedure has also a positive side. We were also able to take into consideration the results of qualitative data such as interviews with teachers/parents, which could not be included in the quantitative meta-analysis.

4.3. Recommendations

We are aware of the difficulties that teachers face every day, working with children with ND and we acknowledge the complexities of education systems in different countries (Di Battista et al., 2020). However, on the basis of the review, we are able to provide the following recommendations to those planning to conduct an outcome evaluation study on the use of ER for children with SN in school-based settings:

- Sample: involvement of at least 10–15 children diagnosed with the same condition and at the same developmental level, so that the sample could be as homogeneous as possible;
- Control group or condition: Whenever possible, a control group or condition (repeated-measure design) where comparable participants aim to achieve the same learning objective without the robot, should be included;
- Data collection methods: Besides observation and coding schemes, the use of standardized/validated measures (e.g. scales, questionnaires) should be encouraged; studies collecting both quantitative and qualitative data conveys a more exhaustive evaluation of the experience;
- Points of view of the teachers and the parents are welcomed to test the feasibility and to improve the effectiveness of the ER experiences. Given the condition of the involved children, the voices of the parents are in some cases the only voices we could hear from them.
- Reporting of collected data: all the data collected during the experience should be reported in detail in the papers, so that the reader could obtain a general understanding of the effectiveness of the experience; qualitative interview data are valuable in that they provide the priorities and suggestions of teachers and parents.

5. Conclusions

This study presents a systematic review of recently published literature on the use of educational robots with children with ND, in the context of pre-primary, primary, lower secondary and upper secondary education, summarizing relevant empirical findings and indicating recommendations for future research. ER holds significant potential to improve the learning, engagement and social interactions of children with ND.

The majority of selected papers showed an improvement 1) in the performance or abilities in terms of learning objectives, 2) in pupils' engagement and 3) in communication/interaction with peers. However, mixed results emerged in two studies in terms of pupils' performance, calling for the need to carefully design the objective and the related activities of each experience. Teachers and parents were positive about the ER experiences in all the studies where their voice was collected.

This review suggests to direct future research on experiences with ER involving larger samples, more sound methodology and collecting also parents' and teachers' voices. Another suggestion for future research projects and initiatives is to be able to compare the use of different robots with CSN of different age, to evaluate which robots would better fit the educational needs of younger or older children.

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