Artificial Intelligence Methods in Early Childhood Education

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Abstract. Educational technology constitutes an important aspect in modern education providing unique learning experiences to students and improving their learning. Technological resources (especially computers) have been integrated in education for decades. However, integration of educational technology in early childhood education is a more recent trend compared to the other levels of education. This fact creates the need to develop, apply and study application of resources and methodologies specifically addressed to young children. Artificial Intelligence approaches have been incorporated to educational technology resources providing improved interaction to learners. In this paper, Artificial Intelligence methods exploited in the context of early childhood educational technology are surveyed. The discussion mainly concerns computer-based learning systems incorporating intelligent methods (e.g., Intelligent Tutoring and Adaptive Educational Hypermedia Systems) and educational robots addressed to early childhood. To the best of the author's knowledge, such issues have not been thoroughly discussed till now in literature.

1 Introduction

Alan Turing is considered among the researchers that laid the foundations of Artificial Intelligence (AI). He was the one who proposed the Turing test as the means of defining the intelligence of a machine [56]. According to Turing, a machine is considered intelligent if it is able to interact with a human without the human realizing that he/she is interacting with a machine.

Artificial Intelligence methods have been applied in various domains. An interesting field for Artificial Intelligence is educational technology. In fact, Artificial Intelligence methods have been applied in educational technology for some decades. Educational technology is a broad term. It involves technological resources

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X.-S. Yang (Ed.): Artif. Intell., Evol. Comput. and Metaheuristics, SCI 427, pp. 169–199.
springerlink.com

and methodologies employed in an educational context in order to satisfy specific educational needs [48]. Educational technology usually places emphasis on the most modern resources without overlooking useful resources that are not quite recent. The main purpose is to provide students and teachers benefits compared to methods not employing technology. Integrating educational technology into an educational environment can be a challenge. The integration process should take into consideration issues that need to be dealt with in a specific class of students. Technology may assist in handling specific educational problems or may provide the infrastructure for activities that could not have been carried out with non-technological means [48].

There are several reasons for employing educational technology [48]. Educational technology may provide students the motives to learn as their attention is attracted and they are encouraged to take part in creative activities. With the use of technology, unique features are incorporated into the educational environment such as multimedia-based interaction and visualization of problem solving process. Technology also supports pedagogical approaches such as collaborative learning and constructivism. Educational technology acquaints students with resources and principles necessary to all members of the Information Society. Last but not least, technology may provide the means to connect schools with their communities [36].

Computer-based learning is a significant aspect in educational technology. Computers have been used in education since the 1950s as they may be exploited in several ways by students and teachers working individually and in groups. However, educational technology usually involves a combination of resources besides computers in order to exploit the corresponding characteristics and the advantages offered by each type of resource. This is especially the case in early childhood education. Popular types of technological resources used in early childhood education besides computers are interactive whiteboards and programmable toys. Game consoles and robots may also become popular in early childhood education.

Artificial Intelligence methods have been applied in computer-based learning in order to provide enhanced learning experiences. Traditional Computer-Assisted Instruction (CAI) systems are based on shallow representation of teaching domain, learner data and pedagogical methods [59]. It is difficult for them to adjust effectively the learning process as they provide limited ways of adaptation and learner evaluation. Intelligent Educational Systems (IESs) [6], [10], [43] are computer-based systems incorporating intelligence. Intelligent Educational Systems incorporate Artificial Intelligence techniques and mechanisms. The goal is to model learners as well as knowledge regarding the teaching subject and tailor learning experience to learner needs [43]. Main types of Intelligent Educational Systems are Intelligent Tutoring Systems (ITSs) and Adaptive Educational Hypermedia Systems (AEHSs) using intelligent methods.

Intelligent robots constitute a popular paradigm of Artificial Intelligence methods in education besides (computer-based) Intelligent Educational Systems. The characteristics of educational robots provide advantages compared to computer-based learning systems. Educational robots are autonomous, mobile and come in different forms. They may express emotions and respond dynamically to human interactions. Robots offer unique interaction experiences resulting in the creation of bonds with young children. As results of certain studies have shown, young children may treat robots more like peers rather than machines or toys.

In this paper, Artificial Intelligence methods exploited in the context of early childhood educational technology are surveyed. The discussion involves on the one hand, Intelligent Tutoring and Adaptive Educational Hypermedia Systems and on the other hand, robots addressed to early childhood. To the best of the author's knowledge, such a survey has not been presented till now in literature.

This paper is organized as follows. Section 2 covers general issues concerning educational technology in early childhood, Intelligent Tutoring and Adaptive Educational Hypermedia Systems as well as robots. This discussion serves as background knowledge for the following sections. Section 3 summarizes approaches using Intelligent Tutoring and Adaptive Educational Hypermedia Systems in early childhood education. Section 4 presents representative approaches integrating robots in early childhood education. Finally, Section 5 concludes.

2 Background

This section discusses general issues concerning early childhood educational technology, Intelligent Educational Systems and intelligent educational robots for young children. Each issue is discussed in a corresponding section.

2.1 Educational Technology in Early Childhood: General Issues

Early childhood education curriculum covers several aspects such as language, science, mathematics, arts and special education [53], [25], [47]. Early childhood education involves both teacher-directed and student-centered activities putting emphasis on collaboration, constructivism and interdisciplinary tasks. Students interact with resources available in classroom during structured and non-structured activities [46]. Game-based learning possesses an important role as it promotes collaboration and creativity in an appealing way for young children.

Various educational technology resources can be used in early childhood. The term 'educational technology' in early childhood education is used in a broad sense covering a combination of several types of resources such as computers, interactive whiteboards, digital photo cameras, digital video cameras, scanners, programmable toys, game consoles, robots and various types of software [53], [25], [47]. Several of these resources are available (or can be accessed) at home as well (e.g., computers, cameras, free software, open source software and Web-based activities). This gives parents the opportunity to acquaint themselves with their children's educational tools and take part in their children's learning [46].

A significant aspect is the recording of data concerning classroom and home activities. Devices such as digital photo cameras, video cameras, webcameras, microphones and scanners may be employed by teachers, students and student parents for such purposes [47]. The recorded data provides valuable information as it incorporates the views of teachers, students and student parents. Robots may also record data concerning classroom and home activities. Data concerning children's work on an interactive whiteboard may be also saved. Interactive whiteboards are popular in early childhood as they constitute large interactive screens facilitating collaborative work. Whiteboard functionality is available using fingers and markers and this gives pleasure to young children [47]. Through the whiteboard, children interact with software installed on a connected computer without having to work in front of a computer screen. Programmable toys are also popular in early childhood as they introduce young children to control technology. Children become accustomed to inputting, storing and executing instruction sequences. Programmable toys assist children in developing mathematical language, comprehending concepts involving numbers, direction and measurement of movements in space [53], [25], [47]. Results have shown that young children may independently use aforementioned devices in individual and collaborative activities [47].

There is a variety of available software tools addressed to early childhood students. Such software tools are based on multimedia as multimedia items are appealing to young children and often incorporate game-based learning. Time-efficiency is a feature required by software addressed to young children. Available tools involve aspects such as computer literacy, digital painting, math, science and language. Certain tools (e.g., GCompris, Tux Paint, Drawing for Children, Kid Pix, Tux Typing, TuxMath and Kidspiration) have gained popularity throughout the world. Table 1 outlines some of the most popular tools as well as their functionality.

Table 1 Certain popular software tools addressed to young children

GCompris	Free educational software suite with more than a hundred activities regarding every curriculum aspect.
Kidspiration	Problem solving and conceptual understanding in every curriculum aspect through visual learning
TuxMath	Game-based math activities
Tux Typing	Enhances typing and spelling
Tux Paint, Drawing for Children and Kid Pix	Digital painting tools

The aforementioned tools require installation on a computer. An important portion of these tools are freely available enabling installation on any computer. There are also several Web-based activities (e.g., Java applets and Flash animations) addressed to young children and most of them can be accessed without restriction. Virtual Learning Environments may be also used [47], [46].

Early childhood teachers are required to employ various multimedia-based tools. With such tools, teachers may perform tasks such as the following: (a) recording of data involving classroom activities, celebrations and outings, (b) processing of recorded data, (c) creation of educational content and (d) authoring of educational applications. Image, audio, video processing and animation tools are used to create and process multimedia items whereas multimedia authoring tools may be used to create multimedia applications for young children. E-portfolio tools are also used to collect and manage students' achievements through time. Assessment in early childhood is frequently based on e-portfolios. Asynchronous and synchronous forms of communication may be exploited by teachers to establish a link between home and school [47], [46], [36].

Digital games constitute amusing means of learning in early childhood. As game-based learning is an integral part of the curriculum, digital games in early childhood may yield significant results. In [42] it is argued that most aspects can be taught more effectively through digital game-based learning. Turing realized the value of digital games. He worked with a colleague to program a chess game for a computer. Programming of the game was completed but there were no time-efficient computers during that period for executing the game. In Wikipedia's article concerning Turing, it is reported that he simulated the computer in order to play the programmed chess game against two human adversaries.

2.2 Intelligent Educational Systems

An Intelligent Educational System (IES) is an e-learning system personalizing instruction to learner's needs [6], [10], [43], [23]. The main purpose is to provide (or guide the learner in accessing) the most suitable learning activities to meet learner goals. This is achieved with the incorporation of Artificial Intelligence methods used to model learner characteristics and knowledge regarding the teaching subject. An IES mainly consists of the following components: user (or student) model, domain knowledge, pedagogical module and user interface. The user model records learner data. Domain knowledge contains learning content and relevant information facilitating content retrieval. The pedagogical module provides knowledge used to tailor instruction based on user model data. In certain cases, the IES may also include the expert model used to represent expert knowledge in the domain. Intelligent Tutoring Systems (ITSs) and Adaptive Educational Hypermedia Systems (AEHSs) using intelligent methods are the most representative types of IESs.

Intelligent Tutoring Systems take into consideration learner characteristics (e.g., knowledge level) and customize accordingly presentation of learning activities [41], [59], [58]. ITSs traditionally lay emphasis on Artificial Intelligence techniques to achieve their tasks. An ITS should be able to perform tutoring tasks such as selecting and sequencing of presented learning items, analysis of learner responses to presented items and determining when assistance is needed and how to provide it [41], [43].

Adaptive Educational Hypermedia Systems are specifically developed for hypertext environments, such as the Web. They use techniques from Adaptive Hypermedia to enable a guided navigation to user-adapted educational pages. Main services offered are adaptive presentation of learning content and adaptive navigation by adapting page hyperlinks [8], [9], [40]. Compared to ITSs, they offer greater sense of freedom to learners as they provide them guidance to identify the most suitable learning activities matching their needs. In ITSs, selection and sequencing of learning items is performed by system mechanisms. AEHSs also dynamically construct or adapt educational pages whereas in ITSs educational page contents are typically static [40]. However, it should be mentioned that several Web-Based Intelligent Educational Systems combine ITS and AEHS technologies to provide more effective learning activities [10].

Knowledge representation and reasoning is an important issue in IESs. Usually a combination of Artificial Intelligence methods is required to achieve all online and offline tasks [23]. Artificial Intelligence methods typically used are structured and relational schemes, rule-based reasoning, case-based reasoning, neural networks, Bayesian networks, fuzzy methods, genetic algorithms [43]. Structured and relational schemes are used to represent structural and relational knowledge useful in domain knowledge representation [8]. Rules are used in several pedagogical tasks [24]. Neural networks are used to perform classification and clustering tasks involving online learning process and offline analysis of accumulated data [11]. Fuzzy methods enable representation of vagueness and uncertainty useful in user modeling [14]. Case-based reasoning provides empirical experience useful in instructional tasks [12]. Genetic algorithms may be used in offline tasks concerning optimization of system modules and in online tasks such as sequencing of learning content items [35]. Hybrid knowledge representation formalisms integrating two or more formalisms may also be employed such as neuro-symbolic rules [45], [22], [44] and neuro-fuzzy approaches [40].

Prior the advent of the Web, IESs were implemented as standalone systems. Nowadays for the implementation of IESs Web-based technologies are frequently employed since learning contents are usually presented to learners through a Web browser. In fact, various programming languages and tools may be used. For instance, Java and XML were used to implement the system presented in [11] and Active Server Pages (ASP) were used to implement the system in [40]. A useful tool for implementing Web-based IESs is Jess, a Java based expert systems shell which is free for educational use [17]. Jess was used for instance to implement the runtime parts of the expert systems in [24] and [35]. Agent-based approaches have also proven useful in the implementation of IESs.

Tools may be also used for the offline construction of the IES knowledge bases. Quite frequently, the contents of the knowledge bases (e.g., rules, neural networks) are produced from available datasets. In such cases, tools such as the free software Weka [20] which includes a collection of machine learning algorithms are useful. Matlab also includes a tool for the construction of neural networks. For the construction of hybrid knowledge bases, specialized tools may be required (e.g., [21]).

Databases are also required to store data concerning the user model, domain knowledge, pedagogical module and expert knowledge. In educational applications and especially those involving young children, time-efficiency in data storage and retrieval is a requirement. Obviously various RDBMSs can be used for this purpose. For instance, in SHAIEx [3], [4], [16] MySQL was used whereas in INSPIRE [40] SQL Server.

In contrast to other types of learners, IES learning content addressed to young children should be based on multimedia rather than on text. This involves all types of IES activities (e.g., presentation of content, interactive activities such as exercises). For instance, in a multiple choice exercise the alternative choices presented to learners should be multimedia items such as images, sounds, animations or video instead of mere text. Virtual agents as in [14] and [57] could prove useful in IESs. Obviously, an IES addressed to young learners requires more time and effort for its implementation compared to an IES addressed to older learners. In fact, several phases may be required for the design and implementation of an IES to cater for young children's needs and preferences [16].

2.3 Intelligent Educational Robots for Young Children

A number of research efforts have been presented that involve integration of intelligent robots in early childhood contexts. The presented research approaches mostly involve robots integrated in a classroom or clinical setting. Robots may be exploited at homes as well. There are also general research efforts concerning robot-child interaction in any type of setting such as approaches regarding methods for recording and analyzing interaction data. Interesting approaches addressed to children with special needs have also been presented.

In classroom settings, robots are mainly used for edutainment purposes. Children may learn about, from and with robots [54]. Children learn about robots as they constitute a technology that according to certain predictions will be available in most homes in the near future. Robots may act as teaching assistants providing learning and social activities. Children may also learn with robots since after long term child-robot interaction, children may regard robots as peers [54], [55]. Long term child-robot interaction raises an important issue. The issue is whether the child will retain interest in interacting with the robot or not. In the initial period that robots are introduced to childhood settings, it is very likely that children will be very interested in the newly introduced technological resource. Afterwards, as children become accustomed with the introduced robots, their interest may decline. Therefore, robot designers as well as robot content and service providers should incorporate characteristics ensuring a dynamic and rich child-robot interaction.

Robots may record data (e.g., images, videos) concerning children they interact with. Such data may be incorporated in children's e-portfolios maintained by teachers. They could be exploited by teachers for assessment purposes, to record children's development, to show them to student parents during their face-to-face meetings or to make them available to parents through Internet-based technologies. Specialized intelligent technologies may assist the robot in acquiring quality data [60] and in recognizing/classifying children faces. Children in cooperation with their teachers and parents could maintain recorded data (e.g., data concerning free playtime activities) using a customized Web-based environment [46], [47]. Robots may send data recorded in classrooms to parents through the Internet as in [28] so that they may obtain information concerning their children's activities in classroom. Obviously robots at home could also be used to record data involving children's activities and to make it available to teachers and classmates. Therefore, robots could be exploited to connect homes with schools.

Robotic technology can be useful in special education. Young children with special needs require modified teaching methods and environments and the technological assistance of robots could prove to be beneficial. Promising results have been published concerning young children who are blind [7], with mobility impairments [2] and with autism [19], [51].

In a clinical setting, robots could be useful in several roles. They could provide therapy assistance and enable disability detection. Robots may generally record data concerning children that would have been otherwise difficult, impossible or time-consuming for clinicians or therapists to record with alternative means [51].

In the following, the functionality of certain robots addressed to early childhood is summarized. In Section 4, research results concerning the specific robots are presented.

The robot iRobiQ is a small robot weighing 7 kg [52]. It was designed and developed by Yujin Robot Co. Ltd. in Korea. It is useful for human-robot interaction involving gestures and expression of emotions. It has two arms and LCD based eye units which can be coupled together with the LED in the mouth region to express facial emotions. Its head contains a camera for visual interaction. Its software runs on an internal computer providing voice and vision capabilities. Voice capabilities include voice recognition, name call recognition, sound source recognition, detection and response to clapping sounds and voice synthesis [52]. Its vision capabilities include face detection, face, object and gesture recognition. Touch sensors in different parts of the robot's body facilitate interaction with humans. In iRobiQ's body there is also a touch screen LCD display providing a multimedia-based interface to various functionalities. It moves using wheels under its feet and is capable of self-navigation avoiding obstacles. It may connect to servers through networks in order to deliver available contents and services.

Sponge Robot [13] is a small humanoid robot developed for playful interaction. It is based on the Robovie-X platform developed at ATR Robotics and Vstone Co., Japan. Its height is 37cm and its weight is 1.4 kg. The robot's shape is thus similar to that of a human baby. Humans may easily lift it up and play with it. Among its features are thirteen (13) degrees of freedom that is, two degrees of freedom in each arm, four in each leg and one in its head.

Porongbot is a small-sized robot designed for young children by KT robotics in Korea. It is intended to provide affectionate and emotional edutainment to young children [32]. It can wag its two ears, turn its head and move using wheels under its feet. To receive input from children, the robot has an LCD touch screen, touch sensors, microphones and buttons. The colors of Porongbot's head, ears and feet may change. It can also make sounds and display output on the LCD screen. Porongbot connects to a server to download edutainment content.

PaPeRo is a robot developed by NEC Corporation. It is a small-sized robot and its height is similar to that of young children. PaPeRo has been designed for interaction with children and teachers in classrooms. PaPeRo has eye cameras used to obtain image and movie data involving children and the classroom. Such data include children's facial expressions since the robot's height enables the eye camera to be in the same level with children's faces. It obtains instructions via touch control and text messages sent by remote users through the Internet. It may also send data to remote users in a proper form. In [28], parents use cellular phones to send PaPeRo instructions and receive data regarding children.

Kibo is a humanoid robot introduced in [31]. It weighs 7 kg and its height is approximately 0.5 m. Kibo has been designed for entertainment purposes. It may walk and dance with twenty-two (22) joints. It may recognize human gestures and voice and respond accordingly. It may also recognize human facial expressions and generate its own face expression with moving eyebrows and lips. To respond to events in real time, the robot incorporates distributed processing units. There are also computers outside the robot communicating with the robot's internal units via wireless LAN.

In [19], two humanoid robots (i.e. Troy and Trevor) are developed to assist in autism therapy in therapy settings. Both of them satisfy defined requirements for autism therapy. They are semi-autonomous and the therapist uses a specially designed interface to control them. Sequences of actions may be programmed and made available to therapists. They may move objects with their arms. Troy is an upper-body robot roughly the size of a four year-old child. It has two arms with some degrees of freedom, a large base to hold it still and a computer screen for its face. The computer screen enables the therapist to change the robot's face. Trevor is created using LEGO Mindstorms. It has a face and hands and is about the size of a human toddler.

Tito is a socially interactive robot emulating a humanoid shape and approximately 60 cm tall [37]. It is teleoperated using wireless remote control and is designed to help children with autism. It moves using wheels. Its head and arms may also move. It may generate vocal requests and incorporate pre-programmed behavior sequences.

Roball is a mobile robotic toy in which the robot is encapsulated inside a sphere [37], [49]. It is addressed to toddlers. Roball is therefore capable to move in an environment filled with various obstacles such as toys and other objects. Roball satisfies requirements concerning child-robot interaction since it is small, light, inexpensive, its fragile parts are protected inside the shell, interaction is simple and safe and most children previously know how to interact with spherical objects such as balls. Roball is also useful for children with autism due to its simplicity, inexistence of distracting features and ability to perform child-robot communication by touch.

QRIO is a humanoid robot with a size smaller than toddlers and has been developed by Sony after years of research. It is autonomous and able to perform a range of tasks such as real-time human imitation, audio and visual recognition of humans, dialogues in many ways, walking, running, jumping, dancing, singing, playing soccer and learning [54]. It incorporates three CPUs. Moreover, remote computers may be exploited as remote brains using its embedded wireless LAN system. Research results have been presented showing that young children interacting with it regard it as a peer [54], [55].

Table 2 summarizes the characteristics of the specific robots.

Table 2 Characteristics of robots used in early childhood settings

Robot Name	Developer	Use
iRobiQ	Yujin Robot Co. Ltd.	Interaction involving gestures and expression of emotions, content downloading
Sponge Robot	[13]	Humans may lift it up and play with it
Porongbot	KT robotics	Affectionate and emotional edutainment, content downloading
PaPeRo	NEC Corporation	Interacts with children, teachers, parents, receives instructions and submits data through networks
Kibo	[31]	Entertainment
Troy and Trevor	[19]	Autism therapy
Tito	[37]	Designed to help children with autism
Roball	[49], [37]	Addressed to toddlers, moves in environments filled with obstacles
QRIO	Sony	Designed to interact as children's peer

3 Case Studies of Integrating IESs in Early Childhood Settings

In this section, specific case studies concerning integration of IESs in early childhood settings are outlined. Some of them concern children with special needs [57], [18], [15]. Section 3.1 presents an outline of the relevant approaches whereas Section 3.2 discusses the derived conclusions.

3.1 Outline of IES Approaches in Early Childhood

In [29] an adaptive mobile learning approach for kindergarten mathematics is presented. Learners were six-year-old children. Mobile learning (m-learning) has become important the last decade due to the popularity of mobile devices and advances in wireless infrastructure that enable ubiquitous access to learning services. The specific approach presents a geometry learning game for handheld devices (e.g., PDAs) with a touch screen. The PDAs were Compaq iPaq PocketPCs. It is easier for young children to use devices with a touch screen than computers with a mouse. The PDAs were wirelessly connected to a Web server. The game provides simple adaptation to user behavior and the positive results demonstrate that a more complex behavior could provide additional benefits.

SHAIEx is an adaptive hypermedia system for foreign language learning in early childhood. The system is addressed to three- to six-year-old children. Design and implementation aspects have been presented in a series of publications [3], [4], [16]. The overall development of SHAIEx was carefully designed to include six phases so that specific early age language learning needs and preferences are catered for [16]. The phases involved a preliminary study of the adaptive system, development of hypermedia learning content, study of language learners' profiles, definition of an adapted interface, integration of the system in an education environment and system evaluation. The content and context adapt to the levels of the European Portfolio of Languages. The study of language learners' profiles demonstrated the crucial importance of color, images and sound. Tests also showed that learner comprehension improved in case a suitable pet friend or interactive mascot was employed in the presented topics. Children were asked to choose and color their favorite characters. SHAIEx supports adaptive presentation and adaptive navigation. Adaptation is based on aspects such as language, activity difficulty, age, learning style and knowledge level. In contrast to usual AEHSs, the content presented by SHAIEx is multimedia-based to accommodate the needs of young children. The pedagogic domain consists of didactic units such as 'hello', 'the body', 'home', 'the family', 'toys', 'food' and 'school'. The activities for each unit concern presentation, interaction, evaluation and review. Games were also incorporated in the system involving aspects such as object selection, counting, matching, coloring and body identification. Rules are employed to decide the next task to perform. The system architecture is Web-based. The learner accesses the activities with a Web browser. The user interface is implemented with Adobe Flash. The system functionality is executed on an Apache Tomcat Server. Java Servlets are executed to provide adaptation. The server side also includes a MySQL database storing the user model, the pedagogic domain, tasks and rules.

SHAIEx has also been used to teach English vocabulary to young Iranian children [1]. Forty (40) six- to seven-year-old children that had no prior knowledge of English participated in the study. Twenty of them were taught using SHAIEx and the rest of them with traditional teaching methods. The study lasted forty-five (45) days and consisted of three 90 minute sessions per week. Results on subsequent vocabulary tests showed that children using SHAIEx had a higher mean score in tests compared to the other children. This indicates the success of SHAIEx. The study also showed that children using SHAIEx learned in a much more entertaining and amusing way than the rest of the children.

In [57] IESs using animated and conversational pedagogical agents for individualized tutoring or therapy are presented. The agents are used to teach reading and to conduct speech therapy. They are able to talk and listen to users providing real-time feedback. They are intended to behave more or less like sensitive and effective teachers or therapists. The systems were developed with the assistance of experts and were deemed as very believable and helpful by users. The user interacts with the systems via mouse clicks, keystrokes or speech. The systems adapt to the user skill level and behavior. Virtual speech therapy systems for four independent treatments concerning Parkinson's Disease and aphasia were developed. Furthermore, virtual tutors for reading instruction, reading assessment and assistive services were developed. By integrating such virtual tutors in kindergartens, improvements in letter and word recognition were reported. The systems are designed to be deployed on the Web. Rules were used to represent the learning process and expert knowledge. The architecture consists of application, communication and common components. Application components were designed in collaboration with experts and include application interface and data (e.g., rules, user data and media objects). The communication components involve perceptive and generative system capabilities (e.g., character animation, automatic speech recognition and reading tracking). The common components are written in Java and connect application and communication components.

In [18], LODE, a logic-based web tool for deaf children is presented. LODE was the first e-learning system in the context of deaf children literacy intervention to address global reasoning on whole e-stories. It is difficult for deaf children to read and write due to the fact that they are not stimulated by continuous oral communication. A specific aspect requiring intervention in young age is the difficulty in comprehending global reasoning such as temporal reasoning between verbal language episodes. LODE employs constraint programming [5] to perform automated temporal reasoning and assist children in inferring correct temporal relations in stories. The system provides famous children e-stories. A child chooses an available story and also responds to relevant reasoning exercises regarding comprehension and production. The difficulty and challenge inherent in presented exercises varies according to the corresponding portion of the story and the child's previous interaction results with the system. In comprehension exercises, (in)consistent temporal relations connecting story events are constructed with the assistance of the automated reasoner and the child has to select the consistent ones with the story. In production exercises, children are asked to compose sentences from scattered sentence units involving the story. The composed sentences describe a temporal relation consistent with the story and LODE provides suggestions to correct sentences with grammatical errors or temporal inconsistencies. LODE employs visual learning strategies using cartoons and images to assist children in story narration and exercises. Textual and spatial visualization techniques in which images represent events are used. In textual visualization, images are connected with an arc labeled with a temporal relation. In spatial visualization, the spatial position of images along the timeline signifies their temporal relation.

In [15] an Adaptive Braille writing Tutor (ABT) is enhanced by incorporating ITS methodologies. The Braille language enables literacy for the visually impaired. Learning to write Braille is difficult as it requires many hours of tedious work. Difficulties in the case of young children increase due to required physical and mental exertion as well as delayed feedback on written text compared to sighted students. ABT was developed at Carnegie Mellon University (http://www.techbridgeworld.org) and uses audio feedback to provide guided practice for young children learning to write Braille. In ABT, an electronic slate and stylus monitor student's writing and transmit data in real-time to a computer linked via a USB cable. Each letter is represented as a combination of six dots of the Braille cell. Software based on received data produces immediate audio feedback to the student. ABT is implemented in C++. The proposed ITS for incorporation in ABT consists of the five usual components of ITSs. Domain knowledge contains the right combination cell dots for each letter. The pedagogical module includes two types of individualized instructions: meta-strategies involving the overall teaching process and instructional strategies involving teaching methods for a particular concept. The expert model represents expert knowledge in writing a specific alphabet. The user interface is primarily based on audio feedback depending on student characteristics such as age, culture and level of progress. Recorded teacher voice and synthetic voice is used as feedback for very young and older children respectively. Sounds encouraging student are used when progress is recorded. The student model is based on the stereotype approach which performs classification to a small number of classes based on student input. It is reported that the plans were to implement the designed ITS.

In [30] the notion of sharing behaviors generated by game users is described. Designers of games may provide mechanisms to users for the construction of behaviors without programming. Game users could share behaviors constructed by them, play with them or against them. The research considers educational games for preschoolers and sports games. The research is based on the author's previous research on MindFarm AI technology that enables behavior construction by teaching. Behaviors are easy to construct, transferrable and reusable. The study on educational games involves Animal Class, a pre-school game in which users play the role of teachers by teaching virtual pets (e.g., octopuses) conceptual structures concerning their curriculum (e.g., geometric shapes). Virtual pets may be used in different competitions. Even six-year-old children found it easy to teach virtual characters. Competition of their characters against their friends' characters was an interesting aspect of the approach. Children were interested in watching their constructed characters in other games.

Table 3 outlines key points of the aforementioned approaches.

3.2 Discussion of Derived Results

The specific approaches cover different aspects in early childhood education and thus it is difficult to compare them. However it is interesting to point out certain useful conclusions.

The approach presented in [29] demonstrates that portable handheld devices with touch screens can be convenient for children to use in order to access e-learning content and services wirelessly. Such an approach could become more interesting with the advent of new generations of portable devices such as tablet PCs. Robots with a touch screen (e.g., iRobiQ) could also be used for this purpose.

An important aspect in IESs integrated in early childhood involves digital game-based learning. The importance of digital game-based learning was briefly discussed in Section 2.1. Most of the presented approaches incorporate (to a certain degree) the aspect of learning games. The approach discussed in [29] involves geometry learning games to present mathematical concepts to young children in an amusing way. SHAIEx incorporates various games that in practice were found effective in teaching young children [1]. The approach presented in [30] focuses specifically in games and goes a step forward compared to the other approaches as it involves children teaching virtual characters and sharing them.

Table 3 Key points of case studies integrating IESs in early childhood

Case Study	Key Points
Adaptive mlearning for kindergarten mathematics, 6-year-old learners [29]	Easier for young children to use devices with a touch screen than computers with a mouse. The positive results demonstrate that a more complex behavior could provide additional benefits.
SHAIEx, a multimedia-based AEHS, for foreign language learning [3], [4], [16]	Several design and implementation phases. Supports adaptive presentation and adaptive navigation. It is multimedia-based and incorporates games.
SHAIEx teaches English vocabulary to Iranian children [1]	SHAIEx games contributed in improved results of children in vocabulary tests. SHAIEx digital games are more entertaining and educative compared to other teaching methods.
IESs using conversational pedagogical agents [57]	Agents teach reading and conduct speech therapy providing real-time feedback. Improvements in letter and word recognition reported.
A logic-based web tool for deaf children [18]	Assists deaf children's temporal reasoning in e-stories concerning verbal language episodes
ITS in an Adaptive Braille writing Tutor [15]	Enhancement of ABT with individualized instructions, quite helpful in developing countries
Sharing of user-generated behaviors in games [30]	Children easily teach virtual pets. Virtual pets may take part in different competitions, compete friends' pets, take part in other games.

Collaborative learning is considered important in early childhood education. Most IESs usually do not focus on collaborative learning. It could be mentioned that the approach presented in [30] incorporates collaborative learning. Collaborative games could thus be one way of incorporating collaborative learning activities in IESs addressed to young children.

Children with special needs usually require early intervention to enhance their skills. IESs such as the ones presented in [57], [18] and [15] could play an important role in this context. More IESs covering additional needs could be implemented as well. For instance, no results concerning the use of IESs in the learning of children with autism have been presented till now. On the contrary, robots have proven useful to children with autism.

Animated and conversational pedagogical agents could prove fruitful in early childhood education as shown in [57]. Virtual agents could constitute the counterpart of robots. More approaches concerning virtual agents could be tested in the future.

Long term evaluation of the presented approaches and comparison with conventional teaching methods are also required. It would be also interesting to obtain evaluation results from young children in different countries as in the case of SHAIEx.

Young children and teachers could also use interactive whiteboards to access IES services. Such an approach has not been presented till now. Touch screens of robots connected to networks could provide an alternative means of accessing IES services.

It should be mentioned that none of the presented approaches involves student parents that is, the presented approaches were not employed to link classroom and home activities. Parents would probably be interested to try out certain of the IES services (such as games).

E-learning systems addressed to young children usually consist of interdisciplinary activities. The presented IESs mostly involve language (e.g., SHAIEx, [15], [18] and [57]) and mathematics (e.g., [29]). Mathematic activities (e.g., counting) are also incorporated in certain SHAIEx games. Science is a domain for which interesting e-learning systems have been developed. In the presented IESs, science aspects are covered in interdisciplinary activities such as in games incorporated in SHAIEx and in [30]. Obviously, more IES activities concerning science and mathematics could be developed.

For obvious reasons, the IESs addressed to young children are based on multimedia technologies. Web-based technologies were also employed in certain of the approaches such as SHAIEx and the approaches presented in [29], [18] and [57]. Web-based IESs may be also accessed by children and parents at home.

Finally, an interesting aspect is that not many IESs addressed to early childhood have been developed till now. This means that early childhood education could become a domain in which fruitful results could be produced by IES researchers and developers.

4 Case Studies of Robot Integration in Early Childhood Settings

In this section, specific case studies concerning integration of robots in early childhood settings are outlined. The case studies are presented in the following four sections. Section 4.1 presents approaches integrating robots in typical early childhood classrooms. Section 4.2 discusses approaches involving young children with special needs. Section 4.3 outlines general approaches concerning robots and young children. Section 4.4 discusses derived conclusions.

4.1 Approaches Integrating Robots in Typical Early Childhood Classrooms

In [27] results of using intelligent robot iRobiQ in early childhood education are presented. The robot was used as teaching assistant for 111 five-year-old children attending two kindergartens and two childcare centers. Children interacted with the robot for about one hour everyday over a period of about two weeks during spring 2009. Children and teachers were interviewed to record their experiences with the robot. The results showed that educational robots may possess contents and functions that promote socio-emotional interactions among children and robots. The indications show that such content and functions should be developed for educational purposes. Robots seem to be more effective when they are in classrooms, close to children and used by individuals rather than by groups.

In [52] iRobiQ provided educational services mainly in the domain of language teaching for kindergarten children. The approach puts emphasis on the concept of ubiquitous network robot that is, a robot combining the advantages of ubiquitous network technologies and mobile characteristics of robots. Through network technologies contents and services developed for the robot may be downloaded from servers and exploited in various contexts. Different types of services that may be developed for the robot include basic services (e.g., photo, video database information), information services (e.g., news, weather and cooking information), education services and entertainment services (e.g., karaoke, games, media player). Education services addressed to early childhood education involve storytelling, sing alone, phrase and word train. The results of exploiting the robot in classroom were very positive. They showed that a robot with bi-directional interaction such as iRobiQ improves young children's linguistic abilities especially in aspects such as story making, story understanding and word recognition. Children's degree of active and adaptive behavior increased. Children also interacted with the robot with increasing familiarity (e.g., they spoke to and touched the robot).

In [28] the robot PaPeRo is exploited to provide asynchronous network-based communication among parents, nursery teachers and children. In this approach, the notion of remote control of a robot for remote collaboration is explored to enable collaboration of parents, teachers and children at times suitable for each other. Synchronous communication may not be always a suitable medium to link parents with teachers and children as they may have different daily schedules [28]. In the specific approach, parents use cellular phone text messaging as a communication tool since this form of communication is convenient. The overall architecture includes a platform to link the robot to parents' cellular phones through conversion of text messages to action commands or conversion of data acquired by the robot to text messages. Parents may send a message indicating a request or even a desired action their child should perform with the robot. The message is received by the robot. The teacher at a suitable time triggers the robot to follow the parent's instructions (e.g., play with the children). The robot's cameras acquire image and movie data concerning the children (e.g., facial expressions during activities). The teacher at an appropriate time triggers the robot to send the requested data to parents' cellular phones in a proper form (e.g., movie file links). Therefore, a two-way communication is established through the robot. On the one hand, parents send messages and requests concerning teachers and children. On the other hand, teachers send data concerning children's activities in classroom. The approach was evaluated in two nursery facilities each involving six young children and their parents. In each facility, trials were executed for about two hours on selected days. Questionnaire results from parents indicated their positive responses to the trials.

The approach presented in [28] could be integrated with an active recognition photography system (ARPS) for child-care robots such as the one presented in [60]. ARPS was implemented based on intelligent technologies for network-based robots connected to servers. It can be used to provide quality photographs of children at classrooms to their parents. ARPS consists of photo evaluation and photo classification modules. The photo evaluation module evaluates picture quality based on detected face features. The photo evaluation module may be also used to control a robot to adjust its posture so that only quality pictures of children faces are taken. The photo classification module recognizes and classifies faces in pictures using stored face pictures. Taken pictures are stored in databases and for faces not recognized the teacher supplies the students' info. The approach was evaluated for two months in a nursery with thirty-two (32) children from three to four years old. The network-based robots acting as teacher assistants employed were AnyRobot I and II developed in Samsung Electronics. These robots were remotely controlled with devices such as remote computers and PDAs.

In [26] a study concerning the daily use of iRobiQ from kindergarten students during their free playtime is presented. Observation sessions were conducted for twenty-three (23) children from the three-year old class and for twenty (20) children from the four-year old class. The involved time period lasted three months i.e. from December 2008 till February 2009. Preparatory activities were carried out before the robots were introduced. Furthermore, robot zones and utilization rules were established. Therefore, when robots were introduced, children and teachers were adequately prepared for effective and safe interaction as well as creation of close relationship. Teachers may be stressed when young children are given free access to classroom resources such as cameras, interactive whiteboards, computers and robots. They are concerned about accidents, damages or malfunctions. Also the price of certain resources may be expensive. Experiences of children's use of robots and other resources have shown that with appropriate preparation and instructions, children are able to independently and safely exploit robots and various other types of resources. Robot activities were accepted by children as readily as any other new activity. Throughout the three months, no changes were recorded in the utilization time and frequency of robots meaning that children remained interested in robots during a long period. Children interacted with the robots in small groups but usually in pairs due to the small size of the robot and its LCD screen. The roles that children assumed while interacting with the robots were similar to roles assumed in other play activities (e.g., principal user, assistant user and observer). Age and gender did not influence the children's interaction with robots. A general conclusion is that in order to effectively exploit characteristics of robots such as mobility and automaticity during their interaction with children, appropriate robot stimuli and contents need to be developed.

In [31] preliminary results concerning introduction of the humanoid robot Kibo to a kindergarten during a robot show are presented. The experiments were based on Kibo's characteristics such as choreography, gesture recognition, facial recognition and expression as well as voice recognition. Four robots were used demonstrating synchronized motion. The teacher started to communicate with the robots using a microphone. During the conversation, the teacher asked the robots to begin choreography along music. The robots followed voice instructions in a synchronized manner. They also reacted to teacher postures and facial expressions and also synchronized their lips and facial expressions.

In [34] an approach to a robot personalized to student traits is presented. The approach combines robot and ITS technologies. It uses visual and vocal data concerning a student to adapt contents provided by a robot according to the student's needs. Robot sensors enabling to a certain degree tasks such as voice recognition, face recognition, recording of facial expressions and body motions can be exploited to evaluate learning process. According to the evaluation based on human-robot interaction, the proper contents are selected. The overall architecture is network-based. Besides the robot, it consists of a main server containing robot learning contents and an agent server. The agent server receives student profiles from the robot which are stored in a database. Based on student information, it acquires proper learning content from the main server and submits it to the robot. The robot uses the received content in the learning process with the student and obtains interaction data submitted afterwards to the agent server in order to perform student learning evaluation.

In [61] the results of a study concerning the relevancy of computer utilization by young children to their use of education robots are presented. Such a correlation could be considered possible due to the fact that robots usually have an LCD screen presenting e-learning content just like computers. The study involved three early childhood classes of three-, four- and five-year-old children. When the study was conducted, the iRobiQ robot had been used in these three classes for about eight months. Three classes were studied to identify relationship between computer and robot utilization according to age. Results showed that although computer utilization skills differed according to the age of students, there was no difference in robot use at any age. This implies that it is easier for younger children to interact with robots compared to computers. Furthermore, children's traits in using computers were not related with the corresponding traits in using robots. More specifically, computer utilization frequency and capability were not correlated to robot utilization. It seems that robot characteristics such as mobility, gestures, sounds, facial expressions, vocal and visual recognition overcome certain computer limitations.

In [55] results of an extensive study involving socialization between toddlers and robots are presented. The study involved 18- to 24-month-old toddlers and the robot QRIO. There were forty-five (45) hourly sessions spanning five months recorded with video cameras. The videos were studied and analyzed for two years. The young age of children enabled researchers to focus on social interaction not much dependent on speech. In addition, children at such a young age do not have preconceived notions of robots. The study consisted of three phases. During the first and third phase, the robot used its full behavioral repertoire while interacting with children. During the second phase, the robot was programmed to produce interesting but predictable behaviors. During the first and third phase, the quality of interaction between toddlers and robot was high. During the second phase, the quality of interaction declined meaning that toddlers preferred interacting with the robot when it exhibited its entire behavior repertoire. The children did not lose interest in the robot throughout the prolonged time period of five months. Moreover, the children's haptic behavior towards the robot progressively changed and resembled behavior towards a peer. The children's social and care-taking behavior towards the robot was very different compared to their behavior towards control toys used throughout the sessions. The results ultimately showed that the robot was close to autonomously bond and socialize with young children for significant time periods.

QRIO can also be used for dance interaction with toddlers in a classroom environment [54]. In fact, QRIO supports various dance interaction technologies from non-autonomous choreographed dance to autonomous one. Two modes are supported for the autonomous dance technologies: activeness and passiveness. In the passive mode, QRIO reacts to the outside motion to provide motion imitation with the partner. In the active mode, QRIO spontaneously moves to maximize the information for the presence of a reactive partner. Activeness is based on contingency detection formulated by Bayesian inference. In real-time dance interactions, the robot is also able to include emotion expressions. Facial expressions and whole body gestures can be used to express emotions. Among others, neural networks and reinforcement mechanisms are employed for this task.

Table 4 summarizes results derived from the aforementioned approaches.

Table 4 Summary of approaches integrating robots in typical classrooms

Case Study	Key Points
iRobiQ as teaching assistant, 111 five-year-old children in two kindergartens and two childcare centers, two-week study [27]	Robots seem to be more effective when in classrooms, close to children and used by individuals.
iRobiQ for language teaching in a kindergarten [52]	Children's linguistic abilities improved especially in aspects such as story making, story understanding and word recognition.
PaPeRo in two nursery facilities, 12 children and their parents [28]	Robot provides asynchronous network-based communication among parents, nursery teachers and children.
Active recognition photography system, AnyRobot I and II in a nursery with 32 children from three to four years old, two-month study [60]	Photo evaluation and classification, provision of quality photographs of children at classrooms to parents.
iRobiQ, 23 three-year-old children, 20 four-year-old children, three-month study [26]	Children remained interested in robots during a long period. Children usually interacted with robots in small groups but usually in pairs, roles similar to those assumed in other play activities.
Kibo introduced to a kindergarten during a show [31]	Four robots demonstrated synchronized motion and facial expressions, followed teacher's voice instructions and reacted to teacher's postures and facial expressions.
Robot personalized to student traits [34]	Student's visual and vocal data used to adapt contents provided by a robot according to student's needs, network-based architecture.
iRobiQ in three early childhood classes of three-, four- and five-year-old children, eight-month study [61]	There is no relationship between computer and robot utilization.
QRIO, 18- to 24-month-old toddlers, video camera recording, five-month study [55]	Throughout the 5 months, children retained interest in the robot. The robot was close to autonomously bond and socialize with young children for significant time periods.
QRIO, dance interaction with toddlers in a classroom environment [54]	Robot supports dance interaction technologies ranging from non-autonomous choreographed dance to autonomous one. Robot expresses emotions during dancing.

4.2 Robots and Young Children with Special Needs

In [2] an approach to train toddlers seated on mobile robots to steer using force-feedback joystick is presented. The main purpose of the approach is to train infants with special needs that display limited independent walking. Mobility impairments limit the typical development of a child hindering exploration and social contacts and thus negatively affecting life quality. The hardware in the experiment setup consisted of a mobile robot, sensors and a force-feedback joystick. The study involved toddlers that on average were thirty months old. Separate driving experiments were performed for ten typically developing toddlers as well as two toddlers with special needs. The two toddlers with special needs were a two-year-old with spina bifida and a three-year-old with cerebral palsy. The first child had good control of hand movement lacking the ability to walk and balance himself whereas the second child had decreased control of hand movement and coordination. The results were positive for all groups of toddlers. More specifically, the toddlers with special needs were able to learn to make turns and follow lines after five non-consecutive days of training. The learnt behavior was displayed several days after training and also in different configuration and location.

In [19] requirements for robots in autism therapy and preliminary trial results in a clinical setting are presented. The purpose of the defined requirements for robots and user interfaces are to provide guidelines in developing robots that will effectively assist child autism therapists. Robot design requirements defined concern functionality and appearance, safety and autonomy. Each type of robot exhibits different characteristics, advantages and disadvantages and thus robot design requirements enable a robot to perform desired therapist activities. As far as autonomy is concerned, it should be mentioned that therapists need to have certain control on the robot and so autonomy to a certain degree is desired. The user interface should be friendly to therapists, responsive, flexible and controlled with a (preferably small) handheld device. The researchers built two humanoid robots (i.e. Troy and Trevor) that satisfied the defined requirements. They present preliminary trial results for Troy. Troy has been tested with two typically developing children, a four-year-old boy and a three-year-old girl. Results concerning the children's social interaction with Troy and the clinician were positive. Promising preliminary results involving two children with autism are also presented. The two children showed interest in Troy and a higher degree of interaction with the therapist compared to sessions without Troy.

In [37] socially interactive mobile robots are presented such as Tito and Roball. For instance, Tito was used in trials conducted by a psycho-educator with four five-year-old children with autism. Tito records and stores the timing between its interactions with a child. Preliminary results show that Tito becomes an incentive for the child.

In [51] issues concerning the use of social robots to diagnose, treat and understand autism are discussed. The discussion is based on three years of integration and immersion with a clinical research group at the Yale Child Study Center which performs diagnostic evaluations of children for autism. A person with autism is characterized by social and communicative impairments. Diagnosis is based on a child's social skills such as eye-to-eye gaze, facial expression, body posture and gestures. There have been various studies showing that a robot motivates and engages children. However, an argument of the research is that when interacting with robots, persons with autism may not display a behavior such as the one expected by typical persons. This aspect should be studied and taken into consideration. For instance, a pilot study involving typical and autistic preschool children's interactions with ESRA, a simple robot generating facial expressions, was carried out. Children reactions to two robot conditions (i.e. a contingent and a non-contingent condition) were studied. Typical children were attentive to the robot only in the contingent condition whereas children with autism responded with attentiveness to both robot conditions. The research also introduces quantitative, objective metrics of social response to handle autistic diagnosis problems. Metrics concern passive and interactive observations. Passive sensing can be performed by social robots and relevant metrics involve detection of gaze direction, position tracking and vocal prosody. Socially interactive robots with certain autonomy provide the opportunity to effectively obtain information concerning children's social behavior. A clinician could possibly obtain relevant information in similar quality and quantity only with extensive work.

In [7] a robotic dog was used for pre-orientation and interaction of toddlers and preschoolers who are blind. The robot used was a modified Sony Aibo to suit interaction with the blind. The results showed that very young children who were blind were able to operate the robot. A difficult task in robot operation for persons who are blind concerns connection and disconnection of the recharger. The use of distinctive texture solved this problem. Very young children who were blind due to their interaction with the robot became more active, excited and engaged into playful learning activities. The results show that robots can be used in an education environment at least as assistants for people with disabilities. For people with low vision, language and text presentation is important. In this context, robots can also act as human-computer interface enhancing accessibility. In a constrained environment, robots could be used in autonomous vehicles for individual transport of people who are blind and restricted to a wheel chair.

In [33] a robot-assisted observation system for children with autism was developed. The system was developed for a specialized kindergarten for developmentally disabled children. The system consists of six pet robots, a handheld device (e.g., PDA) used to input data concerning observations, video cameras with microphones to record data and a remote server to maintain a database with recorded data. Experiments were conducted three times per week for three months. Children with autism interacted with the robots and recorded data was transmitted to the database. The system provides efficient information processing and facilitates data analysis (e.g., statistical graphs are produced). Further data analysis facilities could be provided but the successful trial in the kindergarten demonstrated that the observation system is useful for education environments.

Table 5 summarizes results derived from the aforementioned approaches.

4.3 General Approaches Concerning Robots and Young Children

In [32] scenario-based behavior design concerning a network-based robot is explored. The robot used in the research is Porongbot. Scenario-based design was used to extract basic scenarios and detailed scenarios concerning robot behaviors and user responses during human-robot interaction. Appropriate tasks (e.g., turn on/off, play with) for the derived scenarios were also defined. Behaviors were evaluated via computer simulation according to three parameters: sociability (i.e. robot's easiness in generating dialogues), activity (i.e. how intense robot movements are) and agreeableness (i.e. how kindly the robot behaves). Robot behaviors should be diverse, understandable, appropriate to current situations and coherent with personality profile. Scenarios were implemented in the form of scripts and a behavior selection model was implemented. The approach was implemented and evaluated through a simulator.

Table 5 Summary of approaches involving robots and children with special needs

Case Study	Key Points
Training of toddlers that display limited independent walking, tested with a two- and a three-year-old child [2]	Toddlers seated on mobile robots are trained to steer using force-feedback joystick. The learnt behavior was displayed several days after training and also in different configuration and location.
Troy and Trevor in autism therapy, Troy tested with two children with autism [19]	Two children with autism showed interest in Troy and a higher degree of social interaction with the therapist compared to sessions without Troy.
Tito, four five-year-old children with autism [37]	Preliminary results show that Tito becomes an incentive for the child.
Social robots used to diagnose, treat and understand autism [51]	Introduction of quantitative, objective metrics of social response to handle autistic diagnosis problems. Socially interactive robots with certain autonomy may effectively obtain information concerning children's social behavior.
Robotic dog for pre-orientation and interaction of children who are blind [7]	Very young children who were blind were able to operate the robot and became more active, excited and engaged into playful learning activities.
Robot-assisted observation system for children with autism in a specialized kindergarten, experiments conducted for three months [33]	The system provides efficient information processing and facilitates data analysis.

In [50] requirements and specific tools for extended human-robot interactions with children as subjects are presented. More specifically, special recording and analysis tools are required. The study of human-robot interaction may become sophisticated and in the specific research the focus was on extended interaction sequences. There are multiple recording devices (e.g., sensors, cameras) producing data (e.g., facial expressions) from multiple viewpoints. The time scale of events varies and certain behaviors (e.g., changes in eye gaze) may occur within seconds. All data needs to be time-synchronized to constitute a consistent source for analysis. Furthermore, the large amount of (audio and video) data produced needs to be automatically annotated. Manual annotation would be too time-consuming and certain important details from the multiple sources may be missed. Therefore, tools based on computer vision algorithms that would automate detection and documentation of behaviors are required. The researchers mention solutions they have developed for recording and analysis. For recording, they present a scalable system based on seven cameras and microphones in which audio and video data is automatically synchronized and timestamped. A technique with appropriate control interface was developed enabling robot control by a concealed human operator so that the person interacting with the robot believes it is totally autonomous. Two analysis tools are presented. One analysis tool processes video data to provide annotations involving head pose and eye gaze. The other tool provides a framework for combination of visual data so that it can be explored by other applications and tools across a common timeline. The presented tools were used to record and analyze interactions of four- to eight-year-old children with a robot. Such tools are necessary to robot designers, teachers and therapists. For teachers specifically the need for such tools is twofold. On the one hand, teachers need to study and evaluate educational technology used in classroom. On the other hand, analyzed recorded data could be used in educating teachers to new practices [38].

In [13] full-body gesture recognition for interaction with a small robot (i.e. Sponge Robot) is investigated. An aspect that had not been considered prior this research concerned full-body gestures that is, gestures affecting the whole body of the robot (i.e. position and orientation). A small and light humanoid robot needs to recognize such gestures because people will pick it up and interact playfully with it by hugging, shaking and moving it around. A robot should be able to respond to such interaction to create bonds with humans it interacts with. The specific research identifies corresponding gestures and presents a system for their recognition. Data to identify gestures was collected at a research institute and a university from participants interacting playfully with the robot. Video recording was used to record more than a thousand gesture instances. An intelligent system based on Support Vector Machines was developed to learn from the collected data and perform gesture recognition. It should be mentioned that certain gestures have a stronger effect than others whereas certain gestures are interpreted in different ways.

Detailed results concerning Roball are presented in [49]. In this work, requirements concerning child-robot interaction are defined. Roball satisfies such requirements. An adaptive algorithm was developed for adapting Roball's behavior to the received interaction so that children's communication with the robot is reinforced. For instance, according to the interaction it is receiving, the robot may simply wander, avoid obstacles, make noises, produce speech or go faster. Roball was used to study toddler-robot interactions. Roball's characteristics attracted the interest of young children and demonstrated that locomotion capabilities are required in child environments. Trials with young children were conducted in the lab and in typical environments for children. A trial was also conducted at a high school.

In [39] a humanoid robot was developed that dances in real-time with spontaneous and dynamic movements in synchronism to music. It was the first approach in which a robot dynamically danced in correspondence to music rhythm. The overall framework consists of two main modules: a music analysis and a robot control module. The music analysis module is based on Marsyas, an open source software framework for audio analysis and synthesis emphasizing to music signals. This module perceives music rhythm. The robot control module reacts to rhythm data sent by the aforementioned module and to sensor data to promote dynamic dance movements. The researchers mention that their future plans involve the issue of multi-robot dance that is, the synchronization of multiple dancing robots.

Table 6 summarizes key points of general approaches concerning young children and robots.

Table 6 Summary of general approaches involving robots and young children

Case Study	Key Points
Porongbot, scenario-based design [32]	Scenarios concerning diverse, understandable, appropriate and coherent robot behaviors were designed, implemented and evaluated through a simulator.
Tools for extended human-robot interactions, used to record and analyze interactions of four- to eight-year-old children with a robot [50]	Tools and algorithms for scalable recording, synchronization, automatic annotation of interaction data.
Sponge Robot, gesture recognition [13]	Full-body gesture recognition for small and light robots.
Roball [49]	Requirements concerning child-robot interaction are defined. An adaptive algorithm was developed for adapting Roball's behavior.
Real-time robot dancing [39]	Real-time robot synchronization to music rhythm. Dynamic dance movements achieved based on music analysis and sensor data.

4.4 Discussion

A general comment that can be made concerning robots in early childhood settings is that several approaches have been presented employing different types of robots. A direct comparison among the approaches is difficult to be made but certain issues can be pointed out.

A requirement to assess the effectiveness of integrating robots in early childhood education concerns evaluation of the results. Long term interaction of young children with robots could highlight advantages and limitations of robotic technology. Some of the surveyed approaches involved long term child-robot interaction. Such were the approaches presented in [26] and [61] that involved integration of iRobiQ in classroom activities for a time period of three and eight months respectively. Furthermore, in [55] it is mentioned that children interacted with QRIO for five months, ARPS was used for two months [60] and in [33] experiments concerning the presented observation system were conducted for three months. In certain approaches, the total duration of interaction was brief. For instance, in [31] robots were introduced to a kindergarten during a show. There are also approaches for which the total duration of interaction is not mentioned.

For evaluation purposes, data regarding child-robot interaction needs to be recorded and extensively analyzed by teachers and experts in robotic technology. A set of video cameras and microphones are necessary for recording data. Handheld devices such as PDAs or tablet PCs could be useful for inputting observation data perhaps to a database hosted on a remote server [33]. Analysis of recorded video and photo data concerning child-robot interaction is explicitly mentioned in certain approaches (e.g., [55], [13], [60]). The most extensive analysis of recorded video data seems to involve young children's interaction with QRIO [55]. Children interacted with QRIO for five months but analysis of recorded data was carried out for two years. Moreover, in [13] it is mentioned that more than a thousand gesture instances were recorded in video. As the study of child-robot interaction may turn out to be a time-consuming and sophisticated process, special recording and analysis tools are required such as the ones presented in [50]. Useful ideas in this context could also be found in the observation system described in [33]. A system such as ARPS could also be used in this process to evaluate and classify photos [60].

Closer correlation of robot-assisted learning with early childhood education curriculum is also necessary. In [31] it is mentioned that iRobiQ was successful in improving children's linguistic abilities in specific aspects. Children's communication skills were also enhanced with robots especially in the case of children with special needs. Research on other aspects such as mathematics and science is also required.

Several of the approaches explicitly mention testing in classroom environments. Such approaches were for instance the ones presented in [27], [52], [28], [60], [26], [34], [61], [55], [54], [31], [33] and [49]. Certain of these approaches such as the ones presented in [27], [28], [26] and [61] explicitly mention testing in different classes and/or different facilities. Such evaluation results would be useful for the generalization of the reached conclusions.

As mentioned in Section 2, educational technology in early childhood usually involves a combination of technological resources. Most of the approaches do not describe how a combination of robots and other technological resources (e.g., computers, interactive whiteboards, programmable toys) were effective in enhancing different learning aspects. This is a missing point in most of the surveyed approaches. Combination of robots with other technological resources is presented in approaches involving observation, recording and analysis (e.g., [33], [50]).

Some type of robot and computer functionality combination is described in certain approaches. More specifically, computer functionality is provided to learners through robots. This could be an interesting research direction. Robots connected to networks such as iRobiQ, Porongbot and the one presented in [34] could provide contents and services hosted in remote computers to students. Moreover, robots with a touch screen provide to a certain degree similar functionality to computers as they are able to display software applications and receive inputs from students. For there reasons, the research presented in [61] explored the relevancy of computer and robot utilization by young children. An analysis comparing the effectiveness of computers and robots in enhancing young children's learning would be interesting.

A further comment that can be made is that more approaches concerning integration of robots in early childhood settings have been presented compared to the approaches discussing integration of (computer-based) IESs in corresponding environments. It seems that more researchers are working in the field of robotics in early childhood. Furthermore, even very young children may interact with robots whereas with IESs this could be more difficult. An interesting approach with difficulties in its implementation could be the combination of robotic and (computer-based) IES technologies as in [34].

An interesting aspect involves the form and size of robots that have been integrated in early childhood settings. The size of the robots is small so that young and very young children may find it appealing to interact with them. Most of the robots have some type of humanoid form. Such robots are iRobiQ, Sponge Robot, PaPeRo, Kibo, Troy, Trevor, Tito and QRIO. Troy was used in autism therapy and differs from other humanoid robots as it has a computer screen for its face. Robots in the form of pets have also been used in early childhood (e.g., [7]). Roball is quite different from robots described in the other surveyed approaches as it is encapsulated within a sphere. Roball signifies that different robot forms than the 'usual' ones may be explored. Requirements concerning learners and learning environment need to be carefully studied when implementing robots. Children with special needs may impose different requirements from robots as their reactions may differ from other children. Roball and Sponge Robot are robots that young children are able to lift up. Specifically, Sponge Robot has been developed for playful interaction when lifted up and differs from other robots in this context.

Certain robots were developed especially for children with special needs. Such robots are described in [2], [19], [37], [51], [7] and [33]. Some of these robots in spite of being developed for children with special needs were also tested with typical children (e.g., [2], [19], [51]) to record differences in children's reactions. There are no explicit reports concerning interaction of certain robots such as QRIO, iRobiQ, Sponge Robot, Porongbot, PaPeRo and Kibo with children having special needs. In [49] it is mentioned that Roball satisfies requirements of children with autism.

The surveyed approaches concern young children with a variety of ages. Certain approaches concern very young children. More specifically:

- In [55] QRIO interacted with 18- to 24- month-old toddlers, in [2] the study involved toddlers that were on average thirty months old (i.e. two to three years old), in [7] the robotic dog interacted with very young children.
- iRobiQ in [26] and [61] and Troy in [19] interacted with three- and four- year-old children. This was also the case for the study in [60] involving ARPS also concerned three-year-old children.
- In [26] and [61] iRobiQ interacted with four-year-old children and in [19] Troy was tested with a four-year-old child. ARPS in [60] involved four-year-old (besides three-year-old) children.

- The approach in [28] was evaluated in nursery facilities thus it probably involved children under five.
- In [27] and [61] iRobiQ interacted with five-year-old children and so did Tito in [37].
- In [31], [52] and [33] Kibo, iRobiQ and the robot-assisted observation system respectively were used in a kindergarten and thus the specific research probably involved children who were at least five years old.
- In [50] interactions of four- to eight-year-old children with a robot were recorded and analyzed.

In total, it can be mentioned that approaches presented in [55], [2], [7], [26], [61], [19], [60] and [50] were tested with children under five. The approaches presented in [27], [61], [37], [31], [52], [33] and [50] were tested with children who were at least five years old. Certain approaches (e.g., [50], [61]) were tested with children under five as well as with children who were at least five years old. Roball in [49] was also successfully tested in a high school setting. Perhaps certain robots discussed in the surveyed approaches could also be used in elementary schools.

5 Conclusions

This paper discusses issues regarding application of Artificial Intelligence methods in early childhood education. The discussion involves Intelligent Educational Systems (i.e. Intelligent Tutoring and Adaptive Educational Hypermedia Systems) and robots. Such a discussion is useful to Artificial Intelligence researchers and practitioners, educational technology researchers and practitioners, teachers, undergraduate and postgraduate students.

Research work in early childhood educational technology is not yet as extensive as in other levels of education. Approaches surveyed in this paper demonstrate that fruitful results may be produced by incorporating Artificial Intelligence methods in early childhood education. Results have shown that children are motivated in taking part in learning and social activities and remain interested in the technological resource even in long term interaction. Approaches enhancing literacy of children with special needs have also been successful. An important aspect is that learning goals are achieved.

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