The Use of Internet of Things Devices in Early Childhood Education: A Systematic Review

Abstract

Internet of Things (IoT) devices are becoming ubiquitous and gradually impacting on young children's play, learning and growth worldwide. It is vital for educators and parents to understand how the IoT devices have been used and with what consequences. Attempts have been made by researchers to explore varied IoT device usage in ECE, but there lacks a consolidated review on this topic. Therefore, we conducted a systematic review on the IoT device deployment in ECE using four major databases over the past 20 years. A qualitative synthesis was performed to analyse the data extracted. The results revealed that for young children from birth to 8 years of age, the IoT devices were normally used as IoT playthings. Additionally, the IoT devices could provide the young children with opportunities to connect digital and physical worlds for their playful explorations, help them to build their knowledge base, arouse their interest and enthusiasm, and encourage them to be autonomous learners. No negative influence associated with the children's IoT device use was identified in the selected articles. However, high prices and data security were two concerns raised as influencing the educators' and parents' IoT device adoption. The findings may serve as a rationale for practitioners' and parents' decision making. Implications for future research are also suggested.

Keywords Internet of Things devices; Early childhood; Play; Learning; Internet of Toys

1. Introduction

Internet of Things (IoT) devices are becoming increasingly prevalent. It is estimated that over eight billion IoT devices are being used across the globe (Statista, 2021). They are being deployed in diverse domains such as agriculture (Subahi & Bouazza, 2020), healthcare (Ray, Dash, Salah, & Kumar, 2021), smart buildings (Jia, Komeily, Wang, & Srinivasan, 2019) and education (De La Guia et al., 2016), and are bringing automation and connection to people in an unprecedented way. IoT devices, in the context of this study, refer to the physical devices belonging to the IoT paradigm. According to the Institute of Electrical and Electronics Engineers (IEEE), the IoT works as a network that connects uniquely identifiable objects which have sensing and/or actuation capacity to the web (Minerva, Biru, & Rotondi, 2015).

In the education sector, IoT devices have been utilised by parents, educators and institutions to attend to varied needs. For instance, some IoT devices can assist educators to monitor class attendance (Alotaibi, 2015), while some IoT devices can be employed to facilitate students' learning of different knowledge such as foreign languages (Cheng, Wang, Yang, Yang, & Chen, 2020) and data interpretation skills (Davies, Beauchamp, Davies, & Price, 2020). Regarding early childhood education (ECE) which focuses on children aged between birth and eight years of age (Sumsion, 1997), the ways of IoT device deployment may vary due to the considerations about young children's cognitive development levels, pedagogical needs and the IoT devices accessible to them. Early childhood is a critical period towards a person's lifelong development (Mukherji & Dryden, 2014) and technologies may bring lasting influences on young children. It is warned that young children's new technology use often proceeds ahead of enough policy and regulation, which might expose them to risks of harm (Livingstone & Stoilova, 2021). Therefore, it is of great necessity to closely examine new technology use in ECE, in order to recognize and utilize the benefits, and to minimize the potential risks. Although attempts have been made by researchers to explore IoT device use in ECE, there lacks a systematic review to provide synthesized evidence on a key question: “How have IoT devices been used in early childhood settings, and with what consequences?”

In 2017, Kassab et al. (2020) conducted a meaningful systematic review on the benefits and challenges of incorporating the IoT into education, which covered all the stages of learning. Among the 89 articles selected by Kassab et al. (2020), there were 61 articles about higher education and only three articles were about ECE, indicating that the IoT was not widely investigated in ECE in 2017. Besides, Kassab et al. (2020) focused more on checking the IoT system as a whole than analysing the terminal devices connected to the IoT network. Accordingly, the results presented by Kassab et al. (2020), are not closely relevant to the use of IoT devices in ECE, and cannot illustrate the possible advantages and/or issues associated with the usage. We are going to fill in this gap. Eleven empirical studies conducted between 1999 and 2020 which explored IoT device use in ECE were selected for the current systematic review. The findings from this study are important towards future practice and research. The synthesized outcomes will enable parents, educators and policy makers to identify the benefits and challenges of using IoT devices, so as to assist them to make informed and evidence-based decisions regarding IoT deployment in ECE. Furthermore, the findings might add a basis for the critical discussions around young children’s technology usage and suggest some significant research gaps that worth investigations in the future.

1.1. Theoretical background

1.1.1 Technologies and early childhood

Digital technologies have become natural parts of young children’s lives, so contemporary young children are often described as digital natives (Recalde &

Gutiérrez-García, 2017). Their first use of technologies, if not since birth, might be before the age of one (Dardanou et al., 2020; Kabali et al., 2015). Debates over young children's technology use have lasted for decades (Lentz et al., 2014; Papadakis, 2021b). For instance, some researchers warn that technologies may hinder children's social development (Cordes & Miller, 2000), while others believe that technologies could promote social interactions among young children (Plowman & McPake, 2013). As for the specific technologies involved in the ever-lasting debates, they keep changing and evolving. For example, discussions around television viewing by young children started in the 20th century (Black & Newman, 1995), but in more recent years, related research extended to include some other devices with screens or even mobile touch-screens (Papadakis, 2021a). We believe that new technologies could bring new opportunities and possibly new challenges to young children's development. Therefore, updated research and evidence are always needed.

Nowadays, IoT devices are commonly accessible in many households and schools. Young children's play, learning and communication patterns might be reshaped by those devices. In the current debate, there lacks secondary studies that consolidate all the empirical research exists on IoT device use in young children's digitalized childhoods.

1.1.2 Play and development

Play is essential towards young children's development. Engaging in play can support young children to practice useful later skills (Smith, 1982) such as social, language and motor skills (Holmes et al., 2020; Moghaddaszadeh & Belcastr, 2021), promote their mental development (Vygotsky, 1967) and stimulate their creativity (Sutton-Smith, 2001). Play-based learning and play-based pedagogy are, thus, very prevailing in ECE (Allee-Herndon, Roberts, Hu, Clark, & Stewart, 2021). Describing and theorizing young children's play practices are also popular research topics in early childhood literature. In the era of technologies, many of children's playthings become digital, creating a new branch of play which is called digital play (Fleer, 2016; Marsh, Plowman, Yamada-Rice, Bishop, & Scott, 2016). While the importance of play is widely acknowledged, the influence of digital play on young children's development is controversial (Bird & Edwards, 2015). Anxieties around the appropriateness of digital play in early childhood actually come from the concerns about technologies.

When discussing the use of IoT devices in ECE, we assume that play is an indispensable part of ECE and young children's play activities might involve IoT devices as well. Thus, research outcomes concerning IoT-facilitated play should be studied and summarized in the current research.

1.2 Aims and research questions

The present systematic review aims to investigate the state-of-art of the research on the deployment of IoT devices in ECE and to identify certain significant research gaps that may be addressed in the future. The first two research questions (RQ1 and RQ2) focus on summarizing the evidence about the ways in which IoT devices have been used in ECE. The third research question (RQ3) relates to the benefits that the IoT devices may bring and the last research question (RQ4) explores whether there exist any concerns related to the use of IoT devices. By doing so, some least considered yet important topics will also be recognized which might help shed light on the future research. Accordingly, the questions listed below are targeted in this study:

RQ1: What are the contexts (e.g. activities, venues and participants) of the IoT device usage reported in the empirical studies?

RQ2: What are the IoT devices used in the empirical studies?

RQ3: What are the advantages of deploying the IoT devices in ECE?

RQ4: Are there any concerns and issues associated with integrating the IoT devices in ECE?

The remainder of this paper is organized as follows. Section 2 describes the review procedure. Section 3 provides the results obtained. Section 4 further discusses the results and identifies several research gaps to be addressed in the future. Section 5 concludes this work.

2.Method

A systematic review method was adopted to gather, analyse and synthesize all the accessible and related research papers. Based on the guidance of Gough, Oliver and Thomas (2017), this review was performed in three phases, consisting of planning, conducting and reporting.

2.1 Planning the review

In the planning phase, a review protocol containing the research questions, search strategy and inclusion/exclusion criteria was developed. The research questions are listed in Section 1.2, and the rest of the protocol are presented in detail below.

2.1.1 Search strategy

To answer the research questions, we searched the literature in four international bibliographic databases representing the disciplines of education, social science and technology (see Table 1). The searches were restricted to include journal and conference articles that were in English. Additionally, since the concept of the IoT was coined by the Massachusetts Institute of Technology's (MIT) Auto-ID Labs in 1999 (Ashton, 2009), the searches encompassed a period of 20 years which started from January 1999.

Table 1. Databases and search constraints

Data sources	Search constraints
Education Resources Information Center (ERIC) Education Research Complete (via Ebscohost) ISI Web of Science Scopus	• Search field: All text • Search items: journal articles and conference papers • Language: English • Period: From January 1999 to October 2020

The search terms employed in this study consisted of three strings. String 1 was IoT-related, String 2 focused on young children aged from birth to eight years old and String 3 was about education. The three strings were constructed by the Boolean logic as follows: ("Internet of things" OR IoT OR "Network of Things") AND (children OR preschooler OR toddler OR "early childhood" OR "primary school") AND (education OR learning OR teaching OR play). Notably, many children attending primary school may be more than eight years old. We added "primary school" in String 2 with a goal to search out all the possible papers for further evaluation in the exclusion phase.

2.1.2 Inclusion and Exclusion Criteria

After the search, we used a set of inclusion and exclusion criteria (see Table 2) to decide if an article should be included for the current review. A paper was considered eligible when it satisfied all the five inclusion criteria. If a paper met any one of the exclusion criteria, it was excluded.

Table 2. Selection criteria

No	Inclusion Criteria (IC)	Exclusion Criteria (EC)
1	The article is peer reviewed.	The article is not peer reviewed.
2	The article addresses issues in the discipline of education.	The article is not related to the discipline of education.
3	The article focuses on the application of the IoT.	The article does not focus on the application of the IoT (e.g. It is about the application of other

		technologies or it is about teaching the concept of the IoT).
4	The article contains empirical evidence.	The article contains no empirical evidence (e.g. theoretical works, reviews, editorial articles, prefaces and IoT product designs with no user test).
5	The educational level is in ECE (education for children from birth to 8 years of age).	The participants are children in other stages of education.

2.2 Conducting the review

This section focuses on reporting how the review was conducted and how the data was extracted and synthesized.

2.2.1 Manuscript selection

Following the aforementioned strategy, we did a search in October, 2020 and identified 3461 potentially relevant research articles. To minimize the risk of excluding any relevant studies, the selection was conducted in three steps. Firstly, all the duplicated articles were removed (-134). Secondly, the titles and abstracts of each article were read carefully and certain irrelevant articles were excluded based on the selection criteria (-3122). As it was sometimes difficult to judge whether a paper could satisfy all the inclusion criteria by reading the title and abstract alone, in the third step, the rest of the articles were downloaded and scrutinized in full text. At this step, 194 articles were further excluded according to the exclusion criteria. Among the 194 articles, 55.2% (N=107) were removed because the participants were not in early childhood education (EC 5), 30.4% (N=59) were removed as they contained no empirical evidence (EC 4), 11.3% (N=22) were removed because they did not focus on the application of the IoT (EC 3), 2.6% (N=5) were removed since they were not peer-reviewed (EC 1) and 0.5% (N=1) was removed as it was not related to the discipline of education (EC 2) . Regarding EC 5, the age range of the participants in certain articles may be quite large, covering children from different educational levels. Therefore, when an article included both children aged between birth and eight years old and children aged above eight, we made a further decision as follows. If the article reported a study on children aged between birth and eight years old and another separate study on children above eight, we included such an article into this review, with a focus on the empirical study conducted among children aged between birth and eight years old only; if all of the children were investigated by the same empirical study, we excluded it, as the age range of the participants exceeded the requirement of ECE (EC 5). Finally, a set of 11 eligible papers were obtained. (see Fig. 1).

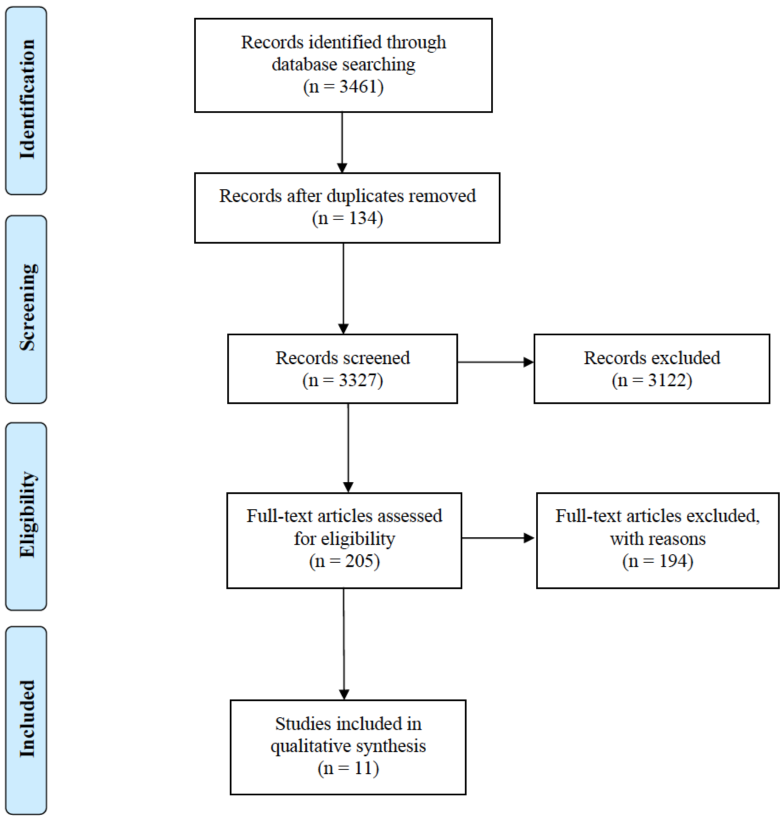

Figure 1. Systematic review process (adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [PRISMA] flow diagram, Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).

2.2.2 Data extraction and analysis

From the articles selected, the following details were extracted into an Excel sheet: (a) purpose of research; (b) research method; (c) country/area of research; (d) participants; (e) ages of participants; (f) IoT devices used; (g) contexts of usage; (h) knowledge domains that IoT devices claimed to foster; (i) advantages brought by IoT devices to children; (j) disadvantages brought by IoT devices to children; (k) challenges of applying IoT devices in ECE. To identify the types of the IoT devices employed, and the advantages and issues associated with the IoT device use, a qualitative synthesis suggested by Brereton, Kitchenham, Budgen, Turner and Khalil (2007) and Spolaôr and Benitti (2017) was then conducted based on the information extracted.

3. Results

3.1 Overview of the studies

Although IoT products are being used by young children around the world, empirical studies on this topic are still scarce and are unevenly distributed. The systematic review found 11 research articles, among which, a majority (N=8) were conducted in Europe and a few (N=3) were in Asia.

In terms of the years of publication, we did not identify any relevant articles with empirical evidence prior to 2014. Between 2014 and 2017, we located 3 relevant papers. In 2018 and 2019, the number of publications increased sharply. As the search was conducted on October 7, 2020 and certain papers may still be in press, a decrease of the publication number was seen in 2020. Figure 2 depicts the year distribution of the selected articles.

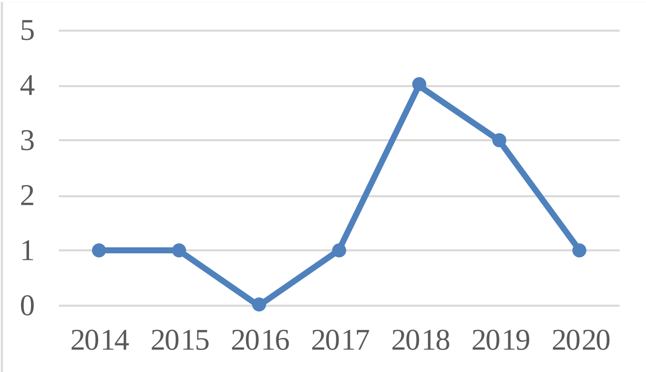

Figure 2. Year distribution of the selected papers

3.2 RQ1: What are the contexts (e.g. activities, venues and participants) of the IoT device usage reported in the empirical studies?

To answer the first research question, we extracted and synthesized the context information about the IoT device use, which included the activities where the IoT devices were applied, the venues of the activities and the participants. Table 3 lists the details.

It was identified that the IoT devices were mainly used in play and learning activities. Six studies (54.5%) incorporated the IoT devices into play processes, three studies (27.3%) used the IoT devices to facilitate play-based learning and two studies (18.2%) focused on employing the IoT devices to support learning. Meanwhile, those IoT-enhanced activities were usually conducted in the participants' homes or at school (see Figure 3). We further compared the scenarios of application at home with the scenarios at school. It was discovered that the IoT devices were normally used in unstructured play activities at home (N=5), while a majority of the activities involving the IoT usage at school tended to be more structured, which included the learning and play-based learning activities (N=4).

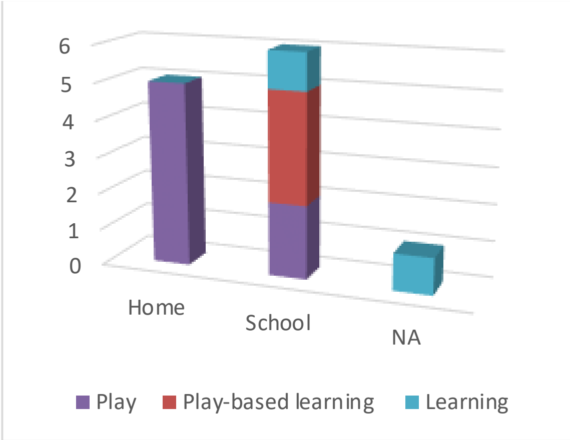

Figure 3. Venue distribution of the IoT-related activities

In addition, young children were the major participants of all those aforementioned activities. When dividing those young children into three age groups, we found that ten studies (90.9%) included the children aged between three and six years old, four studies (36.4%) included the children aged between six and eight years old and only three studies (27.3%) included the children who were under three (see Table 4).

3.3 RQ2: What are the IoT devices used in the empirical studies?

As shown in Table 3, varied IoT devices were included in the selected studies. After synthesizing the scenarios of usage and the functions of the devices, we classified the IoT devices into two categories: IoT playthings and IoT teaching aids.

IoT playthings referred to the IoT-based toys and the other IoT devices that were used in play activities. Meanwhile, IoT teaching aids denoted the IoT devices that were employed to scaffold knowledge acquisition in learning activities. Since play-based learning stems from play (Allee-Herndon et al., 2021), the play-based learning scenarios involved with certain IoT-based toys and educational games reported in the studies of Lee and Kim (2019), Miglino et al. (2014) and Ihamäki and Heljakka (2019) could be deemed as structured play activities as well. Therefore, nine studies (81.8%) employed the IoT devices as IoT playthings, while two articles (18.2%) used the IoT devices as IoT teaching aids.

It is worth noting that smart devices like tablets can both work as IoT teaching aids and IoT playthings. For instance, the e-TextBook designed by Sigarchian et al. (2018) could function on smart devices, so as to promote young children's literacy learning. In the interim, tablets could also be used as playthings in some other contexts (Arnott, Palaiologou, & Gray, 2019; Marsh, 2017).

3.4 RQ3: What are the advantages of deploying the IoT devices in ECE?

In the synthesis of the benefits reported in the selected articles, four themes emerged. The possible educational values of the IoT devices are illustrated as follows.

3.4.1 Theme 1: A connected digital and physical world to explore

The first benefit is that IoT devices can link the physical and digital world for young children to explore. Seven studies (63.4%) identified this point as an important advantage of applying the IoT devices into ECE. For instance, certain IoT devices were able to connect the physical surroundings to the online materials, so as to create hybrid game-play or learning experiences for young children (Chang et al., 2020; Heljakka & Ihamäki, 2018; Ihamäki & Heljakka, 2019). Some tangible toys together with the corresponding apps, could allow the children to transition between digital and non-digital play or to combine those two entertaining experiences (Arnott et al., 2019; Marsh, 2017). However, the frequencies of young children's transmedia practices depend on the capability afforded by the IoT devices and the types of the play and/or learning scenarios.

Table 3. IoT device usage reported in the selected studies

Paper	Activity	Venue	Participant	IoT device
Miglino et al. (2014)	Play-based learning	School	Study 1: 257 children (2.5-7 years old) and 10 teachers Study 2: (not included in this review); Study 3: 52 children (mean age: 5.12 years old)	Study 1: Block-Magic (educational game based on logical blocks) Study 3: WanBot (Lego NXT robot within serious games)
Manches et al. (2015)	Play	Home	Study 1: 10 children (4-8 years old) Study 2: (not included in this review)	Activision's Skylanders and Disney Infinity (plastic figurines that can evoke a corresponding virtual avatar within certain digital games)
Marsh (2017)	Play	Home	One child (3 years old)	Furby Boom (an app-connected robot toy)
Al-Khalifa et al. (2018)	Play	Home	4 children (3-6 years old) and 4 parents	Basma (IoT-based plush toy)
Brito et al. (2018)	Play	Home	21 families with their children (4-8 years old)	Smart watch, Toys-to-Life, programmable cars, Drone and Emilio
Heljakka & Ihamäki (2018)	Play	School	20 children (5-6 years old) and 17 parents	CogniToy Dino, Wonder Workshop's Dash Robot, Fisher-Price's Smart Toy Bear, and Hatchimal
Sigarchian et al. (2018)	Learning	School	126 children in Grade 2 and 6 teachers	Smart devices with Hybrid e-TextBook
Arnott et al. (2019)	Play	Home & School	25 children (2-6.5 years old)	Osmo (tangibles used together with tablets) and Cosmo (robot)
Ihamäki & Heljakka (2019)	Play-based learning	School	20 children (5-6 years old)	iPad with an augmented geocaching game app
Lee & Kim (2019)	Play-based learning	School	26 children (5 years old)	S-Block (traditional block toys integrated with IoT)
Chang et al. (2020)	Learning	NA	10 children (2-5 years old) and their parents	Smart hat with camera

Table 4. Young children involved in the selected studies

Paper	Birth to 3 years old	3 to 6 years old	6 to 8 years old
Miglino et al. (2014)		X	X
Manches et al. (2015)		X	X
Marsh (2017)	X	X	
Al-Khalifa et al. (2018)		X	
Brito et al. (2018)		X	X
Heljakka & Ihamäki (2018)		X	
Sigarchian et al. (2018)			X
Arnott et al. (2019)	X	X	
Ihamäki & Heljakka (2019)		X	
Lee & Kim (2019)		X	
Chang et al. (2020)	X	X	

Marsh (2017) observed a child’s free play with an app-connected robot toy at home and unveiled that the child’s play became complex as multiple connections were made across many domains, such as in the online/offline, public/private and material/immaterial domains. Manches, Duncan, Plowman and Sabeti (2015) also observed several young children’s free play at home. The IoT devices in Manches et al. (2015) study were simple plastic figurines whose only function was to evoke their corresponding on-screen characters into action within a video game context. Thus, they discovered that the actual trans-media behaviour in that context was not evident. In more structured contexts such as in the early years of school, the use of IoT devices involved more deliberate attempts to focus on multimodal learning experiences. In such contexts, it was found that playing with the IoT devices could enhance children’s interactions in both the digital and physical environments (Chang et al., 2020; Ihamäki & Heljakka, 2019; Miglino et al., 2014; Sigarchian et al., 2018).

3.4.2 Theme 2: Knowledge building

The second benefit is concerned with knowledge building. Seven studies (63.4%) mentioned some knowledge domains that might be fostered in the children's use of the IoT devices. A list of the knowledge domains is included in Table 5. It was noted that knowledge building could take place both in a learning activity organized by educators and through children's free play with some IoT devices (e.g. Heljakka & Ihamäki, 2018; Lee & Kim, 2019; Miglino et al., 2014).

Table 5. Knowledge mentioned and research approach employed by the selected papers

Paper	Knowledge	Research method
Miglino et al. (2014)	Study 1: Logical, mathematical, creative, strategic, linguistic and social skills Study 3: Second language vocabulary (English)	Study 1: Qualitative research Study 3: Quantitative research (experimental study with post-test)
Manches et al. (2015)	NA	Qualitative research
Marsh (2017)	NA	Qualitative research
Al-Khalifa et al. (2018)	General knowledge, culture values and morals	Mixed methodology
Brito et al. (2018)	NA	Qualitative research
Heljakka & Ihamäki (2018)	Language learning, sound making, music producing and how to read	Qualitative research
Sigarchian et al. (2018)	Literacy (animal concepts)	Mixed methodology (including an experimental study with post-test)
Arnott et al. (2019)	NA	Qualitative research
Ihamäki & Heljakka (2019)	Art	Qualitative research
Lee & Kim (2019)	Logical-mathematical and spatial skills	Mixed methodology (including an experimental study with pre-test and post-test)
Chang et al. (2020)	Object identification	Qualitative research

Of the seven articles which considered knowledge building, three employed an experimental approach to examine the effectiveness of the IoT devices on the children's learning outcomes (Lee & Kim, 2019; Miglino et al., 2014; Sigarchian et al., 2018). Miglino et al. (2014) found that the children who played with an IoT device named Wanbot could learn a similar amount of foreign vocabulary as those children taking lectures from a teacher could. Sigarchian et al. (2018) noted that the children learning with a Hybrid e-TextBook outperformed the children studying via traditional courses in the spelling tests. Lee and Kim (2019) proved that the children's logical mathematical performance was significantly improved after playing with S-Blocks — some traditional blocks integrated with the IoT. Yet, he found no significant improvement concerning the children's spatial ability. The remaining four articles did not consider the effectiveness in terms of knowledge acquisition, since they either conducted user acceptance test after describing their product design process (Al-Khalifa et al., 2018; Chang et al., 2020) or employed qualitative research methods to demonstrate children's edutainment experiences with the IoT devices (Heljakka & Ihamäki, 2018; Ihamäki & Heljakka, 2019).

3.4.3 Theme 3: Enjoyment and pleasure

The third benefit relates to young children's overall attitude. Six studies (54.5%) discovered that no matter the purposes of the IoT usage, those children who had the opportunity to use the IoT devices held positive attitudes towards the IoT-related experiences. For example, Miglino et al. (2014) compared the children who learnt new foreign words through lectures or traditional games (Group A) with the children who learnt the same words with Wanbot (Group B). They discovered that the children in Group A considered the lesson to be boring while the children in Group B regarded the experience as fun and engaging. Al-Khalifa et al. (2018), Brito, Dias, and Oliveira (2018), Chang et al. (2020), Heljakka and Ihamäki (2018) and Sigarchian et al. (2018) also described children's enthusiasm towards some IoT-based toys.

3.4.4 Theme 4: Autonomous play and learning

The last benefit is that IoT devices can help young children learn knowledge or acquire skills with little or no help from adults. Three studies (27.3%) remarked on the children's autotomy. For instance, the smart hat, designed and tested in Chang et al.'s (2020) research, could help the children identify objects in their surroundings without the presence of a third party. In Arnott et al.'s (2019) research, they noted that despite the sophisticated technologies involved, the young children became experts in terms of using the IoT-based toy, whereas the adults were novices who may not be able to assist children in their play with the toy. Al-Khalifa et al. (2018) also found that after receiving instructions around operating an IoT-based toy named Basma for the first time, the young children understood how it worked instantly and no additional help was then needed.

3.5 RQ4: Are there any concerns and issues associated with integrating the IoT devices in ECE?

Although no negative impact of IoT devices on young children was reported in the empirical studies, there existed two concerns about IoT device deployment in ECE. They are listed as follows.

3.5.1 Theme 1: High price

Despite that many IoT devices, such as IoT-based toys, can facilitate engaging play and/or learning experiences to young children, their high costs were deemed as being prohibitive to their use more broadly across all groups of children (Brito et al., 2018). Meanwhile, some ECE teachers were hesitate to incorporate IoT-based toys into the curriculum because many of those toys were believed to be expensive and fragile (Arnott et al., 2019).

3.5.2 Theme 2: Data security

Two studies (18.2%) raised concerns around data security related to the IoT device use. Manches et al. (2015) explored how children's data might be captured by the IoT-based toys and suggested that it was of great importance to monitor any data-capturing activities operated by those devices. Arnott et al. (2019) ensured that the IoT-based toys selected for their study had not been criticized for security issues.

4. Discussion

The purpose of this study was to systematically review the state-of-art of the research on the deployment of IoT devices in ECE and to identify significant research gaps that may be addressed in the future. We identified both the prevalent types of IoT devices used in ECE and the associated advantages and concerns. The findings can deepen current understanding of young children's IoT device use, provide parents, educators and policy makers with evidence for their decision-making, and indicate directions for future research.

Although in the other stages of education, IoT devices have been leveraged in diverse ways, the IoT application in ECE fell into two categories, namely IoT playthings and IoT teaching aids. A majority of the selected articles (81.8%) presented empirical studies on IoT playthings. This finding is not surprising considering the significance of play towards young children's development (Holmes et al., 2020; Vygotsky, 1967) and the prevalence of play-based pedagogy in ECE (Allee-Herndon et al., 2021). In addition, the availability of IoT playthings keeps increasing. Mascheroni and Holloway (2017) pointed out that numerous IoT-based toys that might be called the Internet of Toys (IoToys) were on the market in different countries like Australia, Germany, Finland, Portugal and Italy. Apart from the IoT playthings designed and manufactured to be children's toys, our finding also suggested that certain daily IoT devices such as tablets could be used both as IoT playthings and as IoT teaching aids in varied scenarios. This finding is confirmed by the result reported by Dias and Brito (2017) in their case studies. According to Dias and Brito (2017), most of the children interviewed claimed that tablets were their toys and even their favourite toys.

Previous research showed that parents were trying to maximize the opportunities and minimize the risks of children's Internet use (Livingstone et al., 2017). Our findings revealed four benefits and two concerns related to IoT device deployment in ECE. Facilitating young children's interactions between the digital and non-digital domains (e.g. Sigarchian et al., 2018) is the most prominent benefit noted in this review. This benefit is determined by the innate characteristics of the IoT system (Minerva et al., 2015), so parents and educators can easily take advantage of this benefit and connect the physical environment to the digital sphere for young children to explore. Marsh (2017) remarked that connected play with IoT devices could generate many opportunities to extend traditional play. Another important benefit is related to knowledge building (e.g. Miglino et al., 2014). Despite that many of the IoT devices used in the empirical studies were educational, the actual learning outcomes in the IoT-enhanced activities were seldom examined. Three studies included in this review employed an experimental approach and their results proved that adopting proper IoT devices into classroom teaching could assist young children to obtain better academic performances in different domains (Lee & Kim, 2019; Miglino et al., 2014; Sigarchian et al., 2018). Meanwhile, using IoT devices may also increase young children's autonomy (e.g. Chang et al., 2020) and arouse their interest (e.g. Al-Khalifa et al., 2018). Nonetheless, not every IoT device could afford all of the four benefits synthesized. Careful product selection is still needed from parents and educators.

As for the two concerns around the IoT device adoption, we believe that with technological advancements, the issue of high costs will be eliminated soon and that of data security can be under well control (Quwaider & Shatnawi, 2020). In fact, the original intention of IoT innovation was to empower "things" to gather information and communicate by themselves without human intervention (Ashton, 2009), so it is almost impossible for one to find a perfectly "safe" device that will not disclose any information. Apart from cautious product selection, we suggest that IoT data security education needs to be discussed with young children from the beginning. Researchers like Edwards et al. (2016) have stressed the urgency of cybersecurity education among young children. Edwards et al. (2018) found that many young children were unaware of the Internet or at least unfamiliar with the concept of the Internet. Mertala (2019) discovered that a majority of young children did not know that tangible objects could be connected to the Internet. Thus, the first step towards effective IoT data security education can be to help young children understand what the Internet means and represents.

4.1 Implications for future research

The empirical studies selected in this review did not explore or failed to discover any negative impact that the IoT devices might bring to young children in their play and learning processes. This phenomenon might be caused by the publication bias, which refers to the fact that researchers only publish the positive results of their studies, as it is more difficult to get the negative findings published (Keele et al., 2007). Nonetheless, as forerunners of new technology use, young children might be exposed to risks of harm (Livingstone & Stoilova, 2021), so it is urgent to investigate the negative side of using

IoT devices among young children, such as technology addition and distraction (Selwyn & Aagaard, 2021).

In addition, the use of IoT devices and the requisite information collected in their operation confirm the necessity of being very aware about data security education for young children. However, knowledge and experience concerning how to properly teach young children about IoT data security remain scarce. Thus, future research may work on developing age-appropriate data security education programs.

4.2 Limitations of the review

In the current study, we limited the search to journal and conference articles published in English from four major databases. Relevant publications may exist outside this scope and were not included in this review. To mitigate the limitation of search coverage caused by the databases, we chose four most popular databases which were ERIC, Ebscohost, Web of Science and Scopus. They well presented the domains of education, social science and technology. In terms of the documents that we searched, they were restricted by the language option and article type. In the future, it can be beneficial for researchers to conduct similar reviews on other types of literature, including papers published in languages other than English and grey literature such as dissertations and working papers.

5. Conclusion

Results of this systematic review show that the IoT devices have mainly been used as IoT playthings and IoT teaching aids in ECE. The associated benefits suggest a promising future for parents and educators to incorporate those devices into pedagogical processes and play practices. IoT devices, in general, could create a connected digital and non-digital world for young to explore, facilitate knowledge acquisition in an engaging way, arouse young children's interest, and turn them into more independent and autonomous learners/players. No negative influence has been reported in the empirical studies selected. Nonetheless, two main concerns around IoT device adoption, which relate to the high prices and data security of those devices, need to be addressed. Educators and parents could pay more attention to educating their children about data security in the first instance. Overall, it has been noted here that the use of the IoT devices in ECE is an important but under-explored topic. In the future, it would be beneficial to conduct research on negative influences of IoT devices and research on IoT data security education.

Declarations

No potential conflict of interest was reported by the authors.

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