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Author
Dr. Pekka Mertala
University of Oulu, Faculty of Education; KTK 323, 90014 University of Oulu, Finland
pekka-oskari.mertala@oulu.fi
+358407196796

Abstract
Ubiquitous computing (ubicomp) and the Internet of things (IoT) are turning into everyday household technology at an ever-increasing pace, for example, in the form of connected toys. However, while ubicomp and IoT are changing and shaping children's digital and technological landscape, not much is known about how children perceive these omnipresent and concealed forms of digital technology. This qualitatively oriented paper explores 3- to 6-year-old Finnish children's perceptions of ubicomp and IoT via interviews and a design task. Initially, the children were skeptical toward the idea that tangible objects, such as toys, could be computer and/or Internet enabled. However, these perceptions were subject to change when children were introduced to a scientific conception of what computers and the Internet are and asked to apply their knowledge to a technological design task. Implications for early years digital literacy education are discussed in the paper.

Keywords
Children; digital literacy; early childhood; the Internet of things; ubiquitous computing

Practitioner notes

What is already known about this topic

- The role of computer- and Internet-enabled tangible objects, such as connected toys, is expanding rapidly in young children's lives.
- The need for early years digital literacy education has been acknowledged.

What this paper adds

- This study explores young children's initial perceptions of ubiquitous computing and the Internet of things.
- Children are initially skeptical toward the idea that tangible objects can be computer/Internet enabled.
- This initial skepticism is subject to change when children are introduced to a scientific conception of what computers and the Internet are.

Implications for practice and policy

- The study provides novel insights into how children's digital literacy can be supported in early childhood education.

Introduction

Research on young children and digital technologies has been a subject of rapid growth (Mertala, 2016); especially, children's encounters with tablet computers have attracted scholarly attention (Couse & Chen, 2010; Falloon, 2014; Kucirkova, Messer, Sheehy, & Fernández Panadero, 2014; Neumann, 2018). Notably, there has been less interest in children's perceptions of ubiquitous computing (ubicomp) and the Internet of Things (IoT). Specifically, studies that explore how young children perceive and understand these technologies are sparse (cf. Manches, Duncan, Plowman, & Sabeti, 2015).

Such research and knowledge, however, is urgently needed because ubicomp and IoT are changing and shaping children's digital and technological landscape and life worlds. According to one forecast, there will be more than 75 billion IoT-connected devices installed worldwide as of 2025.[1] Several market research reports also predict that the already notable sales figures of computer- and/or Internet-enabled toys will grow rapidly in the near future.[2] Thus, although IoT toys may not be everyday playthings for the vast majority of children today (Brito, Dias, & Oliveira, 2018), they most likely will be in a few years. This qualitative study contributes to filling this knowledge gap by exploring 3- to 6-year-old Finnish children's perceptions of ubicomp and IoT via picture-enhanced interviews and a design task.

Background

Ubicomp, as defined by Abowd and Mynatt (2000), refers to the proliferation of computing in the physical world. In other words, the core idea of ubicomp is that any tangible object can either include or be a computer. The idea behind IoT, in turn, is that any 'thing' or object that is appropriately tagged can communicate through an Internet-like structure with other objects that are similarly tagged (Pascual-Espada, Sanjuán-Martínez, Pelayo G-Bustelo, & Cueva-Lovelle, 2011). In other words, when appropriately tagged, any tangible object can include Internet connectivity. As can be seen from the definitions above, to a notable extent, ubicomp and IoT are overlapping concepts. The main difference is that ubicomp objects do not necessarily require Internet connectivity, whereas IoT objects need a computer chip (i.e., a microcontroller or microprocessor) to function. To provide a concrete example, there are

[1] https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/
[2] https://www.prnewswire.com/news-releases/juniper-research-smart-toy-sales-to-grow-threefold-to-exceed-155-billion-by-2022-628177033.html; https://globenewswire.com/news-release/2018/09/05/1565750/0/en/Global-Smart-Toys-Market-Will-Reach-USD-5-410-00-Million-By-2024-Zion-Market-Research.html; https://www.statista.com/statistics/320941/smart-toys-revenue/

programmable toys that have no Internet connectivity (i.e., BeeBot and Coderpillar), as well as programmable toys with Internet connectivity (i.e., Dash & Dot and Evolution Robot; (Velicu & Lampert, 2017). The first group can be referred to as ubicomp toys, whereas the latter ones can be labeled IoT toys.

Research-based knowledge of how children perceive ubiquitous computing and IoT also has notable pedagogical value. The importance of supporting young children's digital literacy has been addressed by various stakeholders, including scholars (Marsh, 2017); global agents, such as the Organisation for Economic Co-operation and Development (Taguma, Makowiecki, & Litjens, 2013); and national educational administrations (Finnish National Agency for Education, 2016). As the pedagogics of early years digital literacy education are in the emerging stage (Edwards, Mantilla, et al., 2018) (Edwards, Mantilla, et al., 2018; Salomaa & Mertala, 2019), the development of appropriate and research-based methods requires up-to-date knowledge of children's initial understanding of ubicomp and IoT.

The understanding that tangible, everyday objects can be computer and Internet enabled represents one form of operational digital literacy, which includes the skills needed to understand the functional properties of digital artifacts (Marsh, 2017). It has been stated that the proliferation of IoT toys has provided a new world of Internet experience for young children, and this should be acknowledged in their cyber-safety education (Edwards, Mantilla, et al., 2018). Put differently, due to the rapidly increasing market share and availability of connected toys, it is important to teach children that toys—and other tangible objects—can be connected to the Internet, and especially, that these toys can collect data from them and distribute the data to third parties. To cite the Electronic Privacy Information Center's (2016) complaint and request for investigation,

> By purpose and design, these toys record and collect the private conversations of young children without any limitations on collection, use, or disclosure of this personal information. The toys subject young children to ongoing surveillance and are deployed in homes—without any meaningful data protection standards. They pose an imminent and immediate threat to the safety and security of children. (p. 2)

These concerns are highlighted by the notion that many connected toys have been identified as vulnerable for hacking (Chu, Apthorpe, & Feamster, 2018). In March 2017, it was announced that 2 million voice recordings between parents and children were allegedly exposed to potential hackers, along with 800,000 emails and passwords to their accounts from the database of the IoT toy company CloudPets,[3] to provide one example.

Toys are also the tangibles most often used when studying children's encounters and meaning making with and around ubicomp and IoT. The existing research has approached the phenomenon from the viewpoints of how children perceive, for example, the questions of privacy (Mcreynolds et al., 2017) and learning (Heljakka & Ihamäki, 2017) in relation to Internet-enabled toys. However, the focus with the greatest semblance to and importance for the present paper is Manches et al.'s (2015) study of how cognizant 10- to 11-year-old-children are of IoT toys. According to their findings, even children who commonly played with IoT toys were not aware of how the technology worked. That said, it is important to apprehend that children's limited knowledge is not restricted to ubicomp and IoT; rather, previous research has suggested that children's understanding of the Internet and computers is generally narrow (Edwards, Nolan, et al., 2018; Mertala, 2019; Robertson, Manches, & Pain, 2017). Many children, for example, find it difficult to distinguish whether they are online or offline when playing games or using on-demand streaming services (Mertala, 2019). This also applies to children's understanding of computers. In his study on 5- to 7-year-old children's conceptions of computers, code, and the Internet, Mertala (2019) observed that children conceptualized computers as traditional desktop and laptop computers (or even monitors), whereas smartphones and tablets were considered to be different forms of technology. Accordingly, the children did not spontaneously express that computers could be located in tangible everyday objects, such as washing machines and toys. However, a study by Robertson et al. (2017) suggested that when children are introduced to a scientific concept of computers (i.e., computers as chips) they can identify various devices containing such chips, including tablets, smartphones, video cameras, traffic lights, and watches. This study first tests Robertson's et al (2017) findings and then further examines whether the children are able to apply the new knowledge when engaged in a design task, which is explained in detail in the Methods section. Scientific concept here refers to an explanation of what things are and how and why they work (Edwards, Nolan, et al., 2018).

[3] https://www.marketwatch.com/story/your-childs-teddy-bear-may-now-be-hacked-2017-03-01

Theoretically, this paper draws on a sociocultural tradition in which learning of and about things is understood to occur in interaction with the social and cultural (including material) environment in which the subject acts (Lantolf & Thorne, 2007; Vygotsky, 1978). According to previous research, much of children's learning about digital technologies is based on intentional and/or unintentional tutoring by guardians, older siblings, and other close figures (Edwards, Nolan, et al., 2018; Mertala, 2019); thus, children's digital literacy varies with the quality and quantity of these interactions. One benefit of drawing on sociocultural theory is that acknowledging the role of the social, material, and cultural contexts enables the researcher to go beyond the (unfounded) generational dichotomy discourse in which children are portrayed as born-competent "digital natives" and adults are viewed as unskilled "digital immigrants" (Prensky, 2001). Both of these images are popular in the field of educational research and practice (Kirschner & De Bruyckere, 2017). Put differently, the way one understands and conceptualizes digital technologies is more dependent on the sociocultural context in which one lives than on one's age and/or generation.

Research aims and questions

The aim of this study is understanding how young children perceive ubicomp and IoT. The first objective was exploring children's initial perceptions, which was formulated into the following research question:

- What types of initial perceptions do young children have about ubicomp and IoT?

Based on previous research, it was expected that children's initial conceptions[4] would be that computers and the Internet are tool- (i.e., computers are desktops) and activity-based (i.e., the Internet is for playing games; Edwards, Nolan, et al., 2018; Mertala, 2019) and they would not be cognizant of what ubicomp and the IoT are (Manches et al., 2015). Previous research also suggested that children's perceptions can change when a scientific conception is introduced to them (Robertson et al., 2017). On these grounds, the second objective was examining how children's perceptions change when they encounter a new scientific conception. This was formulated in the following research question:

[4] In this paper, *conceptions* refers to children's explanations of what things are (Edwards, Nolan, et al., 2018; Mertala, 2019). *Perceptions*, in turn, is a broader term that includes reflection on whether the thing/phenomenon under discussion, here ubicomp and IoT, is possible in the first place.

- How do children's perceptions of ubicomp and IoT change when a scientific conception of computers and the Internet is introduced to them?

Methods

Participants, research context, and data collection

The data were collected from 33 children from one Finnish early childhood center in December 2018. Consent to participate in the research was requested verbally from the children and in written form from their guardians. The distribution of the children's ages and genders is displayed in Table 1. The center was chosen via convenience sampling (Patton, 2002). I have been collaborating with the educators since 2013, and I am familiar with the children as well. The participating center was also a teaching practicum placement for the university's early childhood teacher education program, and the children had become accustomed with the culture of new people working alongside their own educators for fixed short-term periods.

Table 1

Age and Gender Distribution of Participating Children

Age	3	4	5	6	Total
Girls	-	-	5	3	8
Boys	2	4	4	15	25
Total	2	4	9	18	33

Providing detailed verbal accounts on functional principles of digital technologies is sometimes difficult for young children (Robertson et al., 2017). Thus, they should be offered alternative mediums for self-expression for ensuring rich data. The use of visual methods and materials, such as drawing and pictures, is typical in contemporary childhood research (Lipponen, Rajala, Hilppö, & Paananen, 2016), and this has proven to provide rich data for exploring young children's meaning making around digital technologies (Brito et al., 2018; Edwards, Mantilla, et al., 2018; Mertala, 2016, 2019; Robertson et al., 2017). In this study, visual materials were used as supports for verbal narration (pictures shown to children) and forms of visual narration (drawing task). From a sociocultural viewpoint, children's drawings do not emerge in a "cultural vacuum" (Mertala, 2016), but instead, they are always influenced by the communication and symbol systems around them (Anning & Ring, 2004).

In practice, the data were gathered via individual picture-enhanced research interviews and a drawing task that took place during the first day of a three-day pedagogical project carried out by a group of preservice early childhood teachers.[5] The project was part of a compulsory course about technology-enhanced learning. The method for data collection, as well as the entire project, was designed in collaboration with the educators of the participating center to ensure the project respects their pedagogical values, as well as the children's interests. The preservice teachers were trained in how to carry out the interviews and drawing task prior to data collection. They were, for example, encouraged to create a relaxed atmosphere by playing, reading, and chatting with the children before addressing the issues related to the research objectives. Before data collection was performed, the children were introduced to the aim and methods of the research (Einarsdottir, Dockett, & Perry, 2009) by me during the morning circle time. Then, the preservice teachers introduced themselves to the children and began to familiarize themselves with the children with support from the educators.

The actual data collection process consisted of five phases. These entailed the following:

i. The children's initial conceptions were explored by asking them to freely explain what they knew about and understood by computers and the Internet.

ii. Next, the children were shown pictures of a car, washing machine, and teddy bear[6] one by one and asked whether these objects could include a computer or the Internet. These specific objects were chosen because they present a pool of everyday objects that are likely familiar to all children. All these objects can contain computers and connectivity. For example, all modern cars have at least one computer in them, and many have integrated on-board computers that can display error signals and/or be used for navigation purposes;

iii. In the third phase, a short scientific explanation of computers and the Internet were introduced to the children. The explanations were based on two children's nonfiction books *Kuinka tietokone toimii? Kurkista ja Koodaa* (Flip-the-flap: computers and coding; (Dickins & Nielsen, 2015) and *Miten Internet toimii* (How the Internet works; (Nilsson, 2015). The size of a computer chip was also concretized for the children by letting them examine a Raspberry Pi computer. Scientific explanations are provided in Table 2. Reference pictures of the books and Raspberry Pi are provided in Figure 1.

[5] Performing the data collection as part of a broader project was partly based on ethical reflection in research. As data collection was carried during the first day, the following two days were considered requital for the time and effort the children had invested into us during the data collection period.

[6] See supplementary file 1.

iv. Next, the children were shown the same three pictures again, and they were asked whether they could contain a computer or the Internet.

v. Finally, the children were asked to use drawing to design a toy that would have a computer or Internet connectivity in it. The children were oriented for the task with a fairy tale about a Christmas elf who hit his/her head on a tree in a sledging accident, and therefore, was unable to invent any new toys for the coming Christmas and needed help from the children.[7] The children's responses to the questions and their presentations of toy designs were recorded by writing them down (Einarsdottir et al., 2009).

All the interviews were conducted with one child at a time.

Table 2

Scientific Explanations of Computers and the Internet

Technology	Explanation
Computer	A computer is a device that can follow instructions and solve problems. However, computers do not come up with solutions independently; instead, they follow the instructions given by people using the buttons, mouse, or keyboard. For example, pressing A on the keyboard is a command to write an A on a computer-connected display. Computers can be really small. Many devices, such as cameras and remote-control cars, have computers inside them.
The Internet	The Internet is a large network of computer cables and computers that enables devices to communicate with each other. You can connect to the Internet, for example, over a telephone network, fiber optic cable, or wireless network. The wireless network is also known as WiFi. The Internet sends things called digital information. This information is made from ones and zeros because computers and computer programs can only read information in that form. Computers then convert this information so that it can be viewed, listened to, and used by humans

[7] See supplementary file 2

Figure 1. Pictures of the books and of Raspberry Pi

Analysis

The analysis process was guided by an abductive approach in which the researcher moved between deductive and inductive reasoning to open up new ways of theorizing the phenomenon (Dey, 2003). To put the results in context, the author reviewed the existing research and acknowledged its findings by using them as the basis for initial analytical readings of the data. However, due to the novelty of the research objective and exploratory nature of the study, data-driven interpretations were also performed to refine the existing theoretical views.

In practice, the data were analyzed via qualitative oriented monotype mixed analysis (MMA; (Onwuegbuzie, Slate, Leech, & Collins, 2007) and the constant comparison method (Boeije, 2002). In MMA, the data—whether qualitative or quantitative—are analyzed using both qualitative and quantitative methods. The use of MMA requires that qualitative data are altered into a form that can be analyzed statistically, while quantitative data are transformed into a type that can be analyzed qualitatively (Onwuegbuzie et al., 2007). This mixing can be characterized as a combination of measurement and interpretation (Biesta, 2010). In the present study, transforming the data meant quantifying the responses containing specific types of information, for example, children's conceptions of what computers and the Internet are. These frequency counts were then converted to percentages for calculating the frequency effect size (Onwuegbuzie, 2003).

Interpretative analysis was carried out by reading the data, comprising both the drawings and interviews, in a holistic manner; the aim of doing this was identifying the essential qualities of the phenomenon under investigation (Miles, Huberman, & Saldana, 2013) and making comparisons between the theory and data, between the data from different participants, and within the data from individual participants (Boeije, 2002). In other words, the analytical focus was not only on *what* the children said but also on *how* they expressed their views and perceptions. For instance, it was noted that some children used more intense narration when describing why there could not be a computer inside a teddy bear than why there could not be a computer inside a washing machine or car.

First, children's descriptions of what computers and the Internet are were coded and categorized based on content using three literature-informed (Edwards, Nolan, et al., 2018; Mertala, 2019) categories as starting points. The categories were as follows: "function-based explanation" (i.e., how computers and the Internet work), "tool-based explanation" (i.e., what counts as a computer/the Internet), and "activity-based explanation" (i.e., what can be done with computers/online). Next, the children's answers to the first-round questions on whether there could be a computer and/or Internet in a car, washing machine, and teddy bear were coded and categorized based on whether the children thought these items could or could not include computers and/or Internet connectivity. The answers were then further coded and categorized regarding the nature of their reasoning. Three categories were formed, as follows: "function-based explanation" (the child explained what a computer and/or connectivity would afford for the object), "non-function-based explanation" (the child explained where a computer and/or connectivity could be located but did not provide an explanation of what this would afford for the object), and "no explanation" (the child agreed that there could be a computer and/or connectivity in the object with no further explanation). A similar procedure was conducted for data from the second round of questions. In the last phase, children's toy designs—that is, the drawings and what the children said about them—were coded in relation to how ubicomp and/or IoT features were exhibited in them. Data extracts from each category are provided in the Findings section to improve the clarity and transparency of the analysis process.

Before presenting the findings, the limitations of the data should be addressed. The types of objects used as examples and the way the scientific concept was introduced potentially influenced the data by providing cues to the children. To put this in context, a remote-controlled toy car was used as one example of a computer-enabled toy, and remote controllability was one of the ubicomp features included most often in the children's toy designs. This skewness in the data is considered in the analysis and conclusions made from the findings. Another possible limitation is that the unbalanced age and gender distribution of the participating children prevented gender- or age-based comparisons between them.

Findings

The findings of this study are presented in four subsections. The first discusses the children's initial conceptions of computers and the Internet, while the second considers their initial perceptions of ubicomp and IoT. The last two subsections focus on the change of children's perceptions after the introduction of the scientific concept of computers and the Internet.

Children's initial conceptions of computers and the Internet

Table 3 displays how children's initial views of what computers and the Internet are were distributed regarding the nature of their conceptions. In some cases, a child's response included examples from several categories, and thus, the number of examples is higher than the number of children.

Table 3.

Distribution of Children's Initial Conceptions of Computers and the Internet

	Function	Tool	Activity	Appearance	"I don't know" or unclear response
Computer	3	6	23	5	6
Internet	-	6	16	-	14

Function-based explanations of computers and the Internet were rare in the children's initial perceptions. One child, for example, commented that computers are built from different types of parts. His knowledge had strong sociocultural roots, as he related that he knew this because his grandfather had different types of computer parts. Relatively few tool-based references were made. Some children commented that computers include laptops and desktops, while a few noted that tablets and smartphones are computers as well ("Tablet is a computer" [Child#6, 4y]; "Smartphone, it is a computer too [Child#20, 6y]). In terms of the Internet, tool-based explanations included notions like "Mother's phone has Internet" (Child#23, 5y).

Activity-based conceptions were the most prominent category. Most often, the mentioned activities were playing games and watching movies and children's programs. Some of the children commented that an Internet connection is needed for buying things and ordering food: One child remarked, "You can buy stuff" (Child#14, 4y), while another stated, "You can order pizza" (Child#13, 5y). In addition, one child commented that an Internet connection is needed for video streaming services to function, stating, "You cannot watch YouTube if you don't have [an] Internet [connection]" (Child#27, 6y). Nevertheless, the main trend in the data was that the difference between being online and being offline was unclear for the children. One child, for instance, stated that he had searched for ideas for Christmas presents with a computer, but at the same time, he stated that he had never used the Internet. Finally, five children made references to computers' appearance, that is, size, shape, and color, in their responses. Two children commented that computers are big, which is essential information regarding children's initial perceptions of ubicomp and IoT: If computers are big, they cannot be found inside small objects.

Children's initial perceptions of ubicomp and IoT

Table 4 summarizes the quantitative distribution of the children's initial perceptions of ubicomp and IoT. As the table shows, the great majority of the children thought that cars, washing machines, and teddy bears could not include a computer or Internet connection.

Table 4

Distribution of Children's Initial Perceptions of Ubicomp and IoT

	Car			Washing machine			Teddy bear		
	Yes	Don't know	No	Yes	Don't know	No	Yes	Don't know	No
Computer	9 (27%)	4 (12%)	20 (61%)	8 (24%)	1 (3%)	24 (73%)	7 (21%)	3 (9%)	23 (70%)
Internet	9 (27%)	7 (21%)	17 (52%)	8 (24%)	5 (15%)	20 (61%)	5 (15%)	6 (18%)	22 (67%)

However, there were notable variations in the depth and level of detail in the children's descriptions of why there could or could not be computers and/or Internet included in cars, washing machines, and toys. In terms of cars, for example, there were children who were aware that some modern cars are self-directed. One child stated, “My cousin’s father has an electric car. The car can reverse by itself” (Child#26, 6y). In addition, some of the children knew that the navigating systems of modern cars require computers and/or an Internet connection. A data extract from Child#33 (6y) provides an illustrative example: When asked whether a car could contain a computer, he answered, “Yeah, because it has a map that guides you to where you are going.” However, at the same time, several children commented that there could be computers and/or Internet in cars, but they were not able to provide explanations for what these components could do in them.

Table 5 presents how the children’s answers were distributed on a function-based/non-function-based/no explanation scale. “You can put on a navigator with an Internet [connection]” (Child#6, 4y) is an example of function-based reasoning, whereas, “It [washing machine] has a screen that has a computer in it” (Child#1, 4y) was categorized under non-function-based reasoning. The main difference between these categories is that the first describes how the specific technology affords the essential functions of the Internet-enabled device in question, whereas the second includes no such description; instead, it merely states where a computer could be located. Comments with no concrete explanation, such as, “Yeah, there could be Internet” (Child#21, 6y), were labeled with the “No reasoning” code.

Table 5

Qualitative Distribution of Children’s Yes Responses in the First Interview Round

	Function-based explanation		Non-function-based explanation		No explanation	
	Computer	Internet	Computer	Internet	Computer	Internet
Car	3	3	4	2	2	4
Washing machine	2	-	4	3	2	5
Teddy bear	4	4	3	1	-	2

Changes in children’s perceptions of ubicomp & IoT

Table 6 summarizes the quantitative distribution of the children’s perceptions of ubicomp and IoT in the second round of interviews. As can be seen in the table, there were notable quantitative changes in the children’s views after the introduction of the scientific concept of computers and the Internet, the most prominent being the increase of 49% points in the perception that cars could contain a computer.

Table 6

Distribution of Children's Perceptions of Ubicomp and IoT After the Introduction of Scientific Concepts of Computers and the Internet

	Car			Washing machine			Teddy bear		
	Yes	Don't know	No	Yes	Don't know	No	Yes	Don't know	No
Computer	25 (76%)	1 (3%)	7 (21%)	17 (52%)	3 (9%)	13 (39%)	14 (42%)	1 (3%)	18 (55%)
Internet	16 (48%)	5 (15%)	12 (36%)	15 (45%)	3 (9%)	15 (45%)	14 (42%)	1 (3%)	18 (55%)

When comparing the distribution of answers, it appears to be easier for children to apprehend computers and connectivity in objects that are mechanical to begin with. The teddy bear was the only object that more than half the children said could not contain a computer or Internet connection. In other words, even the introduction of scientific concepts was sufficient for shaping the children's perceptions about cars and washing machines; the teddy bear, at least in part, was a different matter. For instance, Child#26 initially thought that there could not be a computer or connectivity in any of the three objects. After the introduction of scientific concepts, he changed his mind about cars and washing machines, but not about the toy. In his words, a teddy bear "is a soft-toy. It helps you to fall asleep. There can't be a computer in it" (Child#26, 6y). Put another way, the plush toy bear and digital technology were mutually exclusive categories for him.

Comparably to the first interview round, there was notable variation in the depth and level of detail in the children's responses. Table 7 displays how the children's answers were distributed on the function-based/non-function-based/no explanation scale. As can be seen from the table, the increase mainly took place in the "no explanation" and "non-function-based" categories. In other words, although the shift of perceptions was notable in a quantitative sense, much of this change took place at a rather superficial level.

Table 7

Qualitative Distribution of Children's Yes Responses in the Second Interview Round

	Function-based explanation		Non-function-based explanation		No explanation	
	Computer	Internet	Computer	Internet	Computer	Internet
Car	5	3	7	2	13	11
Washing machine	2	1	8	5	7	9

Teddy bear	6	6	2	2	6	6

There were also cases in which the children's perceptions had evolved significantly. The data from Child#3 (6y) provide a piquant example of such a case. When asked about his initial conceptions, he stated that there could be no computers or Internet connection in a washing machine. In the second round, however, he was able to provide a rather detailed description of how an IoT-enabled washing machine could work. In his words, "There could be an Internet connection in it. You could control it with a computer and turn it on."

Ubiquitous computing and the Internet of Things in children's toy designs

In the last phase, the children were asked to design a toy via a drawing that included computers and/or Internet connectivity. Once again, there was notable variation in the children's responses. Some of the children provided detailed descriptions of what a computer and/or connectivity enabled in their toy. For instance, one child drew a toy robot and stated, "[This is] a robot. The computer is inside the robot. The computer makes the robot move" (Child#17, 5y; see Figure 2); another related, "Somebody moves this [toy car] with a smartphone. It has an Internet connection" (Child#4, 6y; see Figure 3).

Figure 2. Ubicomp robot

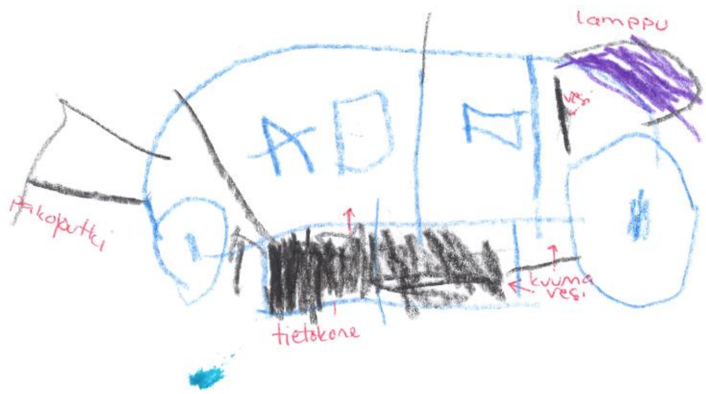

Figure 3. IoT car

Nevertheless, designs in which references to ubicomp and IoT were more implicit appeared more commonly. One child, for instance, designed a toy hamster (Figure 4) and stated that it was "remote controlled. It has three buttons. One button makes it dance. [One button] makes it walk forward. One button makes it make sounds" (Child#13, 5y). However, she did not explain what the specific technology was that enabled these features. Furthermore, in some cases, the children's initial activity- and tool-based conceptions of computers and the Internet were reflected in their toy designs. Child#13 related that computers can be used for playing games and games can be downloaded from the Internet. These activity-based conceptions were also present in her toy design (Figure 5). In her words, "[This is] Barbie's smartphone. You can download games on it. It has a heart-shaped screen that you can watch and play stuff" (Child#31, 6y). In other words, she did not incorporate ubicomp and IoT into the doll, but instead, she designed a ubicomp- and IoT-enabled accessory for her.

Figure 4. Toy hamster and its house

Figure 5. Barbie's smartphone

The types of toys the children designed can be understood to reflect the material environment they live in, and all four examples above can be traced back to existing toys. Remote control cars and Barbies (and other fashion dolls), for instance, have been regular items in young children's "toy pool" for decades. Accordingly, technology-enhanced hamsters (and other animals) designed by several children recall popular interactive "care toys" that are either IoT enhanced (i.e., Hatchimals) or traditionally battery operated (i.e., Chatimals). One more example comprises the remote controllable and camera-enabled helicopters and airplanes designed by four children, as these designs notably resembled miniature unmanned aerial vehicles, known as drones in colloquial language. Figure 6 provides a piquant example of this; here, the child has designed "an airplane that can make YouTube videos on the Internet" (Child#28, 6y). The arrow indicates the location of the camera.

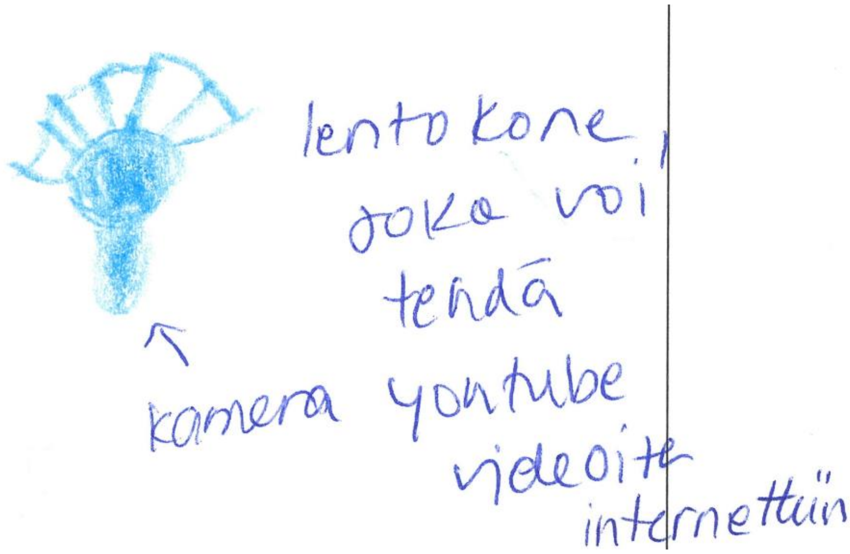

Figure 6. IoT-enabled airplane

Discussion and conclusions

This qualitative study has explored 3- to 6-year-old Finnish children's perceptions of ubicomp and IoT. It was found that the children were initially skeptical about whether tangible objects could include computers or connectivity. This was mainly due to the children's initial conceptions of computers and the Internet, which were profoundly activity- and tool-based, as also identified in previous research (Edwards, Nolan, et al., 2018; Mertala, 2019). The findings also suggest that children's perceptions of ubicomp and IoT can be shaped and refined by providing them an age-appropriate scientific definition of what computers and the Internet are and having them apply this new knowledge to a design task. In some cases, there were notable qualitative changes in the children's perceptions. However, in most cases, the changes in the children's perceptions were superficial rather than profound. Thus, more research is needed to explore the further development and persistence of children's changed perceptions.

To conclude, this study has provided original knowledge involving young children's perceptions of ubicomp and IoT. The use of multiple child-centered data collection methods, such as picture-enhanced interviews, drawing-based design tasks, and reading of non-fiction books and thought-provoking stories, has made it possible to gather rich and deep data, which is one of the prerequisites of credible and trustworthy qualitative research (Fusch & Ness, 2015). Furthermore, detailed descriptions of the research context, data, and methods support the transferability of the findings to other contexts in the areas of research and practice (Shenton, 2004). In other words, while the findings cannot be automatically generalized to other populations, the study provides several implications for early years' digital literacy education in early childhood education centers, which are discussed next.

According to the present study, the huge majority of young children do not possess an initial understanding that tangible objects can be connected to the Internet. This finding implies, that we should move beyond the prominent screen-based understanding of technology toward a more holistic approach. It is important that both, children's guardians and their professional educators, demonstrate for children that computing and connectivity are not features restricted only into screen-based devices. This, as shown in this paper, can be done by using children's non-fiction books and drawing-based design tasks. This notion challenges the contemporary discourses around digital literacy that are dominated by a device-centered view in which the focus is on the affordances of different digital tools (i.e., tablets, interactive whiteboards, and apps; (Neumann, Finger, & Neumann, 2017).

This notion positions this study in the emerging branch of research indicating that traditional (and non-digital) early childhood education practices, such as drama, drawing, and crafting, are sound methods of exploring our digitized lifeworld with young children (Edwards, Mantilla, et al., 2018; Salomaa & Mertala, 2019). These are valuable notions for early years professionals, who have been found to struggle with how to provide digital literacy education (Edwards, Mantilla, et al., 2018; Salomaa & Mertala, 2019) and who find it difficult to integrate digitality and technology into the traditional practices of early childhood education (Lindahl & Folkesson, 2012). As Bassey (1981) proposes, if practitioners believe their situations to be similar to the one described in the study, they may relate the findings to their own positions. The present study was carried out in a natural early childhood education setting by using means and materials familiar to all practitioners. Thus, the findings presented in this paper are potentially empowering for practitioners struggling with the new and somewhat ambiguous curricular alignments around supporting and developing young children's digital literacy.

Statements on potential conflicts of interest
The author does not report any conflicts of interest.

Statement on open data and ethics

The researcher has followed the ethical guidelines of the University of Oulu. The data cannot be distributed openly as the participants are underaged. However, requests for data may be made to the corresponding author.

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