BUGBITS:
MAKING TANGIBLES
WITH CHILDREN

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ABSTRACT

The thesis presents and discusses the processes that lead to the development of a tangible toolkit for supporting design workshops aimed at building tangible interfaces with children. The toolkit, called BugBits, was used to explore and instantiate participatory design workshops with children enabling them to be creative and develop new prototypes. BugBits was tested in three case studies with children of different ages. The first study was conducted in a modern art museum, where children aged between 13 and 15 years old (N=185) built personalised artefacts with the toolkit. The artefacts were then used to perform an augmented visit to some of the exhibition rooms of the museum. The second study (N=31) was conducted in a kindergarten with children between 3 and 6 years old. The toolkit was adopted to perform two educational exercises about colours characteristics. The third study (N=24) explored how the toolkit can be used to instantiate creative processes during participatory design workshops with children between 7 and 11 years old. During the studies, qualitative and quantitative data were collected and analysed.

The outcomes of the analysis show that the toolkit can be used with success to keep the children engaged (study 1, 2, 3) and obtain an active and effective participation (study 3) and allow them to build new and evolving TUI prototypes (study 3). By retrospectively reflecting on the process, the thesis presents the KPW process to guide and instantiate the design of generative tools for TUI design with children. The KPW process poses particular attention to the children roles, and how the technological choices affect the design.

STATEMENT OF CONTRIBUTION

The development of the BugBit a tangible-based toolkit involved various researchers and research fellows. For this reason, it is necessary to specify the actual contribution of the author in the project. The author fulfilled the following roles:

- Researcher: the author defined and managed the design processes of the development of the BugBits toolkit involving domain experts and other researchers (Chapter 4). Organized and designed and analysed the processes of the case studies with the collaboration of other researchers and domain experts (Chapters 5 6 7).
- Designer: the author was the lead designer of the Bugbits tinkering toolkit and the implementation of the hardware and software part of it. (Chapters 4 5 6 7).
- Facilitator: the author assumed the role of facilitators in all the three case studies presented in this thesis with the collaboration of other researchers and domain experts (Chapters 5 6 7).
- Project manager: the author coordinated the design team and managed the all the activities of the case studies workshops (Chapters 5 7). The author collaborated to the management and design of the second case study, another researcher was the project manager of the study (Chapter 6).

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1. INTRODUCTION

The human computer interaction (HCI) research field investigates the relationships between the technologies and the human beings in order to design better artefacts that take into account the needs and characteristics of the final users (Preece et al., 2015). HCI is a multidisciplinary research field that includes computer science, engineering, psychology, sociology and other disciplines. The HCI tradition focused the majority of the studies taking into account adults as primary users, but in the last two decades, many of the publications started to consider children and young adults as a new area of research to explore (Read and Markopoulos, 2013). The diffusion of Information and Communication Technologies (ICT) lowered the age in which children start using interactive systems; for example, the advent of desktop computer gaming consoles in the '80s, and nowadays the smartphones and tablets. According to Holloway et al., in 2013 some 52% of children aged seven years old used the internet with various devices, and trend analysis highlighted a growing tendency (Holloway et al., 2013). A more recent study confirmed the tendency showing that some 75% of the children of 4 years old owned a smartphone, and almost all of them, 97%, used touchscreen devices daily, only some 3% of 4 years old children never used a mobile media device (Kabali et al., 2015).

One of the most promising research directions in the design of technologies for children is represented by Tangible User Interfaces (TUIs) (Ishii and Ullmer, 1997). TUIs are technologies that leverage the physical interaction with objects, going beyond the boundaries of the screen and traditional Graphical User Interfaces (GUI), thus giving a physical form to the digital-information (Ullmer and Ishii, 2000). TUIs have been often used for learning purposes with children. In particular, children learning is often related to physical actions and the manipulation of toys (Xu, 2005); for these reasons, TUI seems to fit their natural way of learning. However, so far, most research on TUI for children refer to pre-set and rigid artefacts on which children functionalities have little control. The aim of this thesis is the design and evaluation of a toolkit which allows children to design and build their own TUI.

1.1. Tangible user interface

The academic research started to explore the potential of tangible interfaces in 1996 when Fitzmaurice defined the graspable user interfaces (Fitzmaurice, 1996). Only one year later Ishii and Ullmer introduced the TUI concept, as a new way to manipulate the digital information. In their viewpoint, the physical part of the TUI became to serve as input and output device for the interactive systems (Ishii and Ullmer, 1997). The change of interaction paradigm from the GUI to the TUI was accepted by the academic research that tried to apply this new approach to several domains of applications. In particular, research showed TUI applied to musical production (Jordà et al., 2007), children entertainment (Collective and Shaw, 2012), games (Menestrina et al., 2016), education (Geurts et al., 2014), programming (Gallardo et al., 2008), information visualisation and manipulation (M. Horn et al., 2012). The TUI revealed to be an engaging technology, but its efficacy was not always better compared to the traditional interfaces (Marshall, 2007; Marshall et al., 2007). Even if there are multiple contradictions in the results of research, most of the publications assumed the TUI approach to be better than GUI with respect to the user's engagement and well suited to be adopted with children. A large corpus of research on TUI addresses the identification of key elements of their design, but the practical aspects of their implementation are often not explained in details.

The design of TUI is a complex process which needs to balance several elements. This complexity leads to the definition of several guidelines with specialised purposes. For example, Antle et al. defined a framework to design TUI for learning purposes with children (Antle, 2007; Antle and Wise, 2013). While Marshall argued if the TUIs are really improving the learning processes, results suggested that the use of TUIs could be useful for learning purposes, but there was need of additional studies (Marshall, 2007). One of the most interesting applications of TUIs for children's learning was introduced by Zuckerman et al. that used the tangible interaction to enhance the Montessori learning games, this type of devices were defined as digital Montessori-inspired manipulatives (also known as Digital MiMs) (Zuckerman et al., 2006, 2005). The application of TUIs inspired by the early works of Papert led to the more recent approach called tangible programming. This approach aims at teaching programming concepts using tangible user interfaces to the users, in most of the cases theses system are designed for children (Gallardo et al., 2008; Horn and Jacob, 2007; Silver and Rosenbaum, 2010; Wang et al., 2011). Following the same idea, TUIs were exploited to teach computer science topics in high school classes by using devices based microcontrollers and sensors (Goadrich, 2014). Some researches were instead focusing more on using the tangible interaction paradigm to enable children and adults to be able to design simple TUIs and improve their knowledge and literacy about basic electronics (Bdeir and Ullrich, 2011; Collective and Shaw, 2012).

1.2. Design with Children

One of the important research topics that have grown in the last two decades is the children inclusion and participation in the design processes. In this respect, Allison Druin theorized an onion model of four levels of participation: users, testers, informants, partners (Druin, 2002). This model was expanded by new research approaches giving more importance and competences to the children such as becoming protagonists, co-designers or processes designers (Doorn et al., 2014; Iversen et al., 2017; Schepers et al., 2017; van Doorn et al., 2013). Furthermore, Druin proposed some strategies in order to achieve a greater level of participation in design (Druin, 1999). The importance of children's participation is fundamental to design technologies specifically targeted for children because the involvement of them in the design team gives them a voice. Their participation in the decisional process helps the designers to take into account their perspective and what they really want from the technology.

Read et al. presented the IBF participatory continuum model, to help the designers to identify and clarify the aim of participatory design research with children and adults (Read et al., 2002a). While involving children at higher level of participation into the design processes is a difficult task, the IBF offers a series of unique perspectives and resources that are extremely difficult to discover with the more traditional design approaches (Dodero et al., 2014; Gennari et al., 2017; Iivari et al., 2015; Kinnula et al., 2017; Read et al., 2002a). Furthermore, the design of TUI for children benefits from the children participation by enabling the designers to understand what are the physical and spatial elements to take into account and what are the more natural interaction paradigms to adopt. A more recent work investigated how the maker technologies could be used with children in designing physical games (Fitton et al., 2015). The results showed that the introduction of maker technologies early in the design process improved the novelty and the complexity of the children's design ideas.

1.3. Research questions

The research in the literature shows the importance of including the participation of the children in the design of technologies. In parallel, the research community proposed several frameworks and guidelines to guide the designers into the complexity of designing TUI technologies with and for children (Antle, 2007; Antle and Wise, 2013; Resnick and Silverman, 2005; Stanton et al., 2001).

Practical implications, such as the technological choices and the materials, are fundamental in TUIs as the strength of this types of interfaces relies strongly on the physicality of interaction and the material representation of the information (Ishii and Ullmer, 1997). Practical design choices have an essential role in the design processes as they shape one of the most peculiar aspects of TUIs.

To address these open research issues, this thesis focuses on the design of a generative based on an electronic component set for designing tangible-based artefacts and facilitate participatory design activities with children (Sanders and Stappers, 2014), which are not bound to a specific educational or entertainment objective. According to Sanders and Stappers (2014) a generative tool *is a set of 2D or 3D elements that non-expert users could use to express their ideas, feelings and dream.* The work refers to the development of BugBits; an electronic component set flexible enough to be used in different contexts, with different audiences and different purposes. In addition, the work presented in this thesis strives to include children at the highest level of participation during the design activities. To achieve these objectives, the thesis addresses the following research question.

What are the critical elements of the design process of generative tools for empowering children in making new TUIs?

The analysis conducted on the three case studies presented in this thesis highlighted three critical elements such as:

- The Knowledge, defined as the initial phases, processes, guidelines, frameworks and methods used by the designers to identify the design space and requirements of the tool. This knowledge is built on the previous findings in the literature and by the adoption of user studies.
- The Practice, defined as the set of technology dependent elements that are discovered in the field while in use. The technology-in-practice approach presented in section 9.2 introduces the concept of *"instance"* as a method to implement and test the tool in the field collecting meaningful data.
- The Widening of design space, defined as the adoption of the tool in an ecological setting without posing limitation on it. This element creates the condition to test the tool aiming at empowering the children and make them an important voice in the design.

The three elements presented above led to the formalisation of The Knowledge Practice Widening (KPW) process that aims at guiding designers into the development processes of electronic-based generative tools for TUIs. The process relies on previous findings, frameworks and guidelines (Antle, 2007; Antle and Wise, 2013; Resnick and Silverman, 2005; Stanton et al., 2001) and aims at including the children in a high level of participation, giving them the role of design partners (Druin, 2002; Iversen et al., 2017). Furthermore, KPW proposes processes to test the flexibility of the designed set in different contexts and with different purposes. Therefore, the main research question could be expanded to the following specific sub-questions.

Can BugBits be flexibly adapted to different interaction contexts?

Study1 and study2 (chapter 5 and chapter 6), tested BugBits in different contexts and with different purposes. These studies were conducted to answer to this question and they informed the designers on the flexibility of the toolkit by testing it in the field. The results highlighted the flexibility of the toolkit, moreover, the third study (chapter 7) tested the tool flexibility by enabling the children to design their own TUI artefacts.

The design of a flexible generative tool for the design of TUI with children needs to be tested in different contexts aiming at the expansion of design space. The covering of a larger design space opens the possibility to be used for various applications (e.g. entertainment, gaming, education). The KPW process presented in this thesis aims at evaluating and reflect on the ability of the designed set to be utilised in different contexts (e.g., museum and kindergarten). In particular the intermediate phase of the process the "technology in practice" is strongly related to these design aspects, fostering the children creativity and reflection about their needs to include into the design.

Can BugBits empower the children in participatory design activities?

The latest study was conducted to empower the children aiming at involving the children in a genuine participation during a series of participatory design workshops. The empowerment of children is a crucial design element in participatory design activities with children as it enables them to be actively involved in the design activities. In particular, if the technology can be used with ease by the children, it will allow them to participate as design partners into development processes of artefacts and foster their creativity and engagement (Amabile, 1998). The last phase of the KPW process aims at exploring the design space of the generative tools and achieve a genuine children participation by giving them a voice into the decisional processes belonging to design partners (Druin, 2002; Iivari et al., 2015; Kinnula et al., 2017). The use of the analysis of the roles and the empowerment levels following the model adopted by Kinnula et al. in 2017 highlighted an increased level of children empowerment.

1.4. Empirical studies

The research presented in thesis was developed in a period of about two years to develop BugBits, an electronic component set for TUIs used in participatory design activities with children. The research through design approach evolved over 3 case studies where the technologies were designed, developed, and tested in the field. The development followed several iterations, involving domain experts, and other HCI researchers. The first case study was conducted at an art museum as an extracurricular activity with children of 13-15 years old. The second case study explored the potentiality of the set to perform some colour learning exercises in a local kindergarten with children between 3 and six years old. The third case study was a series of participatory design workshops with children between 7 and 12 years old. Reflections about the results and the practical experiences coming from the three case studies lead to the definition of the KPW process, a structured set of guidelines to guide the designers into the design processes for participatory design activities.

1.5. Outline

The thesis is structured in 10 chapters as shown in Figure 1. Chapter 2 illustrates the literature about children characteristics and design with/for children. Chapter 3 describes the Tangible User Interfaces: their application in different contexts, their use with and for children, how they were implemented and evaluated. Chapter 4 introduces the process of design of the BugBits TUIs toolkit. Chapter 5 describes the first case study with the BugBits toolkit in a museum setting, Chapter 6 illustrates the second case study where the toolkit was used for educational purposes in a kindergarten. Chapter 7 illustrates the latest case study where the BugBits toolkit was adopted to conduct a participatory design workshop with children. Chapter 8 discusses the results of the case studies and reflect on the criticalities and positive aspects. Chapter 9 introduces the KPW design process, a structured process to help the designers to develop TUIs with a particular focus on the children participation and reflections about the technology implications. Chapter 10 closes the thesis, discussing and presenting reflections, limitations and the future works.

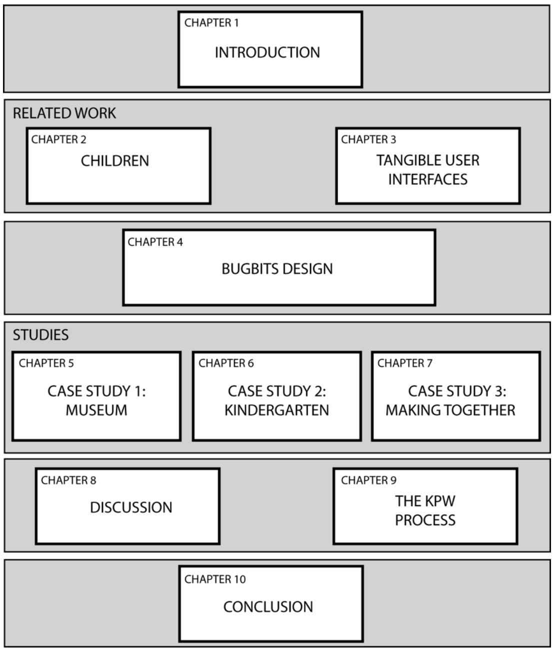

Figure 1: The thesis outline and structure of the chapters

2. CHILDREN

This chapter gives an overview about children following on different aspects, starting from their development to their involvement in the design processes and making activities.

The diffusion of IT technologies such as smartphones, laptops, tablets created a new environment in which children, starting from very young ages, are in contact and become users of those technologies (Resnick and Rusk, 1996). Despite early studies such as those by Papert in the 80ies, the last 10 years showed a significant increase in the number of publications about design for children. This interest gave rise to a new research community called Child Computer Interaction (CCI), a multidisciplinary research field focused on the relationship between children and technology (Read et al., 2008; Read and Markopoulos, 2013). CCI is a specialisation of HCI. Although HCI research produced a large variety of frameworks, guidelines, evaluation methods and empirical works, they were mainly focus on adults. This rich set of knowledge cannot be extended to CCI, because children have unique characteristics which will be briefly presented below.

2.1. Child development

This section focuses on the children development. The main contribution on children development processes were theorized by Piaget and Vygotsky that are briefly summarized in the next sections (Piaget, 1951; Vygotsky, 1987).

Piaget theory states that young children are different from adults; in particular the way they experience and interpret the world and also consequently the way they learn (Piaget, 1951). The learning process of the children is constructivist, and it is divided on two phases: assimilation and adaptation. The first case happens when the children had an experience that was compatible with his previous knowledge. The latter contrarily happens when the experience "forces" the children to expand and modify is knowledge to give it a meaning. It becomes fundamental how children interact with technologies and according to several studies, physical interaction with objects is fundamental for the development of new mental models.

Piaget divided the child development into four cognitive development stages:

- **Sensorimotor stage**: children from the birth to 2. Infants are acquiring knowledge through their sensory experiences and manipulating physical objects. Children in this stage are learning how to move and perform physical actions at the same time children are learning the language from the adults who are interacting with. In accordance with Piaget one of the most important things in this stage is represented by the object permanence, objects continue to exists also when they don't see them. They also learn to distinguish between objects and living beings. During this stage toddlers start to realize that actions can cause effects on the world around them.
- **Pre-operational stage**: children from 2 to 7 years old. Children in this stage start to use words, pictures and drawings to represent objects. Children start to think symbolically giving meaning to objects. The ability to see things from the point of view of other people is not well developed during this stage and they tend to have an egocentric view of the world. Even if the language starts to develop in the previous stage, is during the preoperational stage that children consolidate their language skills and are starting to sustain some conversations. The logical thinking starts during this stage but children struggle to perform logical reasoning, they tend to think in more concrete terms (e.g. physical aspect, size, etc.).
- **Concrete operational stage**: children between 7 and 11 years old. In this stage, children are gaining the capability to use the logical thinking (such as following game rules), but they are able to apply logic and operation only to/with physical objects. Other characteristics which are typical of the concrete operational stage such as conservation, classification and seriation. Conservation is the ability of understanding that if we change the appearance of an object the properties like the mass, volume, length and number are the same of the starting object. Classification is the ability to

solve problems by clustering objects according to some common dimension. Seriation is the ability to solve problems by sorting objects according to a measurable dimension (e.g. weight, length).

- **Formal operational stage** starting from 12 years old and up. During this stage the children are gaining the ability of abstract thinking. They start to being able to think and reasons about abstract ideas and reason about hypothetical situations. They gain the ability to find and think multiple solutions to real world problems and they change their vision of the world towards a more scientific approach. Children are able to perform logical thinking and deduction, so starting from an initial general case going to a specific.

The role of teachers and adults and their interaction with children is equally fundamental enabling the creation of a zone of proximal development as stated by Vygotsky (Vygotsky, 1987). The sociological approach of Vygotsky, in contrast with Piaget and his vision about the innate nature of children development, gives importance to the interactions between peers. For example, with an appropriate peer interaction and guidance, children can solve problems that are too difficult to be solved alone. Learning benefits seem to depend by the close link between perception and cognition (Triona and Williams, 2005).

Several researchers have focused on how technology can foster children learning. One of the pioneers was Seymor Papert who designed one of the first examples of ICT learning system for the children. In particular Papert developed Logo a simple programming language and the Turtle a physical interface able to draw lines and shapes through Logo commands (Papert, 1980). Papert's research focus was not only how to program, but to the whole and broader process of learning, during which children gained new ways of thinking and understanding the world (Papert, 1993). According to Resnick & Rusk as the technology is increasingly more widespread in our lives, for the children becomes fundamental being able to use technologies as tools for success in school and in the future workspaces (Resnick and Rusk, 1996).

2.2. Design Involvement

The CCI community in order to deal with the peculiarities of designing products and technologies for children tried to involve them always directly into the design processes in order to include their point of view. The roles of children into the design processes was studied by Druin in 2002 following a similar approach to the "ladder of participation" by Hart's in identifying the level of participation of the users. The children participation was summarized in 4 ordered levels of participations, where the successive level contains the previous ones.

The lowest is when children are treated as **users**, as the name suggest the children enters only marginally into the design process. Maybe they were considered through observations and ethnographic studies, but they have no direct connection with the designers and they have no decisional powers on the development of technology.

A more inclusive level is when children are treated as **testers**, compared to the previous level children are involved throughout the whole process. Children are becoming testers of prototypes at all level of fidelity and designers and developers collects feedback from them during the whole development process. As for the children as users level, within this level children cannot influence the design directly, all the feedbacks and design decisions are taken by designers.

The next level is when children are **informant**, this role theorized also by Scaife and Rogers is the first one that puts the children in direct contact with the design team(Scaife et al., 1997; Scaife and Rogers, 1999). The children role is not at the same level of a designer but the children can be consulted through interviews, focus groups and questionnaires when the design team think that a direct contact with them is useful.

The highest level of participation is reached when children are **design partners,** in this level the children are becoming effectively part of the design team, designers and children ideas have the same decisional power. The children ideas are considered as good as the ones coming from the other members of the design team.

Furthermore, researchers and children engage in a collaboration to develop meaningful technologies.

Recent studies evolved this classification of children participation levels expanding the children role into the design process giving them more power and control over the design. Iversen et Al. introduced the concept of **protagonist** that pushes the level of the children participation a step further, children are not only design partners, they are the main agents of the design and they improve and learn new skills during the process (Iivari and Kinnula, 2018; Iversen et al., 2017). This gain of knowledge is crucial to empower the children, their improved level of understanding of technology enable them to take more informed design decisions. A recent study of Iivari explored the involvement of children as protagonist in participatory design sessions with making activities (Iivari and Kinnula, 2018). The study showed that there are no clear knowledge on how to empower the children to the protagonist level. Moreover, making the children protagonist of the design resulted in being a complex task.

Another research direction was to include children as **co-researchers** giving to the children the ability to collaborate, discuss and influence the research in a more direct way. Children are becoming an active actor in the research covering roles and tasks that were traditionally done only by the researchers such as the data gathering processes and the analysis processes (Doorn et al., 2014; van Doorn et al., 2013).

A similar study investigated the children roles in participatory design activities analysing the data of several workshops involving 60 children (Schepers et al., 2018, 2017). The authors extended the model proposed by Druin introducing the role of **process designers**. This role enables the children to design the methods and processes of the workshops, the authors suggest that a genuine participation could be achieved by extending the children role to this level. This thesis aims at engaging children as partners in the design and development of TUI.

The children involvement in one of the fundamental aspects of the children involvement, as it requires the children a cognitive effort and to process the information (Xie et al., 2008). For example, in learning application with children engagement is a process that requires a continuative focus and attention in completing some tasks. To assess the level of engagement of children the literature offer different approaches such as observing specific behaviours such as yawns and frowns (Hanna et al., 1997). Read et al. following a similar approach used videos and recorded the positive instantiations (e.g. laughing) and the negative instantiations (e.g. sign of boredom) (Read et al., 2002b). Moreover, engagement of children is a multifaceted dimension that could be divided into three macro-categories: behavioural, emotional and cognitive (Fredricks et al., 2004). Behavioural engagement is defined as the process that involves the children because their participation is considered crucial for achieving a positive result. Emotional engagement is related to the reactions, positives or negatives, to the teachers, classmates that are influencing their will to participate. Cognitive engagement refers to the idea that children will put their cognitive efforts in tasks and activities to understand and gain new skills.

2.3. Methods

There are several ways to involve children and make them design partners, Druin suggested a methodology called cooperative inquiry (Druin, 1999). This approach is based mainly on 3 techniques: contextual inquiry, technology immersion, and participatory design

- Technology immersion: children and adults are introduced to the technologies. During these sessions the capabilities and peculiarities of technologies are explained. The design team and children can choose what technology result to be the more appropriate for the children.
- Contextual inquiry: Adults and children observe themselves during the utilization of technology. Both children and adults are fostered to express their thought about the technology: what is working, what is not working, what can be changed/improved.

- Participatory design: Children and adults work together to develop low-level prototypes. The collaboration between children and adults start from the early phases of the design process. This methodology is more hand-on and aims at developing very simple prototypes to find a good design direction to follow since the beginning. During participatory design session is common to use scholastic materials such as paper, cardboard, pens, boxes to implement quickly these low fidelity prototypes.

The participatory design approach is the highest level of participation that children can assume during a design process, in this case children and adults have the same importance inside the design team. Read et al. proposed the IBF model, identifying three modes of participation: informant, balanced and facilitated (Read et al., 2002). In an informant design the children contribution is limited to inform the designers; a balanced design is characterized by an equal contribution across the participants. A facilitated design gives the decisional powers to the children and the role of the designer is relegated to a facilitator role.

Another methodology, TRAck (tracking, representing and acknowledging) was defined by Read at al. it proposes a process to select democratically the children ideas. In particular the method analyses the children ideas in depth to evaluate and select a predefined number of "candidate ideas" for each design and team. The final selection of the "winning ideas" will represent each one of the children's team, this method enables to elect the ideas that are more represented by the children and not the ones considered the best by the researchers. In particular this method ensure that the winning idea is a representative of all the groups and keeping track of children contributions (Read et al., 2014).

Grounding on the Scandinavian tradition on participatory design, Iivari et al. propose an extensive reflection on the meaning of participation in children research (Iivari et al., 2015; Iivari and Kinnula, 2016). The study focused on a participatory design project with children reflecting and arguing if the currents methodologies are effectively achieving a true participation of the children. The authors analysed the project following the effective participation criteria theorized by Chawla and

Heft (2002). Results showed how a genuine children participation is difficult to achieve and how the stakeholders were influencing the participatory design processes. Recent research showed different attempts in involving children in a participatory design practises to develop video games, starting from the conceptual design up to the implementation phases (Dodero et al., 2014; Gennari et al., 2017). A further study analysed 3 participatory design studies and highlighted how the empowerment of children is often a concept not grounded in the publications (Kinnula et al., 2017). The authors proposed a list of 5 lenses to take into consideration to identify what is the real meaning of empowering in the studies with children. The lenses are the following:

- **Mainstream view**: when the children are invited and motivated to participate into the design but within the predefined limits imposed by the designers;
- **Critical view**: when the design processes enables the children to "combat" the ones in power to expand and reshape the imposed limits;
- **Democratic view**: when the design enables the children to be contributing substantially to the decisions-making processes, report and identify issues affecting their lives;
- **Functional view**: when the design enables children (also with technologies) to improve their life conditions, performance and efficiency in achieving their goals, while staying within the limits imposed by the designers;
- **Educational/Competence view**: when the design offers to the children to gain skills and competences that are useful for the real-life and being part of the society.

Very few research can be found in this direction, one of the first attempts were conducted by Eisemberg in 2003 and 2004 (Eisenberg et al., 2003; Eisenberg, 2004). More recently, a system called Tiles was designed to enable children to design tangibles and interactive systems using a set of 110 design cards in conjunction with some programmable computational units called Squares (Mora et al., 2017).

2.4. Making

Learning activities based on making started from the Piaget theory 1936 and later in the 1980 thanks to the vision of Papert lead to the constructivist model of learning. The constructivist approach gives importance to the children and puts them in the centre of the learning process, they learn while building. Following the Carter's concept of "material thinking", materials are an important factor of the design and they interact with the maker influencing his creative process, actions and ways of thinking (Carter, 2004). While HCI community appreciated the making for its ability to democratise the participation and production of technology, is also seen and criticised for its underlying technosolutionism (Lindtner et al., 2016). This reflection suggests the designers to pose particular attention in how the technology is utilized in the making activities.

2.4.1. Approaches

The research conducted by Brandt et al. identified three main approaches of making: generative tools/toolkits, probes and prototypes (Brandt et al., 2012; Sanders and Stappers, 2014).

- **Generative tools/toolkits**
  The use of a set of 2D or 3D elements that non-expert users could use to express their ideas, feelings and dreams. The generative tools rely on the creation of those sets that are designed to be ambiguous and open-ended to the users fostering them to think and reasons about their choices. These tools enable non-designers to dialogue with the design team and contribute to the design process expressing their thoughts. Usually a good generative tool is composed by fewer elements carefully chosen by the designers to enable the users to express their creativity and thought in a large design space. Generative tools were used successfully to complement the use of interviews and observations to elicit the tacit and latent needs of the users (Elizabeth and William, 2002).
- **Probes**

Are instruments specifically designed to collect data about new technologies or interfaces from the users. As for the generative tools probes are leveraging the use of an ambiguous design to elicit their thoughts and feelings. Probes are usually composed by tasks and a set of open-ended materials to enable the users to participate to the design process in the early stages. The use of probes were introduced in 1999 with the definition of cultural probes, the use of a set of material to enable the designers to understand the role and the differences related to the culture of the participants (Gaver et al., 1999). Hutchinson introduced the term "technology probes" extending the work of Gaver and shifting the focus on the field-testing of technology, inspiring the users and gather data (Hutchinson et al., 2003).

- **Prototypes**

  Are the physical representation of a design idea or concept. They can be implemented at different levels of fidelity. Low-level prototypes explore the general design ideas, while high-level prototypes are offering an experience closer to the finished product. The prototypes are more suitable to explore the technical and social feasibility of real products and working systems, end users are usually using prototypes to evaluate them (Brandt et al., 2012). Prototypes could be used also in early stages of the design process to explore the design space, but they need an already defined set of requirements done by the designers.

All the three making approaches can be combined and used together to target different aspects of the design, one approach does not exclude the use of the others. Often the use of probes and generative tools are used by designers to drive the initial phases of the design while the prototypes are more suitable for the designs in a more advanced stage.

Gielen in 2008 used the generative tools and techniques to identify the design problems and the contexts of use of the technology (Gielen, 2008). Similarly Sluis-Thiescheffer explored different approaches to generate ideas at the initial phases of the design process (Sluis-Thiescheffer et al., 2007). The results showed that children were exploring more design space when using simple prototyping tools in respect to the more traditional techniques such as the brainstorming. Similarly, Barker suggested that only when technology is used in an ecological setting it is possible to observe the natural behaviours of the users, thus the ones representing the real interactions between the technology and the users (Barker, 1965).

The participation in making follows an iterative process of making, telling and enacting (Brandt et al., 2012). Even if the process identified three phases the study showed how these often are happening at the same time, e.g. the children make an artefact at the same time use it and explain how it works. For these reason is very difficult to have a clear separation of the phases.

The creativity is influenced positively by the use of participatory design processes where the users collaborate, discuss and explore more options and design space (Sanders and Simons, 2009). While the creativity benefits the adoption of participatory design the users the elements that affect the user motivation in creative processes are three: expertise, creative thinking skills (e.g. the ability to deal with difficult problems) and intrinsic motivation (Amabile, 1998). The combination of these three factors could improve the overall creativity of the users. The designers could improve the creativity of the users by designing their toolkits, probes and prototypes taking into account the three creativity elements. A study showed how the early introduction of making in the design phases affect positively the creativity , novelty and complexity of the children's designs (Fitton et al., 2015). Conversely, when the design activities happened before the making the creativity was lower.

2.4.2. Tinkering

Makerspaces are places in which the constructivist approach is widespreadly used, science museums nowadays have usually a section dedicated to the making activities. Fablabs, are laboratories dedicated to the digital fabrication, they could be found into the museums as dedicated areas for the making activities (e.g. Exploratorium, Muse, Ars Electronica). One of the most important museum that was promoting this kind of activity is represented by the Exploratorium in San

Francisco, where they had more than 20 years of experience in organising making activities. The learning processes happening during the making activities are commonly defined as tinkering. Tinkering activities facilitate children to be the protagonist of the learning processes through immediate feedback, open exploration and fluid experimentation (Resnick and Rosenbaum, 2013). Children involved in this type of activities showed to be more interested in science subjects and expressed interest in doing science related subjects (Krishnamurthi et al., 2013).

The research in the Tinkering Studio identified 4 main dimension of the learning happening in tinkering/making activities: engagement, initiative and intentionality, social scaffolding and the development of understanding (Petrich et al., 2013). Most of these activities were happening in science museums were the use of electronics and construction materials was directly related to the topics treated in these type of museums, very few examples were conducted in non-science related museums. One exception was represented by the Peabody Essex Museum (PEM) that focuses on art and culture. Studies conducted at the PEM museum in 2015 showed that the learning patterns found in STEM[1] related museums were happening similarly also when the focus was about art and culture. These results were confirmed also by Sheridan et al. (2014) and Litts (2015) that found similar learning patterns across different context and types of makerspaces. A substantial number of museums studies revealed the fundamental importance of the facilitators. Gutwill at al. (2014) identified three approaches to facilitate the children in making activities (Gutwill et al., 2014):

- Orienting: guide the children through the design space and activities
- Sustaining: foster participation by giving suggestions and tools
- Deepening: make the children reflect about their decision and foster them to improve their work

[1] Science, Technology, Engineering and Mathematics.

The maker movement manifesto explicit how the learning processes were fostered by the use of physical materials and dealing with real-world problems (Hatch, 2013). Furthermore Kurti et al showed that children involved in the making activities could be more creative and more prepared for the real-world challenges (Kurti et al., 2014). Roffey and Sverko highlighted that the learning processes in making activities happens not only because children learn from the teachers or facilitators how to build something, but mainly because they were truly engaged in the problem solving and building processes (Roffey et al., 2016). The making approach was considered a powerful tool as in the research performed by Dow and Klemmer showed that people who used physical prototyping during the design phases produced better designs compared to people who followed a non-physical prototyping approach (Dow and Klemmer, 2011).

2.4.3. Programming

The ICT and programming learning is becoming a widespread topic in everyday life. Starting from the Computer Club Houses were social spaces where the learning occurs in a sustainable and social way (Resnick and Rusk, 1996). The expert members become teachers and the young members are increasing their competencies until they become themselves teachers. A more recent approach is represented by CoderDojo “a global movement of free, volunteer-led, community based programming clubs for young people” (Bossavit and Gaillot, 2005). In this case, the community is focused on teaching programming to children starting from 7 to 17 years old. During a Dojo meeting children can learn how to program using tools as Scratch, Lightbot, The Blocky Maze and Code.org. All of these tools are using the metaphor of the visual programming, and so placing on the screen various visual blocks of code to play and interact with simple games.

The literature shows how the approaches for teaching programming to young children evolved. The first attempts of Papert were trying to make the programming languages more understandable for children (Papert, 1980). Moving to a novel digital approach such as Scratch were programming constructs are graphically represented and using shapes and colours the interface itself suggest the possible actions (Resnick et al., 2009). The more recent approaches such as Tern are exploiting the richness of physical actions and spatiality using video streams(Horn and Jacob, 2007). In particular with the help of computer vision techniques children can visually and physically "build" simple programs by placing sequences of wooden blocks on a table.

3. TANGIBLE USER INTERFACES

This chapter gives an overview about tangible user interfaces, starting from their origin and analysing their applications in different domains. A substantial part of the literature presented in the following subsections focuses on the analysis of the strengths and weaknesses of tangible user interfaces, their application with children and how the literature addressed the development of these interfaces.

The history of Tangible User Interfaces (TUI) dates back in time. Starting from the mid-90s, the HCI community began to explore new interaction paradigms searching alternatives to the traditional Graphical User Interfaces (GUI). The idea was to find new ways to use computer technologies going beyond the traditional Windows, Icon, Menus and Pointers (WIMP) paradigm (Van Dam, 1997). In 1993, a special issue of ACM titled "Back to the real world" highlighted how the use of virtual reality was not perceived by the users as a natural way of interaction (Wellner et al., 1993). Back then, the authors claimed that the users were required to adapt their behaviour to the virtual world rather than using their real-life knowledge. Starting from this way of reasoning, the HCI community tried to find alternative solutions to minimise the gap between real lives and the digital world. The physical manipulation of objects was investigated as a promising solution.

One of the first attempts was the proposal of "graspable user interfaces", introduced by Fitzmaurice in 1996 (Fitzmaurice, 1996). In this paradigm, the action on digital elements was mediated by manipulation of physical objects, other than the keyboard and the mouse. The author proposed the use of a set of objects which mirrored the graphical representation of typical GUI elements. The users could interact with the digital environment by moving blocks that were bound with some graphical objects on the screen. This idea was exploited also by Ullmer and Ishii (1997) in the metaDESK project developed at the MIT. In this project, the authors used physical objects, called *Phicons*, as a representation of the traditional concept of the icon of a GUI (Ullmer and Ishii, 1997).

Expanding this idea, Ishii and Ullmer introduced for the first time the concepts of TUI, as a physical and enriched alternative to the GUIs (Ishii and Ullmer, 1997). The new concept differed from the graspable user interface where the focus was mainly on the ability to interact physically with a visual display. The TUI proposal was fundamental because it highlighted how objects of the real world could be used as the interface, becoming both the display and the interaction device (Ishii, 2008). A TUI is the physical representation of a GUI: it embeds a meaningful mapping between the physical input/output and the digital world. The work by Ishii and Ullmer gave rise to increasing interest in tangible interaction, which falls in the broader area of embodied interaction research (Dourish, 2004). Tangible interaction opened the opportunity to narrow the gaps between the virtual and the physical environment, moving the interaction between humans and computers out of the screen boundaries. Over the years, several technological improvements offered new possibilities to further research on tangible interactions embedding the computing hardware directly into the real objects.

3.1. Design

The advantages of TUI over GUI can be explained by Norman's Theory of Action (Norman, 2002). According to this author, the user behaviour with an interactive device can be summarised in 7 stages.

The first stage is the *goal formation*, the users define their final goal. Stage 2, *forming the intention*, is the process in which the user choose mentally how to achieve the goal. In the third stage, *sequence of actions*, the users define a sequence of actions to perform to achieve its goal. The next stage is the *execution* the user in this phase execute physically the sequence of action defined in the previous stages. The fifth stage, *perceiving the state of the world*, happen after the execution of the action. Stage 6, interpreting the perception, in this phase the user interprets the state of the world accordingly to its expectations. The latest stage is the evaluation and interpretation, during this stage the user evaluate if the outcome of his actions fulfilled the initial goal. Norman defined the concept of gulf of execution and gulf of evaluation. The gulf of execution is the difference between the actions performed by the system and the actions the user had in mind. The gulf of evaluation is the effort needed to interpret the state of a system after a user action was performed. A schema of the 7 stages is illustrated in

Figure 2.

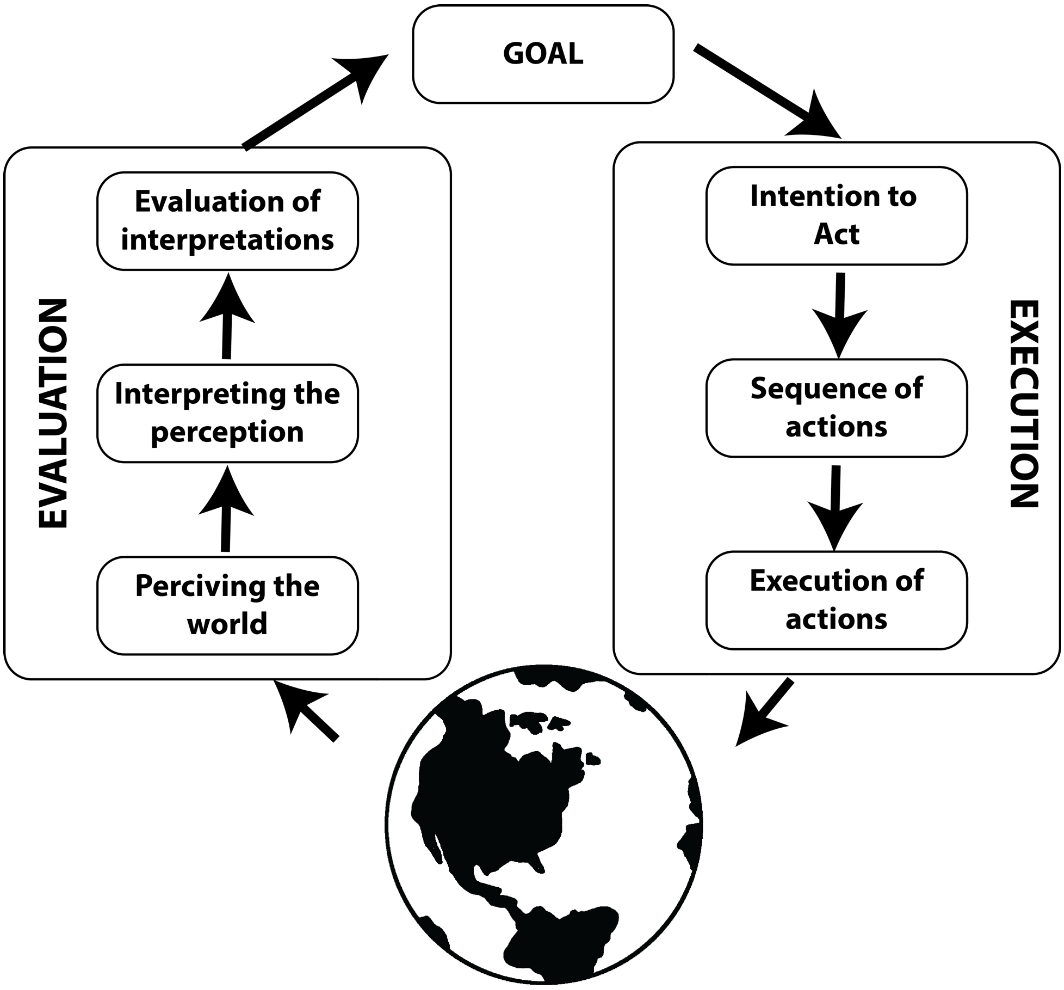

Figure 2: The Norman's Theory of Action, and the seven stages.

A well-designed TUI has the potential to narrow both the gulf of execution and the gulf of evaluation. The key quality metrics of a TUI reside in the perceived affordances of the physical object which should naturally match the system and the user world. For this reason, TUI are better suited to simple interaction contexts, where the user goals are limited in number. The design of TUI for complex applications is complicated by the need to balance affordances and task diversity. Because of this trade-off, the design of TUI is a complex process.

3.1.1. Approaches

The design of TUI follow usually a traditional User Centered Design, informed by instruments such as the PACT analysis (Benyon et al., 2005; Preece et al., 2015). The HCI community showed an increased interest in the practice oriented approach to research in the last decade (Kuutti and Bannon, 2014). In particular the authors labelled this approach as a "computer supported practice". A similar approach in developing the TUI and interactive products is represented by the reflection-in-action. An approach that aims at improving the products/technology while in use (Schon and DeSanctis, 1986). Grounded on this concept Dittirch defined the design-in-use, a methodology in which the design evolves collecting the data in the field and at the same improve the design, the author defined this approach as the process able to *'capture practices of interpretation, appropriation, assembly, tailoring and further development of computer support in what is normally regarded as deployment or use'*.

3.1.2. Models, frameworks and guidelines

Several models, frameworks and guidelines were developed to cope with the complexity of the design and evaluation of TUI. A general framework was proposed by Hornecker and Buur (Hornecker and Buur, 2006). The authors identified 4 main themes characterising tangible interaction, as follows:

- Tangible manipulation: defined as the physical representation, the set of physical characteristics and qualities of the object manipulated;
- Spatial interaction: the interaction between the physical interface and real space movements;
- Embodied facilitation: the relation of the disposition and configuration of the objects in the space and the behaviour of the users;
- Expressive representation: the affordance of the object, its materiality, digital representation, legibility and expressiveness.

Fishkin analysed the tangible interfaces using two perspectives: the embodiment as the distance between input and output, and the metaphor as the use of physical characteristics to elicit metaphorical links (Fishkin, 2004). The authors identified four levels of embodiment as following:

- Full: when input and output happen completely on the same device;
- Nearby: when the output is in close proximity to the input device;
- Environmental: when the output surrounds the users, for example an audio feedback;
- Distant: when input and output are physically distant (e.g. another room).

The classification of the metaphors was divided into five levels:

- None: when there is any metaphor involved (e.g. a command line the typing gesture has no correlation effect);
- Noun: when there are similarities between the objects on the digital and the real world. The analogy is present but it is limited to the appearance of the objects;
- Verb: when the similarities between the digital and the real world are limited to the action performed on the object (e.g. moving an object moves the digital counterpart);
- Noun and Verb: when there is the combination of the Noun and Verb level of metaphor but the digital and the physical object are still different;
- Full: when the user does not need to make an analogy, the virtual system and the real world are completely merged.

Another framework discusses about the relation between actions and information, suggesting six aspects to take into consideration to mediate the relation between the user actions and the system information to obtain a more intuitive interface (Wensveen et al., 2004). The framework identified three modalities on how a product could communicate information to the user: *inherent, augmented and functional.* The **inherent** information concept is related to the concept of affordance, the information that the products communicate is strictly related on its appearance, shape or action performed on it.

The information is **augmented** when the user receives additional information about action possibilities or the response of a direct action.

The information is **functional** when the product generates information when the system is doing his main function or when product communicate its functional features using semiotics or exposing functional parts.

The authors suggest to render the relations between the actions and the information natural, including 6 aspects:

- Time: product reaction and user actions happen at the same time;
- Location: product reaction and user actions happen in the same location;
- Direction: the direction of the movements of the user actions and the products reactions are coupled;
- Dynamics: dynamics of the user actions such as speed, acceleration and position are reflected into the product reactions;
- Modality: the multisensory stimuli of the products reactions are in harmony with the user's actions (e.g. touching an object the system generates a sounds);
- Expression: the expression of the user actions on the objects is reflected in the system reaction.

Analysing the literature, there are examples where TUIs shows that they could offer benefits in comparison with more traditional user interfaces. For example, a comparative study was conducted on the use of a videogame called OHR. The game was implemented as a tablet game and as a tangible-based game (see Figure 3). The study used both qualitative and qualitative evaluation methods and showed a more positive user experience for the tangible implementation (Menestrina et al., 2016). Similarly Zuckerman and Gal-oz compared GUI and TUI identifying pros and cons of them (Zuckerman and Gal-Oz, 2013).

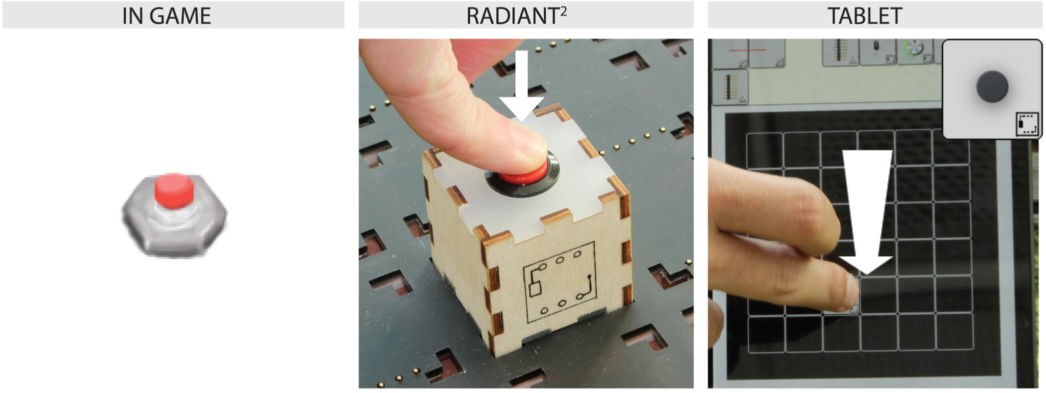

Figure 3: OHR videogame the different representations of the button object.

On the left part of **Figure 3** the graphical representation used in the videogame, in the middle image the tangible implementation and on the right the tablet graphical implementation.

3.2. Development

Developing a TUI is not a standardized process and there are several ways to build the interface. The early implementations of TUI started from scratch implementing custom electronics and writing low level programs to make it working. For example, Frazer et al. in 1980 implemented from scratch an electronic system to realize a modular and stackable system composed by blocks (Frazer et al., 1980). Another common approach was to modify and adapt existing products. Ferris and Bannon in 2001 followed a mixed approach by using custom electronics and exploiting existing technology products such as toys and adapting it to perform other functions, e.g. using the electronic of the birthday cards to detect when a box was opened (Ferris and Bannon, 2002).

Nowadays there are several alternatives to avoid a complete implementation from scratch. In particular, a few development platforms and several boards exist and enabled the possibility of creating cheaper TUI interfaces (O'Sullivan and Igoe, 2004).

This thesis identifies three main technological approaches used to develop TUI: RFID, computer vision, and "microcontrollers + sensors". Each technology has some advantages and disadvantages respect to the others and it is common to find TUI that combine two or more technologies together to get best performances (Xu, 2005). In particular, RFID systems are normally characterized by the need of a specialised hardware to read the tags embedded in the objects. This methodology of augmenting everyday objects embedding RFID tags is often complemented by the use of external screens and output medium. Moreover, this approach loses the co-location of input and output on the same device, losing one of the crucial characteristics of TUIs and potentially leading to split attention issues. The computer vision approach represents the most demanding in terms of computational power required. Moreover, even if external tools such as tags or special readers are not always required the feedbacks of the systems are usually happening on external mediums, thus sharing the same problems of RFID technology. The latest approach, "microcontrollers + sensors", represent a flexible solution that enables designers to choose different sensors that are determining the mediums to interact with. This approach enables the designers also to embed these sensors inside objects and input and output of the interactive system can happen on the same device. On the other end, the computational power of the microcontrollers is limited and often large and complex systems cannot be implemented easily. Even if every approach poses some limitation, the "microcontroller + sensor" approach seems to be offering a more complete solution. It enables the co-location of input/output and the adoption of different interaction modalities. The primary limitation remains the computational power. For this reason, the design of complex interactive systems could require the use of PCs to counterbalance those limitations.

3.2.1. Radio Frequency Identification (RFID)

RFID was one of the first technologies developed to identify objects in close proximity of a reader device. RFID is a wireless technology that uses electronic tokens, called tags, to sends their identification number and other information over radio frequencies. Tags could be active or passive, the first case the tag is powered wirelessly when a reader is in close proximity, the latter is powered by batteries and usually could communicate more complex information together with its identification. One of the strength of the RFID technology was the extreme low cost of passive tags, they were extremely small and often in a form of a sticker. Passive tags due their small form factor could be easily embedded/hidden in objects. One of the first examples of TUI based on this technology is mediaBlocks, where physical blocks were tagged with RFID and used as containers for multimedia content (Ullmer et al., 1998). Another example was Block-Magic a RFID system used for children learning inspired on Montessori and Munari learning theories, the RFID reader was connected to a PC, children could place objects augmented with RFID tags on the reader and play simple videogames on the PC or TV screen (Miglino et al., 2014).

3.2.2. Computer vision

TUI based on computer vision are advanced systems that are using an imaging system as input such as: live video streams and static pictures. As for the RFID technology, the computer vision techniques could use specific tags or automatically recognize specific colours and objects in the scenes. Computer vision technology could exploit the spatiality and physicality of the interaction enabling the designers to create new and complex ways of interaction. Computer vision techniques require a high computational power to work, so a powerful PC and a good quality camera are necessary to realize these types of systems. The tag-based computer vision techniques are the easier to implement thanks to the availability of libraries such as: ARToolkit, Reactivision and Aruco. These libraries based on tags and fiducial are requiring less computational power than the tagless computer vision systems (Kaltenbrunner and Bencina, 2007; Kato, 2002; Munoz-Salinas, 2012). One of the most important example of TUI based on tag/marker was the Reactable an interactive tabletop used to create electronic music by moving cubes over the tabletop surface, the system was successfully used by musicians but also by non-expert users such as children (Jordà et al., 2007). Another significant study was TERN a programming language based on TUI (Horn et al., 2008). Children could place and order wooden blocks in the space to physically build a program. Each wood block was mapped to a snippet of code to execute. More complex and demanding systems enable the designers to use the users body as interface or other everyday objects. An interesting example was the MusicRoom installation that leveraged the embodied interaction paradigm, where two people could create and control the music played in a room by moving and dancing inside it, the system was tested with a broad audience from young children to adults (Morreale et al., 2014). A corpus of researches were implemented using the Kinect sensor avoiding the use of tags, and exploiting the native ability of the sensor to track people movements (Hsu, 2011).

3.2.3. Microcontrollers and sensors

This approach is the most flexible the implementation of TUI. Microcontrollers and sensors have been used since the birth of the TUI as bridge between the digital and the real-world. This flexibility offered by the microcontrollers lies into their intrinsic capabilities of being compatible with very large number of electronic components. Furthermore, a microcontroller is a cheap and reliable microcomputer that can be interfaced to a wide variety of sensors, they normally have a small computing power but they can be programmed to accomplish simple tasks at high speed (O'Sullivan and Igoe, 2004).

The sensors variety enable the designers to measure and interact with the physical properties of the world such as: the temperature, light, colour, magnetic field, proximity, reflection, position, touch, altitude, pressure and other types that are measuring (Schmidt and Van Laerhoven, 2001).

Microcontrollers however needs some additional electronic components in order to to be usable. For these reasons there are several types of microcontrollers boards on the market that are embedding all the required circuitries such that they can be used without a strong knowledge in electronics. Arduino is one of the most diffused microcontroller board solution on the market, supported by a large community of practitioners. The implementation of a large corpus of TUIs is based on the Arduino platform due to its popularity and the large amount of information available online (Banzi and Shiloh, 2014). Its success could be attributed to the ability of being programmable with a standard USB interface, without any external tools such as hardware programmers. Furthermore, users could customize the Arduino behaviour by writing code using a C-like language. The possibility of instructing the board with a well-known programming language, avoiding the use of low level machine codes, opened the proliferation of pre-built libraries and thus lowered significantly the learning curve to use the board (Badamasi, 2014).

Goadrich et al. used Arduino together with Sifteo cubes and Android devices to teach programming concepts and the computational thinking to the students. In particular Arduino was an important part of the course and was appreciated by the students because it stimulated their creativity and the hands-on approach kept them engaged. Wang et al. in 2011 used the Arduino boards to design T-maze a tangible programming platform for young children (Goadrich, 2014; Wang et al., 2011). This approach enables the children to code by placing and ordering wooden blocks over a table instead of typing on a keyboard in front of a screen.

Other platforms, such as Raspberry Pi, Sifteo cubes, Phidgets and Littlebits, have been emerging in research in the last years (Bdeir, 2009; Jenkins and Bogost, 2014; Merrill et al., 2012). Arduino and Raspberry Pi platforms revealed to be the most flexible and diffused options, thus enabling the designers to use almost every available type of sensors and electronic devices. The difference between the two platforms lies into the complexity required to make them working (Cressey, 2017).

In particular, Raspberry-Pi board offers the advantages of a Linux operating system, thus with all the software packages available on the Linux platforms such as: webservers, imaging and audio processing, different programming and scripting languages. Despite the greater computational power Raspberry-Pi is supported by less hardware modules and the use of sensors is more complex requiring adaptations and additional circuitries.

Some of the difficulties in designing and building the external circuitries could be addressed consulting specialized online communities and platforms, where the users (experts or beginners) are sharing the solutions to their problems or asking for a possible one. A study highlighted that the more relevant resources to consult were the following: instructables.com, Arduino official forum, electronics.stackexchange.com (Tseng and Resnick, 2014).

The microcontrollers and sensors approach is used extensively also nowadays and represent one of the best performing technology for the TUI implementation, only considering Arduino and Raspberry-Pi in the last years were published over 350 papers (Cressey, 2017).

The use of the microcontrollers is characterized by the use of several devices of input and output. The output devices found in the TUI implementations could be characterized into 4 main categories:

- Direct audio: the use of sounds or music. Transducers like piezoelectric plates or buzzer used to generate simple tonal feedbacks, speakers in conjunction with specialized circuitry to generate polyphonic audio streams or reproduce music;
- Direct haptics: the use of the vibrations to give a tactile feedback to the user. Normally the haptic feedback is generated by small electric motors with unbalanced weights.
- Direct visual: the use of light to communicate information to the users. The use of light could use simple LEDs, LED arrays, characters LCD screens, graphical screens.
- Indirect: when the feedback happens on a device physically detached from the board. For example, using a Bluetooth communication and a PC monitor, speakers. In these cases the microcontroller communicate through different medium (Wi-Fi, Bluetooth, usb, serial, etc.) with an external device to generate a feedback.

The choice of one or more devices for output enable the designers to give to the user a multi-sensorial stimulation. Furthermore, microcontrollers are well suited to develop highly reactive systems with very fast feedbacks to the inputs. The drawback however lies into the limited computing power offered by these devices, thus rendering very difficult to realize complex systems with advanced graphics on screen or high-quality audio feedbacks. To overcome this computational limit microcontrollers are complemented with external devices and thus detaching spatially the input from the output. For this reason, microcontroller based TUIs are often using the less complex output medium to keep the input and output happening on the same device.

3.3. Application domains

TUI were used across a large variety of application domains and heterogeneous target users. This thesis categorises the related work addressing children and TUI into four application domains: tangibles for learning, programming, entertainment and information visualisation. Brewer et al. showed how the tangible interfaces and the use of gestures could support thinking and learning (Brewer et al., 2007). Although the majority of related work focused on education and the separation between the domains is often blurred (e.g., a tangible system to learn math can be at the same time a playful tool) the distinction is useful to organise the large corpus of related work.

3.3.1. Learning

One of the most interesting learning applications was represented by the digital manipulatives that were built as a series of computationally enhanced educational toys, construction kits and physical materials (Zuckerman et al., 2005).

The Lego Mindstorm platform is one of the most relevant examples of construction kits, it enabled the children to approach robotics and programming. The systems combines the strengths of a classic construction kit with stackable bricks and combines it with augmented parts such as motors and optical sensors that could be controlled using a central programmable unit, this technology derives from the visionary ideas Logo and Turtle by Papert (Papert, 1980).

Topobo, shift the learning focus from the programming to the learning of the system physical dynamics and characteristics. The system was developed to learn balance and the dynamic of movements, it was composed by a set of joinable elements (Raffle et al., 2004). The children's creations could be animated using a demonstration approach, children moved with the hands their creations, after, the system replicated the same movements automatically providing to the children the possibility to reflect and understand the dynamics of the system.

Flowblocks aims at reproducing the dynamics of physical systems. It fostered the children to reflect on systems dynamics by adopting a different interaction paradigm. In particular, the children needed to order a series of light-augmented blocks on a surface and observe and influence the reaction of the system (Zuckerman et al., 2006). The system shows how the physical actions facilitate children learning abstract concepts. Each system block can be connected together with the other ones forming a chain reaction of lights. This flow of lights was generated and modified accordingly to the direction of arrows on top of each block. The behaviour of the system did not replicate the moves of the children but responded to the children actions following specific rules. In particular the system reacted to the disposition of the blocks and used the lights to simulate the paths of water streams. The system was designed and tested for children between 10 and 11 years old. Results showed that the system helped young children to concentrate more on the behaviour of the system and grasp abstract concepts such as flow, rate and the cause effects relations.

Beelight is an interesting example of the use of colours as input and output media o TUIs. The systems was designed to mixing the use of tabletop technology and TUIs in order to teach and learn colours characteristics (Shen et al., 2013). The process of design involved directly children during 3 workshops. The artefact has the shape of a bee and can used by children and teachers to grab colours from real objects. This work showed how Tangible Interaction was a good choice to keep the children engaged and learn colours.

A different approach was shown with Storymat, an application to foster the creativity through storytelling, in this case the TUI was not used in a form of a construction kit, but a set of enhanced materials. In particular Storymat proposed a mat augmented with RFID technology and a set of tokens each specific semantic meaning and a graphical representation (Ryokai and Cassell, 1999). Children could place tokens on the mat and audio-visual feedback was reproduced on a screen, children could create stories by recording and placing the tokens over the mat. Storymat represent an example of the use of microcontrollers with an indirect feedback the mat was only an input device while the output was happening on a PC screen.

Following the same idea iTheatre represent a collaborative storytelling TUI, it followed a mixed approach in which TUIs were used together with a traditional GUI. The system enabled children to create interactive stories on a multimedia system by using RFID augmented physical objects (e.g. puppets) and digitalising and animating their own drawings (Mayora et al., 2009). Ely the explorer, used the same technology to teach cultures and geography and promote the children collaboration (Africano et al., 2004). A shared screen enabled the children to place augmented objects on it, create animations and cooperate to solve some simple tasks.

Similarly, Tsu.mi.ki adopted the TUI in a form of a construction kit to perform storytelling activities (Itoh et al., 2004). The system was an augmented version of the traditional building blocks. The system is able to recognize the shape and disposition of the constructions and renders it in a cyberspace. Children can animate the cyberspace manipulating their constructions. This tangible interface was designed to create a physical environment that stimulates education and entertainment for children. In this research there is a strong component of technology that support and stimulate children in storytelling and fantasy play activities. This system highlighted the importance of physicality and spatial awareness of TUIs.

TUI were used successfully to learn music concepts, their responsiveness and spatiality and manipulability resulted to be well suited to be applied to learn music concepts. For example “child orchestra” an embodied interaction system with elements of storytelling, use of augmented crowns and sceptres and an algorithmically generated audio feedback (Core et al., 2017). The system was used in a kindergarten to make the children (between 3 and 6 years old) aware about some basic music characteristics, in particular, speed, volume and articulation (Masu et al., 2017). The sound maker, utilized a similar interaction metaphor to produce percussive audio feedbacks by tracking the user’s movements in a rectilinear space. The system was designed to introduce the users to an active listening environment and make them aware of tempo, pitch and volume (Antle et al., 2008). The Reactable was one of the most successful computer-vision music making systems, the users were required to place and manipulate tokens over a tabletop to produce and modify electronic music in real-time (Horn et al., 2008; Xambó et al., 2013).

TUIs were explored also with children with special needs to help them to cope with relational, social and learning difficulties. For example, Farr et al. proposed an augmented toy castle to help children affected by autism (Farr et al., 2010).

More recently the Sifteo Cubes an inclusive design, were used to help children with difficulties with Visual Perspective Taking (VPT) (Geurts et al., 2014).The system was based on a set of augmented tiles that can visualize images on embedded screens and play sounds. They were used with children aged between 5 and 7 years to train their skills in VPT with promising results. In this case the design process involved directly children into the development of the conceptual design and into the prototyping phases. The results showed that children were facilitated by the use of Sifteo Cubes showing a significant learning effect in the short-term.

Tangible interfaces were also often adopted in museums, where they were normally used as a playful learning tools. Wakkary et al. proposed a museum guide based on tangible interaction with a display and audio feedback. The authors found that the use of the audio feedbacks and the TUI could be a good combination to balance the playful interaction and the learning effectiveness (Wakkary et al., 2008; Wakkary and Hatala, 2007).

The flexibility offered by TUIs was exploited into the I-cube, an interactive system composed by augmented cubes (Goh et al., 2012). The system was used with success to learn different topics such as grammar and music without changing the interface. Each cube was aware of its position respect to the others, this information was used with success to teach how to write words (each cube represented a letter) and to perform musical exploration (where each cube represented a tone or a musical parameter, the sounds were played accordingly to their disposition).

3.3.2. Programming

The "tangible programming" approach leverages the advantages of a tangible and physical interaction to learn concepts of programming. The use of tangible interfaces opened the possibility deal with programming concepts also with young children. The first approaches to tangible programming were started by Papert with the use of the Turtle and the Logo programming language, children could draw, learn geometry and programming concepts (Papert, 1980). Most of the tangible programming systems are using the concept of constructive assembly metaphor illustrated by Ullmer et al. in 2005, physical objects can be assembled and combined to build a representation of an algorithm that can be executed by the interface or a computer (Ullmer et al., 2005).

Algoblocks was one of the first attempts in trying to avoid the needs of writing code on a pc screen, their approach was to associate a specific function or code snippet to a series of cubes (Suzuki and Kato, 1993). Children could use Algoblocks and build a program by connecting several cubes together.

Electronics blocks was another system to introduce younger children to simple programming constructs, it was composed by several electronics blocks each of which integrated a specific function or operation (Wyeth and Wyeth, 2001). Children could build their program by stacking the blocks one on top of the other. TurTan followed a different direction, directly inspired by the Logo programming language, borrowed the idea of introducing children to the geometry using a system based on tokens and a tabletop; each token represented a specific operation to execute (Gallardo et al., 2008). The children can build programs in order to draw geometries on the tabletop screen, children could interact with the system by placing, connecting and orienting several tokens.

Similarly a programming system based on interlocking wooden blocks called Tern followed the same implementation idea by assigning a semantic value to each wooden block (Horn and Jacob, 2007). Children could build a program by combining different blocks representing: actions, flow-control and values. Tern adopted a computer vision solution rendering the cost of the blocks very low.

Twinkle adopted a different interaction metaphor by utilizing a colour sensor as input device (Silver and Rosenbaum, 2010). The authors mapped different colours to different actions, type of feedback or movements. Children could interact with the system by drawing, using coloured objects (e.g. Lego bricks) to instruct the system to perform one ordered set of actions and execute simple programs (Silver and Rosenbaum, 2010).

A recent implementation of tangible programming is represented by the micro:bit system (Ball et al., 2016). he micro:bit tangible programming offer relies on multiple ways of programming the behaviours of the components of the set, starting from the low-level code as the Arduino passing through more high-level graphical programming interfaces such as Touch Develop (similar to the Scratch programming environment). The system was used by children of 11 and 12 years old in the UK schools. The micro:bit basic system offered different input and output medium: 25 LED, 2 buttons, temperature sensor, light sensor, compass, accelerometer and Bluetooth communication.

A similar system called Tiles empower the children in the development of tangibles and interactive artefacts (Mora et al., 2016). The technological system is composed of small computing units called squares and complemented by a set of 110 design cards. The cards offer a good way to infrastructure the design processes to create interactive systems with children (Mora et al., 2017). Furthermore, some of the cards are representing the squares making a 1:1 mapping between the conceptual design and the future implementation. The use of the cards as a guide in the development of the prototypes is similar to the one designed by Shell targeted to the development of games (Schell, 2014).

3.3.3. Information visualization

Tangible user interfaces can be sometimes used to display only applications, where the users cannot manipulate the data but only visualize it. This approach could be usually found in form of interactive displays in: museum, information centres, exhibitions and shops.

A museum application was a tabletop game to visualize phylogenetic trees, results showed that the TUI game engaged the visitors (parents and children) and fostered collaboration between them (M. Horn et al., 2012). Hornecker et al. in 2008 analysed a tabletop application to visualize questions and answers, visitors (both adults and children) were required to interact with the displayed questions to discover the answer. Results showed how the design of the system was not clear to a large part of the visitors and elicited conversations among them about the interactive system and not about the content visualized (Hornecker, 2008).

3.3.4. Entertainment

Some tangible user interfaces were designed taking into account fun and engagement as important design requirements. The engagement and immersion of TUI could be directly reconducted to the "flow" concept theorized by Csikszentmihalyi, that happens when the engagement is full and there are a loss in the sense of space and time (Csikszentmihalyi, 1996). Those system normally are targeting multiple purposes, hence designed not exclusively for fun. In general research showed that the tangible approach is normally perceived as a more engaging way respect to more traditional user interfaces.

Xie et al. discussed about the perceived fun of children between physical, graphical and tangible interfaces (Xie et al., 2008). The results showed that the level of enjoyment and engagement was similar across the interfaces, but the perceived difficulties were significantly lower for the physical and tangible implementations. Furthermore children showed more interest in re-playing the game for the physical and tangible cases(Xie et al., 2008).

A similar study showed that TUI was more effective to keep engaged the children when compared to an equivalent GUI implementation(Horn et al., 2009).

Leitner proposed mixed reality game based on "the incredible machine" video game (Leitner et al., 2008). The game main purpose was to investigate the efficacy of the mixed reality systems. As for the original game, the mixed reality version was implemented mainly for entertainment. Although the main game purpose was the fun, children could also learn the physics behaviour of the objects and the characteristics of basic cause-effects systems.

A novel approach to design of TUI is represented by Makey Makey a device able to emulate any key of the keyboard and mouse movement (Collective and Shaw, 2012). The key aspect about Makey Makey is its flexibility and easiness of use that enables also non-expert (e.g. children) users to design simple TUI such as games and simple interactive prototypes.

Hinske et al. proposed a set of guidelines to design augmented toy environments, their study used an augmented knights castle, in particular with the introduction of sounds, RFID tags and visual feedbacks(Hinske et al., 2008).

IOBursh, followed the metaphor of enhancing a traditional object such as a brush (Ryokai et al., 2004). The semantic meaning and affordances were clear to the children, hence the use of the system needed almost no instructions to be used by the children. The system was composed by an augmented brush (with an integrated camera) and digital a projector. It was a playful system to enable the children express their creativity by picking real world images or videos and draw them on the projection-based canvas.

3.4. Evaluation

The research focused also on how to evaluate the relationship between children and the technology. There are several methods to evaluate technology with children. Most of the studies can be split in two categories of methodological evaluation: ethnographic studies and comparative studies. Often these two approaches are combined together to perform a data triangulation. Ethnographic studies are often used in the HCI field, and they can be used with profit also for TUI. The use of behavioural observation on the field is commonly used with small group of children, in this setting researchers annotate the children behaviours and relevant actions. When more children are present and there are no ethical issues video recordings are often utilized, when dealing with very young children video recordings are often not authorized by the ethical committee or the parents. The analysis of the videos and observations can follow a qualitative method such thematic analysis. The thematic analysis is often used it goes through several steps performed by multiple researchers to find an agreement; the main phases of the analysis are the familiarization with the data, the coding of the data, the identification of the themes and the definition of the themes (Boyatzis, 1998; Braun et al., 2014). The use of video recordings opens also the possibility to perform qualitative and quantitative analysis for example a usability evaluation (Mansor et al., 2009).

Evaluating the usability and efficiency

The comparative studies were adopted specially to evaluate the efficiency of the system. A more traditional approach to evaluate the usability is the use of comparative studies. For example Zuckerman et al. conducted an comparative between TUI and GUI to evaluate the usability of the systems, their results highlighted that in literature there were contradicting outcomes (Zuckerman and Gal-Oz, 2013). However, they found that the users preferred more the TUI also if sometimes GUI were more usable. Als et al. found that in usability evaluations children were more efficient and found more usability problems when they were working in pairs or small groups, furthermore id the children known each other they were more efficient (Als et al., 2005). Van Kesteren tried six different evaluating methods to elicit verbal feedbacks with children of 6-7 years old and found that best results, in particular more verbal feedbacks, were obtained when children were actively involved in the task and the researcher asked questions during the sessions (Van Kesteren et al., 2003). Hanna et al. investigated the methodologies to assess usability with children and identified a set of guidelines categorized by their age group: preschool (2-5), elementary school (6-10) and middle school (11-14) (Hanna et al., 1997). Think aloud methods were used in several researches evaluate the usability of the systems but demonstrated to be not suitable when the children are younger than 8 years old, the cognitive load in verbalizing their thoughts was too high (Höysniemi et al., 2003; Malkiewicz and Stember, 1994; Vygotskiĭ, 2012).

Höysniemi et al. in 2003 proposed to use a peer tutoring approach to conduct an usability evaluation, in this approach children were teaching other children to utilize a software (Höysniemi et al., 2003). This method resulted effective in capturing usability and authors suggested that the method could be extended to other evaluations.

Evaluating the learning effects

Pre-test and a post-test is the most used methodology to evaluate if there is some learning effect. Sapounidis et al. compared the efficiency of the tangible programming approach and an equivalent GUI based system (Sapounidis et al., 2015). Result showed that young children performed better with TUI but older children were more efficient with the GUI. Similarly Sylla et al. used a comparative study using questionnaires to evaluate the learning effect between a GUI and a TUI to promote the dental hygiene (Sylla et al., 2012). The result showed that the multisensory stimulation offered by the TUI was more effective to make the children learn the hygienic practises. Expert based evaluations, interviews and behavioural observation were utilized to evaluate the learning effect with children between 3 and 6 years old, these evaluations overcome the fact that young children were not able to write; thus it was not feasible to conduct a pre and post-test questionnaire to evaluate them (Core et al., 2017). Horn et al. proposed to use behavioural observations to evaluate the gained knowledge of the children (M. S. Horn et al., 2012). If the children demonstrated to be able to modify a program and execute it again (showing that they understood some programming principle), it was considered a valid proof of the learning effect.

Capturing and evaluating the children experience

When dealing with children an important factor to evaluate is represented by the experience, their feeling and emotions while using a product. An interesting research direction emerged in the last decade is the analysis of drawings. Children are invited to draw their experience, research showed that by analysing the drawings was possible to identify the central elements of their experience (Xu et al., 2008, 2007). Drawing is recognized as a favourite method of communication open a window on children's world (Malchiodi, 1998). The clinical practices are commonly using drawings to study psychological aspects of the children development, for example to evaluate the stress factors (Rollins, 2005) or family attachment. Several studies in the field of Child-Computer Interaction showed how drawings were exploited as data collection tool at various level of design. Sylla et al. used the drawing analysis to perform a summative evaluation of a tangible interface to raise awareness about oral hygiene in children between 4 and 5 year-olds (Sylla et al., 2012). Guha et al. used drawing to engage children in field observations and to guide them in the brainstorming activities. Nicol et al. used them to evaluate a set of prototypes for a museum application (Nicol and Hornecker, 2012). A different approach to evaluating the relation between children and technology was represented by the use of video analysis techniques. This approach was used with profit with children without any particular age limit. For example Africano through a video recording evaluated the behaviour of the children (Africano et al., 2004). The videos were analysed at fixed intervals identifying the children behaviours in each interval. A similar methodology was utilized to analyse a tabletop application, videos were used to identify the most frequent behaviours and have a detailed quantitative analysis of the action performed by the children on the screen (Mansor et al., 2009). The use of video analysis is often supported by the use of the intercoder reliability assessment, this methodology uses multiple actors during the analysis of the videos or observations and compare the number of agreements and disagreements to determine the reliability of the analysis (Holsti, 1969). If the agreement between the coders, on at least the 10% of the data, is greater than 80% would indicate that the analysis is sufficiently reliable, under this threshold the analysis is usually considered not good enough (Neuendorf, 2016). Even if the agreement is lower, sometimes the analysis is considered valid too, when the research is exploring ground-breaking concepts (Riff et al., 2014). The use of questionnaires was also utilized in research for example Moser et al. designed the eSFQ questionnaire with Likert scales and word clouds questions, to evaluate the experience of children playing games (Menestrina et al., 2016; Moser et al., 2012). Wakkary et al. used the fun toolkit to evaluate the children experience with Kurio, a Tui base museum guide (Wakkary et al., 2009). The fun toolkit developed by Read et al. was designed to capture opinions about technology from the children (Read, 2008). The toolkit is composed mainly by three instruments: "*the smileyometer*" used to capture the expectations, the feelings and the fun, "*the fun sorter*" used to compare a set of related technologies or products, and "*the again again table*" used to evaluate if the children liked the activity.

3.5. Children and TUIs

The use of TUI with children is often found in literature, the physicality of these technologic interfaces is well suited to be used with children. In particular the study conducted by Yvonne Rogers theorized that correlation between physical actions and digital effects foster learning, by increasing engagement and reflection (Rogers et al., 2002). Kalenine et al. on the same line of thought showed that young children tend to reason by using tools and by manipulating physical objects, and therefore Tangible Interaction could be used to leverage this tendency in young children (Kalenine et al., 2011).

Zuckerman and Resnick shifted focused on the relation between Tangible Interaction and education, trying to avoid a simple one-to-one mapping system but enabling a more complex and rich interaction. In 2005 they proposed a new perspective on Tangible Interaction, and introducing the concept of digital Montessori Inspired Manipulatives (MIMs) (Zuckerman et al., 2005). Authors were focusing on traditional objects already used for learning purposes called manipulatives, trying to enrich them with technology to enhance learning (digital MIMs). Digital MIMs interfaces were a new approach to learning where children could interact and modify a system that reacts to their actions. Compared to a more traditional system digital MIMs are enabling the possibility to teach and learn more abstract concepts such as: rate, accumulations, flow and other dynamic behaviours (Zuckerman et al., 2006, 2005). The results obtained in two digital MIMs case studies (FlowBlocks and SystemBlocks) showed that children were engaged and they were enjoying the learning activities. Furthermore digital MIMs showed that they were effective learning systems stimulating children towards a more abstract thinking and to find analogies with the real world (Zuckerman et al., 2006).

Research in the psychology and education fields confirms that the use of Tangible Interaction could improve learning in an enjoyable way (Price et al., 2003).

An interesting example of the use of Tangible Interaction for education is Kingdom of the Knights a digital augmented play environment (Hinske et al., 2009). In particular the study compared the digital augmented with a traditional one showing a significant preference for the first one, considered more enjoyable.

3.5.1. Design of TUIs for children

In literature there are several examples of the use of the Tangible Interaction approach applied for learning purposes such as Resnick guidelines and CTI framework, but the research focus was to design a better tool to teach and learn, excluding or giving less importance to the entertainment aspects (Antle, 2007; Resnick and Silverman, 2005). The CTI framework proposed by Antle represent an interesting and more complete approach to the design of TUIs for children. The framework is composed by several elements to consider and to be used to reflect about the design choices. The following list of 5 elements summarizes the CTI framework:

- *Space for action*: consider the spatiality of the possible children actions. Understanding how and why the actions of the children are performed and how they relate to the children development.
- *Perceptual mapping*: consider the mapping between the perceived properties (appearance) of the physical and digital elements of the system. Designers need to consider the age-related limitations such as cognitive and motor abilities to design the system affordances.
- *Behavioural mapping*: consider the behaviour of the actions on the physical and the output on the digital parts of the system and vice-versa. A good

design must consider the cognitive abilities of children and their understanding of the designed behaviours.

- *Semantic mapping*: is the mapping of the information in physical and digital elements of the system. As for the perceptual mapping designer needs to keep into account children cognitive abilities and if children can understand the meaning of things in their various forms.
- *Space for friends*: Consider the presence and the use of the system by multiple users, facilitate children collaboration and take into account unwanted behaviour such as imitation mechanism.

The Resnick guidelines are focusing specifically to the development of TUI construction kits, he identified and suggest to look and reflect about 10 lenses (Resnick and Silverman, 2005). Even if the guidelines are derived from the studies on construction kits the suggested elements to consider could be utilized to broaden the view of the designer, reflect and inform the design of TUIs artefacts. The elements proposed by Resnick could be partially applied to the design of artefacts that are not construction kits. A brief summary of the guidelines is presented in the following list.

- *Design for Designers*: consider children as designers, the kit need to be thought to enable children to design things by themselves. The kits should empower children to design the physical aspects but also the dynamic behaviours and interactions;
- *Low Floor and Wide Walls*: the kit should have a "low floor" so that is easy to understand and usable also by novices. The kit should have "wide walls", the kit should define a wide design space, so that the children are able to design multiple things and find new ways to use the kit;
- *Make Powerful Ideas Salient – Not Forced*: based on the definition of Papert a powerful idea can be used as tool to think with over a lifetime. A kit should not force the children to learn directly the idea, but provide the opportunities to discover and use powerful ideas;

- *Support Many Paths, Many Styles*: the kit should support different styles of playing, designing and thinking;
- *Make it as Simple as Possible – and Maybe Even Simpler*: the kit should not force the inclusion of many features only because the technology can afford to add them. Reducing and limiting the features often lead to an improvement of the children experience and foster the children creativity;
- *Choose Black Boxes Carefully*: designers should choose carefully what to hide and what to show to the children. This aspect determines mainly the design space of the kit and what the children can do and explore with the kit;
- *A Little Bit of Programming Goes a Long Way*: the introduction of some programming concepts in the kits expands their possibility of design, and is a relevant learning activity also for other domains;
- *Give People What They Want – Not What They Ask For*: sometimes is more effective to observe the children using the technology and infer what they want, instead of asking them;
- *Invent Things That You Would Want to Use Yourself*: designing a system that the designers enjoy himself often result in a better product. Furthermore, these kits should be used to some extent also by adults during the activities, designers should consider this factor;
- *Iterate, Iterate – then Iterate Again*: the ability to produce rapid prototypes and investigate multiple design direction is useful both for the children that for the realization of a good kit.

Stanton et al. focused more about the interaction among the children. In particular the author proposed 4 characteristics of TUI to reflect on in order to foster collaboration between children: physical size (size affect collaboration behaviours), different interfaces (each interface foster different actions), aesthetical changes (the appearance affect significantly the interaction) and focus on open low-tech (low-tech solution can involve more the children) (Stanton et al., 2001).

A study conducted by Antle and Wise aimed at the identification of the key design elements of TUIs for learning purposes, the author proposed a framework called Tangible Learning Design Framework (Antle et al., 2016; Antle and Wise, 2013). The elements primary elements of the framework were identified as the following: physical objects, digital objects, actions on objects, informational relations, and learning activities. Moreover, the authors proposed a set of guidelines for to each of the element of the framework to achieve a better design. The Table 1 is representing a short description of the proposed actions/guidelines to follow to target a specific element of the framework.

#	**Guideline**	**Framework element/s**
1	Distribute information on multiple modalities (increase working memory capabilities)	Physical and digital objects
2	Coherent mapping between the real world and digital and physical objects. (reduce the cognitive load)	Informational relations
3	Using personalized tasks and personal objects to form meaningful goals	Physical objects and learning activities
4	Use physical, spatial, temporal and relational property to trigger reflection	All framework elements
5	Distribute mental operations on digital and physical objects to support mental skills	Informational relations and actions on objects
6	Utilize image schemas on the input actions to improve usability and learnability	Actions on objects
7	Use conceptual metaphors based on image schemas to structure interaction mappings may bootstrap learning of abstract concept	Informational relations
8	Objects can use spatial reconfiguration to enable adaptation on multiple different ideas	Physical and digital objects
9	Concrete representation can help to interpret and understand symbols and abstract concepts	Physical objects, digital objects and informational relations

10	Permit configuration that enable participant to monitor each other and support a shared understanding	Physical and digital objects
11	Distribution of roles can promote collaboration	Physical objects and learning activities
12	Constraints and co-dependent access point can foster negotiation between participants	Actions on objects

Table 1: The 12 guidelines to inform the design the TLDF framework.

4. BUGBITS DESIGN

The work presented in this thesis is based on the development and use of a tangible-based tinkering set, called "BugBits". The BugBits were used to engage children in a series of three educational workshops. The design of the BugBits implied the development of the hardware elements composing the set, in particular: the electronics and the mechanical parts. The toolkit was designed to be used in different contexts according to the workshop aims. The toolkit was composed of several technological modules that children could join together to build tangible artefacts. This chapter describes the design process that led to the creation of the BugBits set, while the design of the workshops is reported in details in chapter 5, 6 and 7.

4.1. Design

The design of the BugBits followed a co-design process merging the contributions of the author and other domain experts. The design process was developed together and enriched by the different and specific expertise of the team members. The approach to the design followed the approach of the reflection-in-action (Schon and DeSanctis, 1986), in particular, following the Dittrich definition of design-in-use as the process able to 'capture practices of interpretation, appropriation, assembly, tailoring and further development of computer support in what is normally regarded as deployment or use'. The author contributed to the design by leveraging his experiences in Human Computer Interaction, in the hardware and electronics development. The educator brought his expertise in working with children (from 6 to 18 years old) during museum workshops. He also contributed to the definition of the aesthetic of the set elements. The design team was sometimes enriched by the presence of another member, a HCI researcher with a strong expertise in game design. The contribution of the third member was specifically relevant to the design of the workshop activities to ensure they included playful elements.

The initial design of the BugBits took 5 months and started in October 2015. The author and the museum educator met weekly to find the requirements of the Bugbits set and reason about the design directions to follow. After the initial meetings, a trend emerged identifying an interesting design space to explore with the children. The museum educator reported that in fact all of the activities offered by the education department of the arts museums of the region were focused on the decoration activities such as the artistic expression in paintings, drawings and sculptures. Further research revealed that also other arts museums followed the same trend of offering practical activities of traditional arts techniques. These workshops were proposed usually in a workshop format of 3 or 4 hours long, where up to half of the time was spent to explain theory and techniques and the remaining time was spent actively trying the concepts explained before. These facts highlighted how the educational activities proposed in the arts museums were not considering or proposing workshops and laboratories about the interactive installations. Interactive installations are in fact an important movement in the modern arts of the last decades, and their intrinsic characteristics are well suited for the children. In particular these installations are giving a central role to the visitors, making them an active part of artworks. For these reasons the initial goal of the design of the BugBits set was to find a way to introduce the children to the concepts of interactive installations. Taking inspiration from the workshops format already proposed in museums, the BugBits were conceived to be the workshop material to be used by the children during the practical part of the workshops. Even if the main goal of the initial design iteration of the BugBits was focused towards the use inside museums, the researcher considered as a main requirement the flexibility. In particular with flexibility, the designers refer to the ability to utilize the BugBits set not only to teaching about interactive installations but also for other purposes.

Application of CTI framework

The design was inspired by the CTI framework and the Resnick guidelines. The following aspects of CTI were evaluated when designing the BugBits:

- *Space for action*: The use of spatiality was considered as part of the interaction modalities. The designers aimed at design a system that stressed the spatiality of TUIs. In particular, the spatiality was considered part of the intended way of interaction, not directly within the artefacts but by moving the artefacts into the spaces such as public rooms, museums, classrooms.
- *Perceptual mapping*: The designers focused to include some affordances and visual clues to suggest the intended way of interaction. The mechanical structure of the set was designed to let the children move easily the BugBits in the space. The use of light was suggesting the children to use the BugBits to illuminate objects and different light behaviours such as blinking were used to suggest the changes of the status of BugBits. Both the mechanical and the audio feedback was designed to be easily manageable by very young children and older ones.
- *Behavioural mapping*: The designers reflected about the possible ways to implement the BugBits system by looking and evaluating pros and cons of the different input and output modalities. Since the BugBits was targeted for children with a wide range of ages the designers focused on an audio-visual interaction. In particular the use of colours that were known by very young children, and the audio melodies that can be listened actively by kindergarten children and older (Core et al., 2017; Shen et al., 2013).
- *Semantic mapping*: The initial idea for the semantic mapping is based on the previous experience of the author in using musical parameters with kindergarten children (Core et al., 2017). In particular very young children could recognize easily the speed parameter of the music, thus the BugBits based some of the interaction behaviours considering a relation between the colours and the speed of the music. The final aim of the BugBits was to empower children to design and determine their semantic and behavioural mappings, thus the designers considered those two properties as two variables to work with the children
- *Space for friends*: The BugBits set was designed to be distributed to each child, thus each child will own one BugBits set. Even if the BugBits set

were individually distributed, designers fostered the collaboration between children by designing the workshops activities. All of the activities were designed to be done in groups where the collaboration could happen and sometimes was required to fulfil the tasks.

Application of Resnick guidelines

The Resnick guidelines served as reference to reason about the interaction style and how to shape the BugBits set including some of the characteristic of construction kits. In particular the following were considered:

- *Design for Designers*: The final aim of the BugBits set was to be used by the children with some level of supervision. The role of the researchers was limited to facilitate the children. The physical characteristics of the mechanical parts of the toolkit were designed to be easily modified by the children using scholastic material;
- *Low Floor and Wide Walls*: BugBits was designed to be used exploiting a simple mapping between colours and audio. The BugBits however was designed to enable the children to define more complex designs and rules and thus covering a wide design space;
- *Support Many Paths, Many Styles*: the BugBits set was designed to be used by the children as a workshop material. Some limitations were imposed by the components of the set, but the children could use the set partially or in an unusual way to develop many different artefacts;
- *Make it as Simple as Possible – and Maybe Even Simpler*: The BugBits used this guideline to develop a very simple system but opened the possibility to add a few more features to the set. The set was designed to be composed by a low number of components, thus to be easily accessible to the children of all ages;
- *Choose Black Boxes Carefully*: the design of the set especially regarding the electronic parts stresses the use of no blackboxes. This strong design idea enables the children to look directly to each part of the set and to make them think about their functions;

- *A Little Bit of Programming Goes a Long Way*: the programming constructs were not included into the design of BugBits. But some aspects of the computational thinking could be grasped by the children when using or designing artefacts with the set;
- *Give People What They Want – Not What They Ask For*: This guideline was kept in mind when designing the various versions of the set. The knowledge gained from the previous studies drove the development of the newer versions;
- *Iterate, Iterate – then Iterate Again*: The simplicity of the set was one of the characteristics that was kept through the development. Improvements on the set could be done easily without a complete redesign of the set.

The hardware design included some of the design elements of the construction kits, a series of modules that can be combined together to build some artefacts (Resnick and Silverman, 2005). Furthermore, the development of the hardware could be divided in two main parts: the electronics and the physical structure. The electronics were the part of the set dedicated to the definition and implementation interactive behaviour of the artefacts; while the physical structure was dedicated to realize a container to host the electronics and give a "shape" to the artefacts fostering children to express their creativity.

4.2. Electronics

The design process was informed taking into account the guidelines discussed by Resnick (Resnick and Silverman, 2005). The author realized the BugBits set following the microcontroller and sensors approach that was identified as the more versatile thanks to its ability to be interfaced with a large variety of sensors (Chapter 3.2). The first requirement to fulfil was to design a toolkit that was simple to build so that the children could be able to manipulate and join the different elements. The main inspiration came from the Lego bricks games and Littlebits, in which you can stack multiple bricks one on top of the other to build a solid shape.

The development was informed by several behavioural observations of different groups of children interacting with the Radiant^2 (Menestrina et al., 2016, 2014).

The Radiant^2 was developed by the author in 2014 as a novel tangible user interface to play a videogame. The tangible interface was composed by an augmented checkerboard and a series of wooden cubes. The board was subdivided in 36 positions disposed as a 6x6 matrix (see Figure 4).

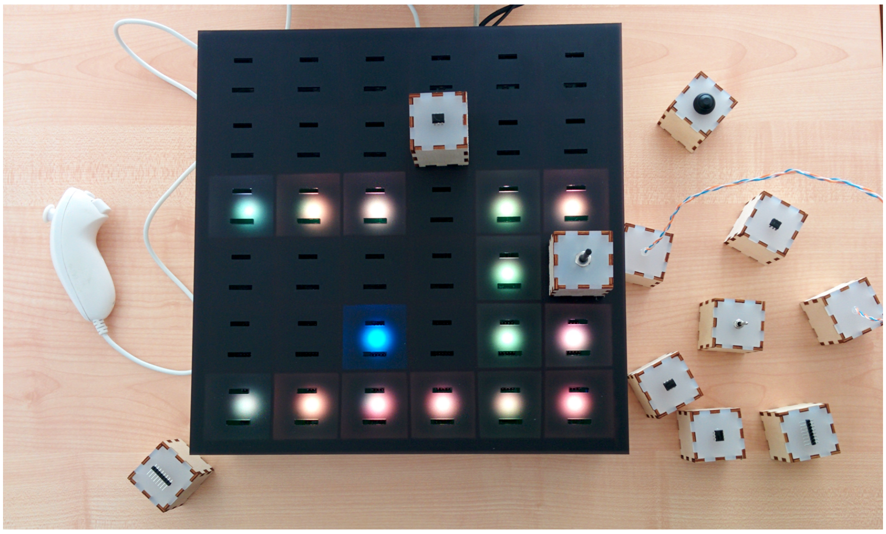

Figure 4: The Radiant2 interface.

The wooden blocks depicted in **Figure 4** could be placed in every position of the 6x6 matrix. Input values and RGB light output could be defined for each position on the matrix**.**

To operate the system, the user needed to place one or more wooden blocks on the board. The system would read input values from each single block (e.g. reading the positon of a potentiometer). Each place of the checkerboard and each block could give to the user a visual feedback by means of a RGB light. The design of the videogame, called OHR, took advantage of this interface. In order to play the game, the players should interact physically on the tangible interface to affect the virtual world.

The most frequent problem identified with the Radiant^2 was related to the identification of the orientation of the electrical connections and the difficulties to connect the electronics in the correct position. In particular the early prototypes utilized a pinheader connector and receptacle that revealed to be too complex to insert for children, but difficult also for the adult. This kind of electrical connection is widespread in the development and prototyping kit but revealed to be easy to use only when it is used in a single line disposition. The Radiant[2] design was characterized by an aesthetic look that hid all the inner workings part in order to let the user focus on the functionalities of the interface. Contrarily to the Radiant[2] design following the Resnick guideline of "black boxes", the design of BugBits followed the opposite direction by making all of the electronic parts explicit and visible to the children. In that way the children can see that their artefacts were not magic boxes, but that they needed several parts joined together in order to work (Ackermann, 2001).

Following the same reasoning, also the use of printed circuit boards (PCBs) was avoided for the main components of the set, because their appearance hides all of the connections. Their realization was exposing all the connection wires so they looked more familiar and easy to understand for the children; they could physically follow the various connection.

4.3. Input and Output

The expressivity of the interactive behaviour of BugBits was strongly influenced by the choice of the input and output devices. The designers evaluated a series of input and output modalities, considering practical limitations, the contexts of use and other factors. The following types of input sensors were considered initially:

- Light sensor;
- Proximity sensor;
- RFID tags reader;
- Temperature sensor;
- Colour sensor.

The weekly design meetings were crucial to determine what kind of sensors to include into the BugBits set. In particular there were pros and cons for each sensor, while there were technical motivations to prefer one sensors in favour of another, the meetings with the museum educator and the researcher in game design highlighted one interesting design direction to explore.

Input sensors such as proximity and RFID were not considered, they would have required a complex technological infrastructure and would have offered less expressivity to the children. Proximity and RFID sensors are based on the use of RFID tags and other active electronic elements that are materials not commonly used by children. Furthermore, the integration of those technological in public spaces such as museums is not always possible. The use of temperature as main interaction medium was evaluated too difficult to control to obtain a sufficient level of creativity. In particular, the system requires a way to control the temperatures of interactive objects, rendering the system too complex to realize.

The use of a colour sensor appeared to be the most interesting to propose to the children. In particular art workshops with children are often dealing with colours, children starting from very early age are playing and working with colours. The use of colours could exploit the children knowledge about colours and an interaction based on colours characteristics could be understood easily by them. These familiarity with colours broaden also the age range of the BugBits starting from very young children. An interaction based on the colours revealed to be also more coherent with the activities that children normally perform at school or in the kindergarten, where the use of colours is present in the majority of the activities.

Following this reasoning the designers chose to explore the use of colours as design space for the BugBits set. The use of a simple light sensor was also considered as it was the closer alternative to a colours sensor, while the concept of strong and weak light intensities could have worked very well with children some limitations were found during the design meetings. In particular even if the use of light intensity as input is simpler than using colours, the light intensity is very difficult to control. The designers considered the fact that the set could be used mainly inside public buildings, such as schools and museums where the intensity of the light is normally difficult to control. The light interaction is strongly influenced by the ambient light and the sensor readings could be easily affected rendering the interaction not stable and reliable.

The colours instead showed some more robustness, even if the light conditions are affecting the readings the colour does not change significantly, e.g. a red cardboard will give similar readings under a wide range of light conditions. Furthermore, the use of an integrated light source could improve the sensor reliability, due to the smaller oscillation of the sensor readings. For this reason, the colour sensor open the possibility to be used inside the public rooms and spaces. For example, children could explore the spaces pointing the colours that are already present in the environment, or augmenting the spaces bringing coloured objects.

Even considering this sensor from the point of view of the costs it represents a good solution since it's possible to design activities by using simple and cheap materials, e.g. coloured cardboard, paper and paint etc. etc. Furthermore, colour sensor allows the identification of several colours enabling the design of multiple behaviours (e.g. a different action for each colour).

The type of output for the interaction was also chosen during the weekly design meetings evaluating different types of output media:

- Light;
- Audio;
- Screen;
- Haptic.

The design team evaluated the sound as the best medium to give the children a feedback as the children independently from their age could react to sounds and music. Moreover previous design such as The Musicroom, and Beatfield revealed that the sounds feedback was considered interesting by children themselves (Masu et al., 2016; Morreale et al., 2014). The sound used as output media open the possibility to create an endless variety of melodies and audio feedbacks, thus extending the longevity of the set. The use of small screens could be a valid alternative but the young children that were not able to read will be excluded, rendering the BugBits set dedicated to children of the primary school and older. Similarly, the haptic modality requires a strong mechanical connection to work properly and thus not suitable for workshop activities with young children.

The light output could overcome the age limitation of using small screen but the choice of using light as the main output medium would make the BugBits a set based only on colour and lights both as input that as output. While the light was considered a valid output modality the designers settled on sounds to give to the BugBits set some differentiation between input and output modalities.

In order to fulfil the portability requirement, the system must be powered by batteries. To make the toolkit there was the need of a microcontroller unit to interconnect the input and output sensor. As many other research, the designers chose to adopt an Arduino for the implementation, the computational power offered by the platform was sufficient to develop the set (Cressey, 2017). However, a simple Arduino board was considered too big to be used in the BugBits set, thus the integration into objects, structures was a difficult for the children. For these reasons the final choice was to use an Arduino Nano board as main microcontroller board. Both the boards have the same computing power, but the Nano version over a much smaller form factor (see Figure 5).

Figure 5: Arduino sizes, the Uno board on the left, the Nano board on the right..

The choice of the colour sensor was not easy because there is a large number of colour sensors on the market, not all of them offered a flexible and reliable solution. The designers identified the TCS34725 as the best candidate since it offered the ability to tune his sensitivity very precisely. Furthermore, the communication over an I2C bus is a reliable communication method, offering advantages over the simpler analogic sensors. The architecture of the sensor adds a clear filter to the more traditional R, G, B filters enabling the use as a simple lux meter and to compensate the variations due to the ambient light. The presence of a small white LED enables the designers to illuminate the object to read with a constant flux of light, this feature enhances the reliability and repeatability of the readings.

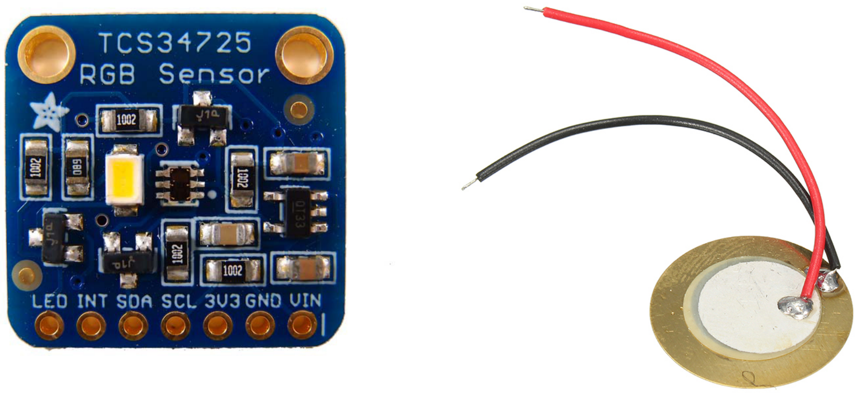

Figure 6: The colour sensor and the piezoelectric transducer.

The size of the sensors in **Figure 6** is not in scale. The golden disc of the audio transducer in the rightmost part of the Figure is roughly of the same size of the other sensor, 20mm.

For the audio output the main decision factor was dictated by the fact that the set will be used by several children at the same time. For these reasons we opted for a simple piezoelectric transducer that is able to produce a relatively low volume audio feedback, thus avoiding an excessive noise in the rooms. Furthermore, the piezoelectric transducer is well suited to be manipulated by children because it can mounted on different surface by using some tape.

At the end of the design sessions the electronic material set was composed by the following modules:

- An Arduino Nano board;
- A main board (used to interconnect all the parts);

- A piezoelectric transducer;
- A TCS34725 RGB sensor;
- A battery connector;
- A 9V transistor battery.

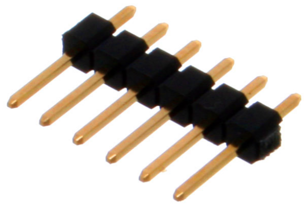

Figure 7: A pinheader male connector.

Particular attention was posed into the design of the main board. The main requirements of the main board were the following: robustness to resist to physical damages, durability to be uses multiple times and in other workshops, easy to assemble, easy to repair (being repairable in-situ). This board was equipped with some connectors for the sensors and on the back the wirings to make them work. The battery connector was the most important because if not placed in the proper orientation could damage all the other electronic components. For this reason, the battery connector was using a 3-wire disposition that made the connector work independently from the disposition or orientation.

All the connector implemented some affordances using physical characteristics such as the length and orientation and some visual clues (coloured marks reflecting the same colours of the wires) to suggest the proper orientation to the children.

The type of connector chosen was the pinheader (an example is shown in Figure 7), it recalls the aspect of an electrical plug suggesting the child how to connect the sensors. Even if the pinheader connector revealed to be difficult to use for children in a previous study on the Radiant[2], this difficulties were due the multiple row disposition (Menestrina et al., 2016). The BugBits implementation adopted a single row disposition for all the connectors.

If the toolkit will be used in a structured workshop setting the repeatability is one of the design elements to consider. For this reason, the designers identified two additional requirements to address the repeatability issues: possibility of being reusable for other workshops (robustness), the ability to be easily assembled, repaired and customized with school/workshop materials.

The BugBits set even if composed by few electronic components, enable the designers to explore a wide design space using colours and audio interactions. Each element of the set could be easily explained to the children enabling them to reason about the possible implementations. The compact dimensions of the set enable the children to integrate the electronics into a large variety of objects. The use of a battery enables the exploration of the physical space widening the design space beyond the workshop tables.

4.4. Physical structure

The non-technologic part of the hardware was a crucial part of the development, in fact the children involved in the activities should be able to build by themselves the electronic components set but also being able to put all the electronics in a "container" that gives a shape to the artefacts. The mechanical structure of the BugBits was designed keeping as main requirements: the ability to personalize the aspect of the artefacts and enable the children to bring the artefacts around safely.

The design team envisioned the pyramid shape as a proper electronics holder. The pyramid shape was considered also a good candidate to be manipulated and brought around. The material choice played an important role into the development as it will affect the robustness but also the ability to be personalized by the children.

A first low-fidelity prototypes were thought to be made of wood as it will assure robustness. The conceptual design of the pyramid was developed digitally by creating a 3d model of the pyramid components (a base and 4 sides). Even if the pyramid shape appeared an easy shape to be built into the 3d prototyping environment, revealed to be more complex to realize in practice. The solution chosen to assemble the pyramid was to use square joints on the sides of the faces and the use of some tape to hold them. In particular an initial batch of 3 pyramids with slight variations in the dimensions were manufactured at the local fablab using a laser cutting machine. A main problem emerged immediately when building the pyramids, the pyramid was impossible to build because the sides were colliding at the vertex. A second batch of pyramids was developed addressing the problem and hence cutting off the vertex (see Figure 8).

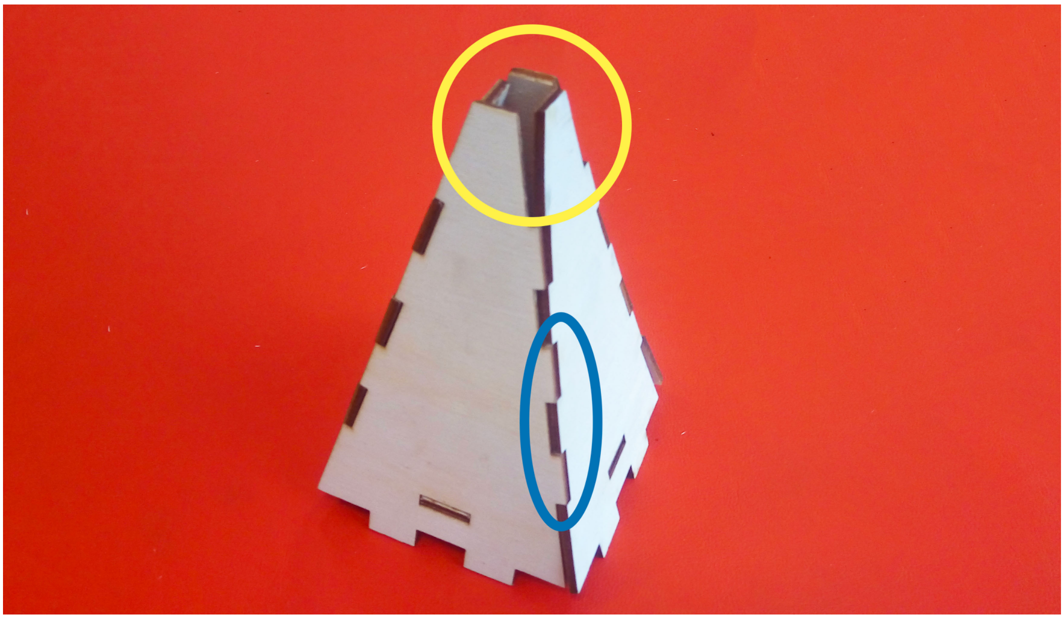

Figure 8: The problems encountered in the physical structure design.

The yellow circle in **Figure 8** highlights the structural problems on the pyramid vertex, the stiffness, rigidity and thickness of plywood forces the pyramid misalignments. The blue ellipse shows the squared joints used to assemble and keep together the pyramid.

Even the second batch highlighted some flaws into the design the square joints were not working properly due to the non-squared inclination of the pyramid walls. Additional trials were conducted by changing the dimensions of the square joints, but the rigidity of the wood rendered the prototypes too loose or too tight to assemble. Even the first design of the bottom of the pyramid revealed to be not adequate because it tended to move from its intended position, the problematic design is shown in the left part of the Figure 9.

To solve these problems another design iteration was required. The bottom of the pyramid was upgraded introducing a slotted hole in the four pyramid faces where the bottom can be locked-in. The rigidity problems were solved by changing the wood in favour of thick cardboard that permits to close easily the pyramid by placing some pieces of tape.

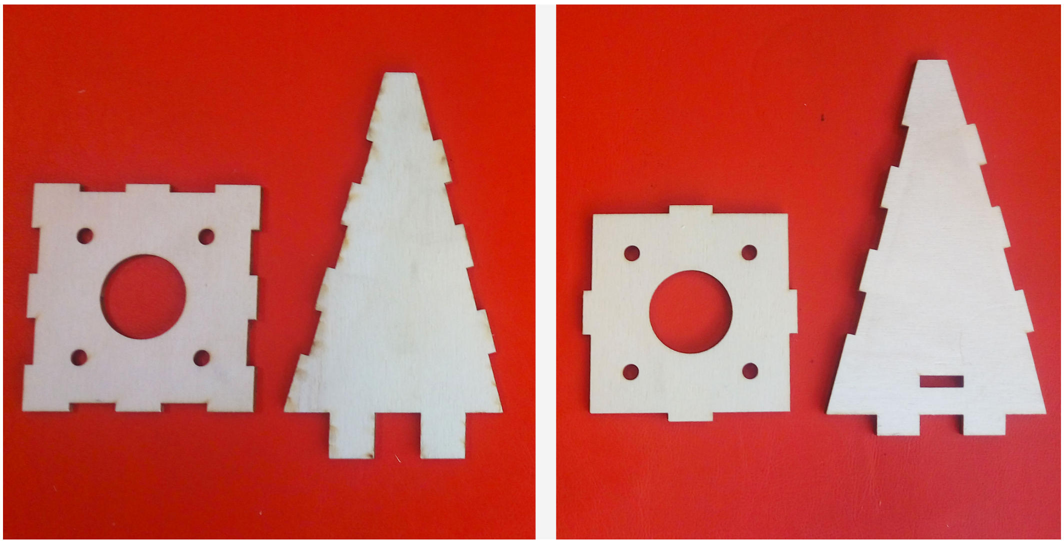

Figure 9: The basic components of the pyramid structure.

The leftmost part of **Figure 9** refers to the first design attempts that were suffering of an insufficient holding capacity of the bottom. On the right the redesigned pyramid structure with the new bottom design thatwill be interlocked in the pyramid sides.

The use of cardboard opened more personalization possibilities, as it can be customized by the children using common tools and materials such as: glue, tape, scissors, wires, paint, sticky paper and so on. The cardboard choice offered a good starting point to make the children work and create their own artefacts.

The cost was one important factor in the design, the designers considered fundamental that the cost of BugBits set should be ideally affordable by the parents, schools and museums. At the end each BugBits toolkit costed about 25 euros: 22 for the electronic components and about 3 for the cardboard and the laser cut.

To conduct the studies 25 BugBits electronics sets were built and about 150 cardboard pyramids kits realized using a laser cutter, thus enabling to provide one BugBits complete set for each child (the typical classroom size in the art museum workshop is between 20 and 25 children). The pyramid sets were realized in higher quantities because they could be used only a few times before they wear out.

4.5. The development of BugBits

The design of BugBits followed several iterations of design, each study led to the definition and creation of a slightly different version of the BugBits in order to match the different purposes and scenarios of the three case studies.

4.5.1. Version 1.0: Modern Art Museum study

The first version of the set was designed to conduct several workshops centred on the modern art and the interactive installations. The discussion and reflections led to the definition of a basic set of requirements for the realization of the BugBits tinkering set in order to be utilized as a technological toolkit in workshops:

- A toolkit that is simple enough to be built by the children;
- Size of the artefact should be portable;
- The artefact can be used in a playful manner;
- An interactive behaviour that can be understood easily;
- The ability to customize the aesthetic of the artefacts;
- Having a feedback system that could be used (safely) in a museum environment;
- Ability to use the artefacts inside the museum exhibition;
- Possibility to use the artefacts to explore the museum exhibitions.

The first version of the BugBits utilised a simple recognition algorithm that compared the colour sensor readings with a list of predefined colours stored in the permanent memory of the microcontroller. To cope with possible leakages of light the algorithm utilized a threshold enabling a correct recognition if minor changes in the sensor readings happened. To ensure the correct readings of the objects colours the BugBits utilized a white LED light in conjunction with an autoranging algorithm to regulate the sensitivity of RGB sensor (see the Code 1 definition). The pseudo code shown above in Code 1 does not show the sensor specific codes needed to control the sensor behaviour such as the I2C messages and the changes performed on the control registers.

```
void autorange(){
  gainSetted=false;
  do{
    //get the raw value of the luminance
    int lum = ReadSensorLuminance();
    if (lum > 0.75*overflow){
      //decrease the amplification factor of the RGB sensor
      decreaseSensorGain();
    }else if (lum < 0.25*overflow){
      //increase the amplification factor of the RGB sensor
      increaseSensorGain();
    }
    else {
    gainSetted=true;
    }
  }while (gainSetted);
}
```

Code 1 The pseudo code definition of the autoranging function used to avoid overflow into the readings.

This latest particular assured a correct colour reading even if there was very low or very high level of ambient illumination. Even if the autoranging feature ensures a correct colour reading avoiding the sensor overflow, the sensor returns a series of fluctuating values. To solve this problem the colours readings were normalized using a luminance reading (a clear neutral filter across the whole visible spectrum) to determine the neutral white reference.

The white reference is crucial to normalize the Red Green Blue raw values. They could be normalised dividing them with the luminance reference (a pseudo-code description of the algorithm is shown in Code 2). Those normalized values lost their luminosity component could be used to compare the colours a under different light condition, e.g. the normalised readings of red cardboard are the same independently from the light levels, the raw values in the other hand are affected by the light levels, thus cannot be compared.

```
int readNormalized(int channel){
  //set the sensor sensitivity
  autorange();
  //get the white reference
  int lum = ReadSensorLuminance();
  //get the channel raw value
  int rawchannel = ReadSensorChannel(channel);
  //normalize reading
  return rawchannel/lum;
}
```

Code 2: the pseudo code definition of a single channel colour reading normalized using the luminance.

The design of the audio focused on mainly on 2 aspects: producing of a recognisable musical audio feedback and generation of a non-repeating audio melody. The first aspect was evaluated by some indoor testing sessions, trying to find the most audible frequencies generated by the piezoelectric transducers. The second important aspect was to avoid the repetition of the same melody over and over and thus annoying the children or losing their interest. For these reason taking inspiration from the past knowledge of the MusicRoom and Children Orchestra studies the design of the musical feedback followed a pseudo-random generation approach (Masu et al., 2017; Morreale et al., 2014). The music generation, in particular, was performed using a simpler algorithm that was computationally feasible on a microcontroller. In particular, the music generation could be controlled by using two parameters: the pitch range and the speed range. A complete implementation of the Markov chain system as in the cited studies was not possible (Masu et al., 2017; Morreale et al., 2014). Thus the next note and duration were determined randomly by checking if the next note falls in a predefined range of values. This check was done comparing if the distance of the next from the note played was not too far. The determination of the length of the played notes was determined by checking that the random duration falls into an imposed range. A pseudo-code description of the melody generation routine is shown in Code 3.

```
void  generateMelody(int  lowPitch,int  highPitch,int  lowTempo,int
highTempo){
  //get the last playedNote
  int last=getLastNote();
  //get the repetition of lastnote
  int rpt = getNoteRepetition();
  //determine if there were to many repetition of the same note
  int next;
  if (rpt>maxRepetition){
    //generate the next note avoiding the last note played
    //pauses are possible
    next=generateNoteNoRepeat(lowPitch,highPitch,last);
  }
  else{
    //generate the next note considering only pith limits
    //pauses are possible
    next=generateNoteRepeat(lowPitch,highPitch);
  }
  //determine the length of the note
  int noteLength=generateNoteLenght();
  //put in queue the net note to be played
  updateMelody(next,notelenght);
  return;
}
```

Code 3 the pseudocode utilized to generate the pseudo-random melodies.

4.5.2. Version 2.0: Kindergarden study

The BugBits set was designed to be used as a Digital MIM artefact in a kindergarten with children between 3 and 6 years old (Zuckerman et al., 2005). This implementation of BugBits can be further divided into two minor versions since the BugBits were used in two different exercises. Both exercises were based on the Montessori colour games, where children needed to order and group colours sharing some characteristics such as the shades of the same colour, complementary colours, warm and cold colours (Montessori, 2013). The two exercises determined the behaviour of the BugBits set: the first exercise associated a different audio reproduction speed to each colour of a rainbow (primary and secondary colours), while the second exercise focused on the different shades of the same colour associating low reproduction speed to the darker colours and high reproduction speed to the brighter ones. The main changes to the BugBits implementation regarded the code. The colours recognition algorithm was changed and improved to identify the different shades of the same colour. The music generation in a

```
ColourScale* colourRecognition(){
  //get the colour channel reading
  int red=readNormalized(0);
  int green=readNormalized(1);
  int blue=readNormalized(2);
  //creation of a colour object
  Colour c=new Colour(red,green,blue);
  //find the most similar colour into the database
  Colour nearest=findNearest(c,threshold);
  //check if the nearest colour make sense
  //if out of threshold range nearest is void (0,0,0)
  if (isVoid(nearest)){
    return -1;
  }
  else{
  //find the scale of shades of colour into the memory
  int scale=findScale(nearest);
  //determine the shade of the colour using linear interpolation
  //and min distance
  int shadeVal=findShade(c,scale);
  //determine the basic colour of the scale using a Lookup Table
  Colour col=findColourFromScale(scale);
  return new ColourScale(col,shadeVal);
  }
}
```

Code 4 The improved algorithm used to determine colour and the shade of the colours readings.

pseudo-random manner was abandoned in favour of a fixed melody that repeats changing only the speed parameter.

The algorithm was improved by using a tighter allowance on the threshold for each R, G and B components of the readings and using a database of colours scales that was embedded into the microcontroller memory. The pseudo-code shown in Code 4 explain the improved colour recognition algorithm. In particular, the new version of the algorithm takes advantage from a complete database of colours and their shades. The algorithm determines the nearest colour into the database and if it enters in the allowed tolerance. If the colour is valid (so is one of the allowed colours) the colour is then compared with the database of colours shades. The grade of the colour shade was determined using a simple interpolation between the shades present in the database. As final result the algorithm returns the base colour of the readings and its scale, a numeric value that identify how dark or bright was the colour.

```
playMelody(int speed){
  //get the index of the latest note
  latestNoteIndex=getLatestNote();
  //check if the note was played completely
  if (notePlayEnded(latestNoteIndex)){
    //get the next note to be played
    note n=getNextNote(latestNoteIndex);
    //determine the new duration
    n.duration*=speed;
    //play the next note
    playMelody(n);
  }
}
```

Code 5 The pseudo-code utilized to stretch the speed of the melodies.

The music generation in the other hand was simplified since it reproduced a pre-composed melody stored in the microcontroller's memory. The melody was stored as a list of tuples composed by pitch and duration. The pitches were specified as British-English standard notation such as C, D, E, F, G, A, B. This enabled the designers to write melodies using a standard notation that is widely used. The algorithm that played the melody, scanned the list present in the memory playing one note at the time. The speed parameter was used as a multiplicative factor to determine the duration of the notes (a pseudo-code description of the operations is shown in Code 5). The output of the piezoelectric transducer was increased maximising the duty cycle of the PWM control signal and using two output pins to increase the current flowing through the transducer.

4.5.3. Version 3.0 Participatory design

The latest version of the BugBits was used as workshop material in participatory design sessions with children. The main requirements of the set changed from the previous 2 version where the BugBits were utilized in a controlled way and a predefined interaction style. In this version, the behaviour of the BugBits was defined directly by the children to implement their own games. For this reason, the main improvement over the previous implementation regarded the ability to tune and modify the code quickly in order to follow the children requests. Furthermore, the set was enriched by 2 hardware elements: switches and coloured lights. The main board of the set was updated to enable children to connect these new input/output devices. The connection of the LEDs was designed such that if connected in the wrong orientation caused no damages to the rest of the electronic components. This could be achieved by using a 3-wires connector instead of the commonly used formed by only two wires. This detail enables a proper connection independently from the orientation. The connector could be reversed without affecting the active wires connections (e.g. the same concept is present in USB-C devices and Magsafe chargers connectors).

```
Typedef struct deviceState{
  //type of sensor, 0 RGB, 1 Switch,2 Potentiometer, 3 audio feedback
  int type;
  //the number of data readings of the sensor
  int ndata;
  // the raw data
  int* data;
  //rescaled data 0-100
  int* scaledData;
  //binarized output 0-1
  int activated;
}
```

Code 6 The pseudo code of the data structure for the sensor readings and output devices

The code was updated to be standardised, returning a data structure that could be easily used to write the system behaviour, described in pseudo-code below in Code 6.

The data structure utilised is designed in to enable an easy integration between input and output devices. For example, the RGB sensor will return a 4-element array containing the raw values of R, G, B, C components, a rescaled value of the same values in the 0-100 range. The variable called *"activated"* allow only a 1 or 0 state, in the case of the RGB sensor makes no sense for this sensor so was kept always zero. Contrarily, if the data structure was the output structure of a switch, the activated variable reflects the actual state of the switch ON or OFF. The "*data*" variable contains the raw values of the sensors, and it could be useful to realise more complex interactions. For example, to discriminate a three-position switch (left/center/right). For each output device was a corresponding function was implemented, this function could be used to control the output state of the output device.

```
//channel 0 identify the first switch sensor port
int channel=0;
//read the switch state returning a deviceState data structure
deviceState out = readSwitch(channel);
// lightchannel =0 means the first output light/LED port
int lightChannel=0;
//turn the light on when the switch state is off and vice-versa
//the false parameters indicate to act in reverse logic
//the last parameters indicate a blink behaviours
lightOutput(lightChannel, out.activated, false,0);
//lightchannel2=1 the second output channel for light/LED
int lightChannel1=1;
//make the second led blink 5times/second if switch is in position 0
lightOutput(lightChannel1, out.data[0]==0, true,5);
```

Code 7 The pseudo-code that generate a simple light output reflecting the switch status.

The Code 7 example shows the 6 lines of code required to read the switch state make an output indication on a LED in reverse logic (enabled when the switch is disabled and vice-versa) and make another LED blink 5 times per seconds if the switch is in the 0 position (only 3 lines can be used considering that the variables *channel*, *lightChannel* and *lightchannel1* were written only to make the code more readable). The flexibility of the code, using the described data structure, enables to obtain the opposite blinking behaviour by changing the third parameter of the lightOutput function to false. By doing so, the blinking happens only when the switch is in a state different from 0.

5. CASE STUDY 1: MUSEUM

The first case study started in 2016 and was developed within a museum setting involving children aged between 13 and 15 years old (N=185). The design process was focused on developing new educational activities for children using the BugBits set, in particular to introduce the children to the concepts of interactive art installations.

Interactive art installations are one of the branches of the modern art that puts the visitor in the centre (Paul, 2003). The visitors are not experiencing the artworks passively, but they become part of the artwork by interacting with it. This branch of the modern art requires the users/visitors to “break the traditional museum rules”, in which the typical visitor behaviour is to stand in front of one artwork and observe it from a certain distance.

Furthermore, the educator was also an expert in the field of the modern art installations because during his artistic career realised several interactive installations artworks, even with the sporadic collaboration of the author. The author had expertise in hardware and electronic design from previous academic and non-academic works such as the OHR & Radiant[2], Beatfield and Child Orchestra projects (Core et al., 2017; Masu et al., 2016; Menestrina et al., 2016). The design process was an iterative process, and the initial conceptual designs were subsequently refined in weekly meetings. The presence of a game designer supported the design team. The contribution of the game designer was crucial to the design of the game-based activities conducted during the exploration of the museum.

These design meetings were fundamental to define how to use the technology, but at the same time, they also shaped the educational format of the workshops conducted at the museum. It is complicated to have a sharp distinction between the two design processes as they were deeply bonded together, the format of the workshop cannot exist without the BugBits technology and vice-versa.

5.1. Workshop aims and design

One of the first design dimensions to define was the topic of the workshops; the decision focused on the interactive installations did not come by chance but was chosen to evaluate several aspects:

- The museum context;
- The audience (children, ten years and older);
- Educational value;
- Exploration of the museum environment;

A particular reflection must be considered regarding the age of the audience since it was not possible to know in advance the exact age of the children involved. In particular, the participation at the workshops was on a voluntary basis. The workshops were promoted in the schools from the final years of elementary to the high schools, and thus suggesting a minimum age of 10 years old.

The interactive art topics fitted well all the restriction and opportunities offered by this unusual location. The interactive art is quite new and not well known, in the Italian school curricula, there are few or no mention of it. The museum context offers big spaces and also a series of artistic installations to show to the children (Maxwell and Evans, 2002). The interaction needed by the interactive art installations fits well with the needs of the children, keeping them active also during the visit to the museum.

For example, behavioural observations of the author and other 2 researchers, conducted in a near science museum (Muse Trento) showed quite clearly that the interactive elements inside the museum revealed to be the most attractive for the children, in which they spend the majority of the visiting time.

The studies on tangible user interfaces showed that physical interaction is more suited for the children as the physical interaction is closer to the way in which they usually reason (Revelle et al., 2005).

Another design dimension that emerged during the meetings was the need to keep the children as main actors of the workshop and to limit the traditional frontal lecture environment. The aim the approach was to keep the children as engaged as much as possible and to make them the relevant actors during the workshops (Druin, 2002; Iivari et al., 2015).

As a consequence, keeping the same rationale, of the first two dimensions suggested avoiding to teach them about interactive installations using frontal lectures and try to make them understand better the interactive installations.

The toolkit for the museum study was designed to collect information about different design questions. The most relevant for this case study were the following:

- Are the children able to build the artefacts?
- What are the most critical issues of the toolkit in the building phases?
- Do the children understand the interaction behaviour of the artefact?
- Is a simple game based on colour triggering engaging enough for the children?
- Is the construction of the artefacts an interesting activity for the children?

For these reasons, this first case study focused on obtaining the children participate as users and tester (Druin, 2002). Following this idea, the designers identified a way to empower the children and make them participating actively. In particular, the researchers aimed at enabling the children to be able to experience the point of view of an artist of an interactive installation, and not limit them to be only a visitor that interact with an artwork. For these reasons the designers chose to enable the children to build a simple interactive art artefact.

5.2. Context

The Mart museum is located in Rovereto a small city about 25km from the city of Trento. The museum is the most important modern art museum of the Trentino (Italy) region and is one of the most important in Italy. The museum was born in 1987 and has 3 facilities two in the city of Rovereto and one in Trento. The activities proposed by the museum are not only exhibits but also activities such as music shows, theatrical performances and educational workshops. Inside the main building in Rovereto there is a dedicated area of the museum for educational activities. This museum section called “Mart education”, exists since the creation of the museum and aims at offering learning activities to everyone. The education activities are not dedicated only to the children but to the whole population: adults, elderly and people with special needs. The museum offers more than 100 different activities, and each year several thousands of people are involved. However, even if the museum educational activities are offered to a broad range age, children are mostly involved in them. Most of the times these activities are offered to schools where each classroom decides voluntarily to participate. The majority of the classrooms involved are doing these extracurricular activities during school trips. The opportunity of developing from scratch one educational activity in an important museum of the region represented the perfect environment where to instantiate and test the BugBits toolkit for an educational purpose and test it in a real context.

5.3. Workshop activities design

The design of the format of the workshop proposed at the Mart was born together with the development of the “BugBits” technology**.** One of the requirements was to keep the children engaged and explore the museum rooms. After several design meetings, the basic behaviour of the BugBits was formalised. The use of the artefacts was integrated with a simple game, the game was inspired by the game mechanics of “treasure hunt”. The pyramid fitted with electronics elements will react to a predefined set of 11 colours; when the sensor is over one of these colours, the piezoelectric transducer is used to give the children audio feedback.

The game will be played into the exhibition rooms of the museum where the researcher and the educator placed in advance several discs of coloured cardboard in front of peculiar and relevant artworks chosen by the museum educator. The objective of the children will be to discover 10 colours that will correspond to 10 different artworks.

To avoid the children to copy from each other particular attention was paid to the mechanics of the game. Each pyramid will generate a random sequence of colours that the children need to discover. The sequence is generated by the microcontroller’s algorithm with the following characteristics: each BugBits reacted to only one colour at the time, when the child found the correct colour the BugBits will respond with audio feedback then it will switch on next colour in the sequence. The use of the random sequencing of the colours ensured the designers to have a different sequence for each child and to foster them to explore different sections of the museum without following each other. The BugBits where able to discriminate if the colour was correct by comparing the colour reading with the colour readings corresponding to the set of predefined cardboard colours set used inside the exhibits rooms.

Furthermore, to foster the children attention on the artworks the BugBits when the correct colour was found played a song for 1 minute and only after this amount of time the pyramid will switch to the next colour in the sequence. For the same reason, the audio feedback was designed not to distract them; avoiding the well-known musical melodies. The audio feedback was programmed to be generated in a pseudo-random manner. With this system each time that a pyramid was placed over a correct colour produced a different melody, reducing the repeatability of the system and at the same time helping the children to not lose interest in the game. To make them focus on the artworks during the 1-minute period each child was asked to find what are the most interesting and relevant parts/ characteristics of the artwork.

Figure 10: An example of children's annotation.

The drawings in **Figure 10** shows the artworks encountered during the "treasure hunt" game in the museum exhibits rooms. The drawings done by the children represent what were the most important and interesting parts of the artworks for them**.**

For this reason, each child was equipped with a block note, a pen and a pencil to annotate their observations about the artworks (an example is shown in Figure 10). To give them an additional feedback the lights used by the colour sensor were programmed to start blinking when the children found all the colours and thus reached the end of the game. The design of the workshop strongly influenced the design of the BugBits and vice-versa. The workshop lasted about 2 hours and 30 minutes, organised in three main phases and subsections:

1. **Knowing** (30min)
    a. Introduction to the workshop activities (5min)
    b. Introduction to interactive art installations (25min)
2. **Making** (65min)
    a. Presentation of the BugBits set (15min)
    b. Assembling the toolkit (20min)
    c. Personalization of the interactive prototypes (30min)

3. **Immersion and Reflection** (55min)
    a. Exploration of the museum exhibit rooms (40min)
    b. Final debriefing & questionnaire (15min)

The followings paragraphs provide a detailed description of each of the three main workshop phases.

Knowing

The workshop began with a brief introduction of the planned activities with the presentation of the researcher and the educator that will guide the children through the workshop phases. Even if the requirements were to avoid a frontal lecture format, there was the necessity to introduce the children to the concept of interactive installation artworks To introduce them to these concepts the educator with the support of some slides, videos and printed images shown to the children several examples of interactive artworks. During this phase, children were encouraged to interact by asking questions about the topics. Both the researcher and the educator tried to engage the children by asking questions and showing peculiar examples of interactive art installations. For example, one of the artworks showed was represented by a picture of a natural pipe organ that was “played” by the tidal waves of the sea, the look of the artwork in the picture was not so easy to understand but strange enough to make the children curious about it and ask questions. This initial phase that lasted about 30 minutes was useful also for the researcher and educator to collect useful information about the children knowledge, familiarise with them, and “tune” the next phases considering their knowledge about the topic.

Making

After the initial phase, most of the children had a clear idea of the definition of interactive art and the researcher introduce them to the next step of the workshop. During this phase, the children could build their own interactive artworks by using the BugBits components set. The outcome of the making phase will include several of the explained characteristics of the interactive artworks presented in the previous phase (e.g. the interaction between the visitor and the artefact). The first approach to the BugBits set was made by example: the researcher showed every single component of the set asking the children to guess what their functionality could be, only after that exploration each element was explained. At the end of this familiarisation phase with the BugBits components, the researcher and the educator showed how to assemble the toolkit starting from the disassembled electronic component set (see figure Figure 11, taken during a pilot of the museum workshop).

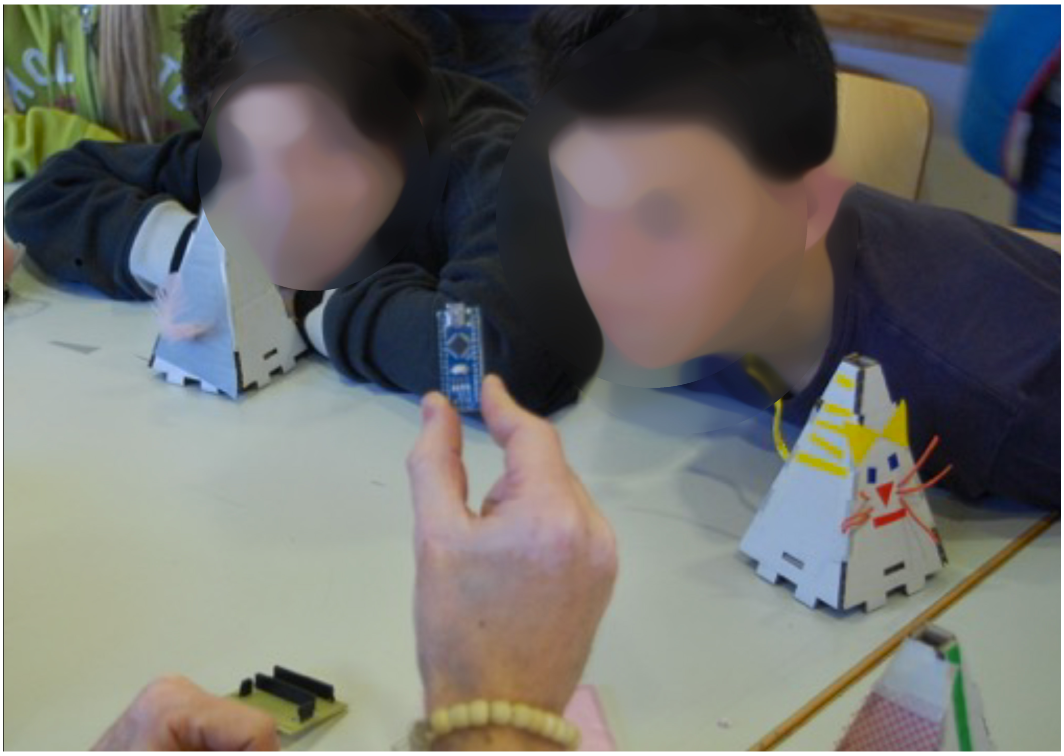

Figure 11: The researcher explains and shows the components of the BugBits set.

This introduction and demonstration of the BugBits set led to the next activity where each child had about 20 minutes of time to build their own electronics. During this phase children were free to assemble the toolkit and try multiple configurations, the researchers and the educators checked at the end the children's works helping them to solve the misplacements.

The next phase the of personalisation of the interactive prototypes, lasted around half an hour; during this time the children assembled their own cardboard pyramid, they placed the electronics in it, and they personalised to their will the aesthetic of their BugBit.

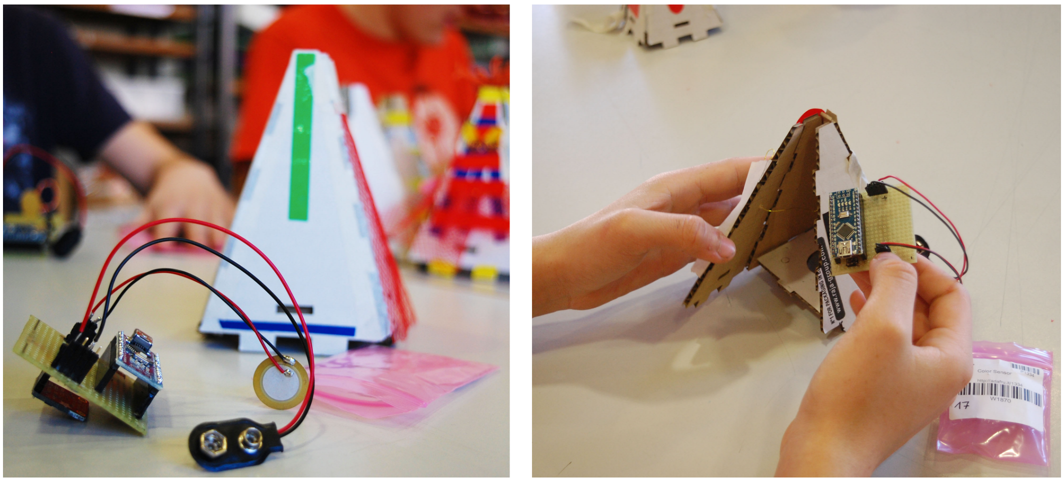

Figure 12: The assembling phases of the BugBits set.

The leftmost picture in **Figure 12** shows the electronic fully assembled by a child, on the background some of the pyramids personalised by the children. On the right, a child is putting the electronics inside an empty pyramid before passing to the personalisation phase of the workshop.

Figure 12 depicts the making phase in two different stages, on the left some of the customisation and the electronics construction were done, on the right a child was closing the pyramid and inserting the electronics. Both the researcher and the educator supported the customization of the aesthetic. The children could use the material and tools that were used commonly during the other museum workshops. In particular, the modern art museum offers several educational/prototyping elements such as different types of cardboard, glue, wires, colours, pens brushes and others materials. At the end of this phase, each child had his/her own personalised interactive artefact, at this point the researcher and the educator checked their works for possible damages or errors in the electronics building and give them the batteries to turn on their creations.

Immersion and Reflection

The next phase was the exploration of the museum rooms, the children were accompanied by the educator and the researcher into the museum and observed the children behaviour during their treasure hunt game.

The presence of the researcher and the educator was fundamental also for helping the children if some breakage happens to the children artefacts. Some spare BugBits sets (pyramids and electronics modules) were available for a last-minute repair. The presence of two adults was also necessary to assure and control if the children behaviour was compliant to the museum rules.

Figure 13 depicts two children playing the “treasure hunt” game, they found the proper colour, and they annotate their impressions about the artwork in front of them. The last phase of the workshop was dedicated to the collection of feedback from the children and their teachers. During this phase, the researcher asked the children to fill a questionnaire based on the fun toolkit format and inspired on the extended Short Feedback Questionnaire (eSQF, it was specifically designed for children) by Moser et al. (Moser et al., 2012; Read and MacFarlane, 2006). In particular the administered questionnaire was short, only one page, and required a short period of concentration for the children at the end of the workshop. The questionnaire is reported in Appendix in Figure 32.

Figure 13: The exploration phase inside the exhibits rooms.

Figure 13 depicts two children while they were annotating some details of the artwork. The BugBits toolkit was playing a melody since the correct colour was the green (the Bugbits is visible in the centre over a green cardboard disc).

Interaction	Hardware	Functions
The children were invited to **build** and **use** the BugBits to explore a museum. The activity was introduced as an augmented "treasure hunt" game with the objective of collecting 10 colors/artworks.	Arduino Nano microcontroller	give some computing power to the BugBits set
	Piezoelectric transducer	produce an audio feedback
	Colours Sensor	recognise colors
	Main board	connect all the component and provide a physical structure
	Battery	power and mobility
	Pyramid kit	give a shape to the artefacts
	Scholastic material	personalisation
Not meant to be used by the children	"hidden" LED	debug indicator of the state of the electronic

Table 2: First study summary of interactions, components and functions.

Table 2 summarizes how the BugBits toolkit was designed for the first study. In particular, the table describes briefly the designed interaction the components utilised in the workshops and their intended functionalities.

5.4. Results

The workshop involved about 185 children aged between 13 and 15 years old. A total of 11 workshops were conducted between the mid of March and the end of May in 2016. All classrooms choose voluntarily to participate in the workshops as an extracurricular activity. The decision to participate in the workshop was fostered mainly by the teachers and only marginally decided by the children. The most frequent decision-making process was to let the children chose between some activities selected in advance by the teachers.

Some classrooms due to strict time constraints some of the classes were not able to complete all of the activities of the workshop. For these reasons, only 132 questionnaires were collected and analysed.

The museum asked each child a symbolic cost of 3 euro to cover the expenses of the consumable materials. The classrooms were coming mainly from north Italy, and they were composed on average of 20 children, 61.2% of the children were male and 38.8% female. All the phases of the workshop were conducted in 2 spacious rooms in the education section of the Mart museum. The rooms were equipped with a video projector, chairs & tables. The children were free to choose how to sit around the tables and to form working groups.

Observational data

The data collected was mainly performed by annotating the observations after the workshop activities. Some notes were taken even during the activities especially into the first phase and the exploration of the museum rooms phase. Keeping the notes after the experience was necessary since both the researchers and the mediator were assuming multiple roles during the progress of the activities. In particular, they were facilitators during the construction and customisations phases, teachers during the introduction activity, guides and security supervisors inside the exhibitions rooms.

The observations highlighted that the introduction phase with the projection of examples of art installations was one critical part of the workshop. Not all of the children were keeping the focus during this phase, but the majority of them attended this part of the workshop actively asking questions. The experience of the educator in this initial phase was fundamental to adjust and tune the duration of the "frontal lecture" phase.

Almost all of the children reported that they had seen interactive installations in other contexts. The science museums represented the most recurrent example, in particular, they reported using interactive artefacts to perform scientific experiments. The teachers showed interest too, especially when examples were presented during this phase. In a few cases there was the need for intervention of the teachers to regain the attention of the children.

Some of the schools coming from distant regions had strict time constraints to respect, in these rare occasions the author and the educator decided to shorten the initial introduction to give them more time for the successive phases. In these cases, some of the topics were briefly discussed during the construction phases.

The majority of the children was unaware of the electronics components and parts that we showed to them. On average only one child for each classroom showed some previous knowledge about electronics; in most of the cases they knew the standard Arduino board, but they never saw the Nano version.

The initial presentation phase of the BugBits set elicited a general interest about its components, keeping them engaged.

Almost all of the children recognised by looking at the aspect of the main board that was realised with simple wires. Moreover, some of the children noticed the affordances of the connectors and they were able to guess how to combine the set elements. Asking them how to assemble the toolkit very few children were not able to figure out the right position and orientation of the components.

A tiny percentage of children, about one child for each classroom, showed a low level of interest on the BugBits.

Children were asked to guess what the purpose of the RGB sensor before the researcher explained how it worked, most of them were able to recognise it as a vision system related sensor. Even if they guessed some of the characteristics of the RGB sensor only 2-3 children figured out correctly the function of it. The piezoelectric transducer represented the most unknown element of the toolkit. Even if the children did not know it, the audio transducer elicited a lot of interest, and children asked for details about how the component worked. A lot of them was surprised to discover that the sensor could also be used as a microphone.

During the construction phases, the majority of the children with very few exceptions showed a lot of interest and their attention was focused entirely on the activity. Children were curious to know how they could switch on the BugBits without any switch or button. Moreover, some of them expected some switches or buttons to change or affect somehow the BugBits behaviour. For example, by pressing the button change the target colour to skip a difficult one to find. Both girls and boys were involved, and there were no evident differences between gender regarding attention and interest.

The Bugbits being made with simple tools soldering wires and connectors on a laminate base exposed some weaknesses. In particular, the connection wires were broken easily by the children. The designers prepared in advance some spare parts to overcome this problem. It was possible also to repair the broken pieces in a few minutes, by using soldering tools.

Even if the broken wires problem slowed down the progress of the children the fragility of the wires increased the children care about the elements of the set. They tended to broke cables or parts only in the first minutes of the construction activity. The children showed a higher level of attention and care to avoid to damage the components.

The personalisation phase showed to be very appreciated by the children, in almost all of the workshops there was the need to give them more time to make them finish their work, as they wanted to accomplish the task in the best possible way. Not all of the children were completely involved during this phase, in a typical classroom a couple of children were paying less attention and participated in the activity with fewer efforts (e.g. achieving the tasks but without particular interest).

The imitation behaviour was present to some extent in all of the classrooms, in particular children tended to customise their BugBits using the same items and the mimicking some of the aesthetic characteristics. Although the imitation behaviours were observed, the children showed to put their efforts into making their BugBits appear different from the other ones.

During the making phase, there were several cases of spontaneous collaboration. The children collaborated to achieve the most demanding operations. Closing the pyramid with the tape was a task that fostered collaboration among children. For example, one child was holding the cardboard pieces firmly in place and another taped them. The operation could be achieved even singularly since the square joints were keeping together the pyramid (see Figure 8). Spontaneous cooperation was also accompanied by some discussions, where children exchanged advices about how to assemble the electronics components, and teaching and learn from each other the best ways to solve problems. The making phase of the workshop did not show noticeable differences in interest and attention between males and females.

The exploration phase was the most appreciated phase of the workshop. Even the children that demonstrated less interested during the previous phases were more active and enjoyed this phase. The algorithm to randomise the children colours sequences worked as expected, limiting the imitation behaviours during the play time.

A few of the children did get upset when they could not find a colour in a short time. In very few cases the researchers needed to show them what was the colour to activate the artefact so that they could start again to play the game. The educator or the researcher used a set of spare coloured discs to find the colour quickly and identify if the electronics components were working properly.

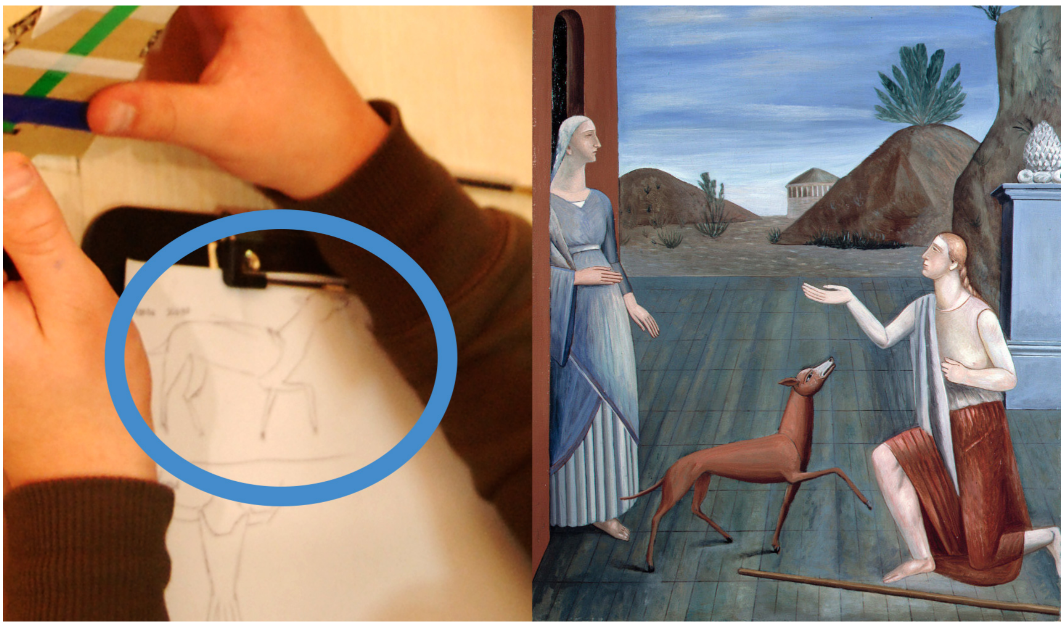

Figure 14: An example of children annotation and the original artwork.

In some cases, the children modified the game rules and picked-up the cardboard discs using them as a form of point/reward system. They used these cardboards even to force the BugBits in making sounds and having fun.

However, all of the children followed the rules of the game, and they annotated some peculiarities about the artworks that they found during the game. Figure 14 shows an example of children annotation, the left part of the figure highlights the sketch drawn by the child, while the right part depicts the artwork from which the child took inspiration. The majority of the children wrote the sequence of colours on their block-note, and there were challenges between them to be the first one that discovered all or the most of colours.

The researchers noted that one of the most interesting behaviours was when children discovered and looked at the internal led of the BugBits (an aspect that was not mentioned during the initial phases of the workshop_. They understood the relationship of the led status with the audio feedback, and they used to have a further visual confirmation that the correct colour was found.

In fact, during the development of the BugBits software a led was used by the designers to debug the program and have immediate feedback about the recognition of the colours. This feature used only for debugging purposes remained implemented in the museum implementation of the toolkit. The children discovered by themselves the presence of this light and they utilised it when in the museum room there was too much noise to understand if the music was playing or not.

A second example of appropriation was noticed when the floor colour was very close to the target colour of the BugBits game, the floor and the light pink were very similar. The majority of the children utilised the white paper sheets of the block-note to stop the audio and find the next artwork colour.

The longevity of the game was appropriate for the time available during the exploration phase, between 3 and 4 children for each classroom reached the end of the game collecting 10 colours and the correlated artwork annotations. This fact suggested that the level of difficulty was balanced for the amount of time spent playing inside the museum rooms. The colours were distributed across about 7-8 large exhibitions rooms that were covering half of the first level of the museum. The distances between colours were more than 15-20 meters away from each other. Furthermore, the rooms were organized in a ring shape, there were no windows, and it was somehow difficult to navigate them because mainly only the artworks were helping the children to be oriented. Some colours were rarer than others (a design choice), for example, the purple colour was present only in 2 spots of the museum. Furthermore, the children went back and forth to find new colours to test, thus giving them more time to explore and look at the artworks. All of the children were able to discover at least 4 colours/artworks, in these cases, children were less engaged by the game, or they were following other children and limiting their chances to find the correct colour.

The children reported spontaneously to appreciate the game, even if sometimes it was challenging for them to find the next colour. The majority of them desired more time to spend inside the museum rooms so that they could have finished all of the 10 colours to discover.

The most frequent complaint was the impossibility to bring at home their artefact, this was not possible due to the costs of the artefacts and rebuilding all the set would have required a too large amount of time. To give them some reward at the end of the workshop the children could vote the best BugBits artefact of the classroom so that they could bring it with them (without electronics). The artwork annotations were also taken at home by the children. Moreover, some of the teachers expressed interest in using the annotations to discuss the experience at school in the days after the workshop.

The presence of the teachers during the workshops was not intrusive, and in very few times they interfered with the progress of the workshop. The weakness of the hand soldered wires revealed to be not a merely negative factor for the workshop progress. When some component was broken the child was interrupted, but on the other hand, this fragility helped the child to remain more focused during the building phases.

The main findings could be summarised as the following:

The making part of the workshop showed some difficulties, but all of the children were able to complete the task. Moreover, the problems/breakages encountered revealed to be useful to foster the voluntary collaboration between the children.

Even if each child had a BugBits set there was space for collaboration, children helped each other to deal with the more challenging tasks during the making phases and during the treasure hunt game in the museum exhibitions rooms.

Some of the children were expecting the presence of switches or buttons to affect the game modality of the BugBits or to power them on.

The phases of construction of the artefacts resulted to be an important element of the workshop, and children asked details about the inner workings of the technology. The workshop design resulted to be a good alternative to the traditional ways of exploring and guiding the children inside the museum rooms.

The game inside the museum revealed to be challenging for some of the children, only a few of them reached the end of the game finding 10 colours/artworks. The difficulties in finishing the game were related mainly to the large museum spaces, the fact that the children were free to stand in front of the artworks as long as they wanted. Some of the children were unable to reach the end of the game because they were following each other and so they had fewer chances to find the proper colours (because the colours order of each child was different). Even if most of the children did not finish the game inside the museum rooms, the level of challenge of the game was considered appropriate with only a few children being upset of being unable to find the colours.

However, the children experience inside the museums was sometimes affected by flaws in the implementation of BugBits. The technologic implementation of the game revealed to be weak due to the colour similarities between the floor and the "pale pink" colour. This led to the origination of some false positive feedback and thus confusing the children. Some of the children found a creative fix of the problem by using a sheet of paper or some spare coloured cardboard to stop the misleading behaviour of the BugBits.

The physical weaknesses of the BugBits set worked as an element to mitigate the children distraction, helping them to focus more on their actions.

The ambient of the museum revealed to be sometimes too loud, in this condition the audio feedback was difficult to hear. This problem and the children curiosity lead to the self-discovery of the children of the internal light feedback of BugBits (previously used for debugging purposes). Some of the children exploited this visual feedback together with the audio to be entirely sure that they found the right colour in the noisier rooms.

The children demonstrated that they were aware of the educational purposes of the workshop and the technology, but they expressed their preference of using/experiencing the museum visits with the BugBits.

Questionnaires

The questionnaire was not too difficult for the children to fill, only on some occasions there was the need to clarify the meaning of some word.

Questionnaires confirm the observations showing that the children rated the activity as extremely fun (M= 4.3, SD= 0.58) on a Likert scale from 0 to 5, respectively extremely boring and extremely fun.

Figure 15: The words selected by the children to describe the museum workshop.

Figure 15 represent graphically the words that the children selected to describe the activities of the museum workshop. In particular the words were used with the following frequencies: fun 38%, easy 24%, intuitive 12%, fantastic 9%, exciting 7%, confusing 3%, childish 2%, tiring 2%, difficult 2% and boring 1%.

The 67.7% of the children expressed the desire to play again with “BugBits”, 30.7% of them declared that “maybe they will play again” and the remaining 1.6% excluded completely the possibility to play again. The questionnaire highlighted that also if the 67,7% of them would like to play again they rated the “BugBits” as an activity to play sometimes at home in the 75.8% of the answers, only the 17.3% will play with it often.

Questionnaire results reported in Table 3 are summarizing the following questions:

- Q1. I had to work hard during the construction phases
- Q2. I had to work hard to play
- Q3. I was focused in playing the game
- Q4. While I was playing I was curious about what could happen
- Q5. Building and playing with this game was a challenge
- Q6. While I was playing I stopped to notice what was happening around me

The questions posed in form of a 5 level Likert scale, ranged from fully disagree (coded in the statistical analysis as 0) to fully agree (coded in the statistical analysis as 4) (Boone and Boone, 2012). The results were supporting behaviours emerged from the observations.

In particular, the children rated the level of commitment to building the artefacts as a slightly demanding task, (Mdn =3.00, IQR =5.00-4.00). They rated as average the effort required to play with their creations (Mdn=2.00, IQR=3.00-1.00).

The children self-reported in the third question that they were concentrated during the workshop activities (Mdn=3.00, IQR=3.00-1.00). Question four showed how the activities proposed during the workshop were engaging the children, that reported to be curious to know what will happen next (Mdn=3.00, IQR=4.00-2.00).

Question five highlighted how the activities conducted were considered challenging very few of them rated them as an easy task (Mdn=3.00, IQR=3.00-2.00).

The last question tried to capture the flow dimension and understand if the activities were engaging for them (Mdn=2.00, IQR=3.00-2.00). All of the Likert scale questions showed a tendency to remain close to the middle value, inspecting the distribution of the results it emerged that most of the answers were around the central value of the scale.

A T-test analysis differentiating on gender showed that the fun-o-meter measure had a significant result $t(130)=2.19$, $p < .05$. In particular, girls reported the activity as more fun respect to the boys, respectively ($M=4.49$, $SD=0.54$) for the girls and ($M=4.26$, $SD=0.60$) for the boys. This result is particularly interesting since in literature the technological activities, like the ones proposed during this workshop, usually are more appreciated by males. As noted by the observations one possible reason for this gender balance could lie into the workshop structure. In particular, the workshop bonded deeply together the technological, educational and game activities.

Question	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Q1	4.5%	11.2%	23.9%	50.0%	10.4%
Q2	11.9%	17.9%	26.9%	35.8%	7.5%
Q3	9.7%	3.7%	32.1%	44.8%	9.7%
Q4	4.5%	10.4%	15.7%	41.8%	27.6%
Q5	8.2%	9.0%	29.1%	42.5%	11.2%
Q6	6.0%	14.2%	35.1%	32.1%	12.7%

Table 3: Frequencies distribution of the eSFQ answers in the first case study.

Questionnaire comments

The questionnaire presented a space to let the children share additional comments, suggestions about the activities and their experience. A total of 54 comments were collected, most of them reported the activity as engaging and enjoyable. A large amount of the comments regarded the building phases of the workshop and suggested to give more time to build and personalise their artefacts. For example, a 13 years old boy wrote: "I would like to deepen my knowledge about the parts of electronics assembly by explaining the electronics bases to young children or people that don't know the electronics". An interesting series of comments were discussing the educational value of the tool by explicitly mentioning its advantage for the artworks exploration. They demonstrated to comprehend technology as a tool to approach art and the aesthetic in general. For example, a 14 years old girl wrote: "it was funny it was intuitive and it make me paying attention on artworks details. If I came alone or with my teachers I wouldn't noticed these details". The analysis of the comments highlighted 5 themes:

- Positive experience: comments that reported or describing the activities as positive; Most of the children expressed their appreciation about the experience they had in the museum. The comments highlight that the children showed their will to bring the BugBits at home or use it again with their friends in the same context.
- Construction: comments that highlighted the importance of the construction phases for the children; The construction phase was commented as an interesting and fun part of the experience, the children suggested to give more time to this part and to go deeper in the making topics (e.g. electronics). There were no negative comments about the construction phases of the workshop; some child described the activity as an easy task to complete.
- Art and education: comments that reported the activity as relevant for art purposes or useful for education activities; Some of the comments were explicitly highlighting the educational value of the experience. In particular, most of the comments compared the BugBits experience with their previous experiences in museums, in particular, they reported the BugBits experience as more fun and helping them to reflect about the meaning of the artworks.

- Other contexts: comments that reported the will of children of trying the technology in other contexts of use; A few comments suggested the use of the BugBits in other museum contexts and with a different audience (e.g. with young children).
- Suggestions: comments that suggested improvement of the toolkit; Children suggestion could be divided into two groups: comments that suggested to increase the time at disposition to build and explore the museum rooms and the technical explanations. The technical comments highlighted how sometimes the audio feedback should be improved with higher volume levels or changing the produced melodies.
- Negative experience: comments that reported the activity as negative experience (e.g. boring, not fun, too complex). Some of the children described the activity as challenging, in particular when in the museum rooms there was noise they faced some difficulties in understanding the audio feedbacks. Some of the children described as negative the fact that they could not bring at home the artefacts.

Figure 16 is summarizes the themes emerged from the analysis of the comments. The radius of the circles and the overlappings are proportional to their relative comments.

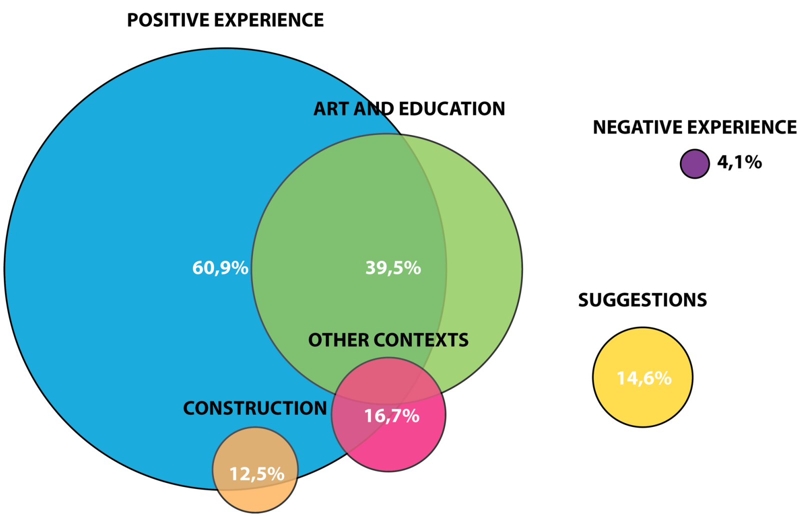

Figure 16: The emerged themes in children's comments.

The sizes of the circles depicted in **Figure 16** are proportional to the number of comments written for the specific theme. The overlappings areas between the circles represent the comments that were mentioning multiple themes.

5.5. Discussion

The workshops conducted within the museums setting presented several weaknesses and strong aspects highlighting what the elements to modify to improve the toolkit effectiveness.

The proposed workshop structure divided into three phases worked well across all the different classes involved. The strongly intertwined structure of each phase helped the children to follow the workshop and kept them interested on what will happen next.

In particular, the approach of letting the children build their artefact kept the level of attention of the children high, fostered them to be creative and created situations of spontaneous collaboration between them.

The children role during the workshops session was mainly of being users and testers of the BugBits (Druin, 2002). The children empowerment, on the other hand, falls mostly into the mainstream view, where children had a low decisional power, they were encouraged by the teachers to participate to the workshop, or they had a limited power of deciding across a set of activities preselected by adults (Kinnula et al., 2017). Following the democratic view, the children were also empowered by giving them the ability to express their thoughts about the toolkit and the activities. The design of the activities empowered the children to build their artefacts but following a predefined schema, in a Lego style activity, where a predefined list of actions and instructions were given and needed to be followed. Furthermore, the design of the workshop could be categorised as an Informant design following the IBF model, the contribution of the domain experts is limited design experts had the stronger influence on the design process (Read et al., 2002).

The evaluation activity at the end of the exploration of the museum lasted approximatively 10 minutes and was short enough to not annoy the children, the questionnaire based on the eSFQ revealed to be appropriate, and the free space to leave comments was one of the most important sources of information (Moser et al., 2012). In particular, it highlighted how the children experience inside the museum rooms was perceived as fun but at the same time a useful activity for their education and stimulating their reflection about the artworks. The questionnaire's results reflected the observations highlighting that the activities were fostering the children curiosity while the level of difficulty and efforts required by the children was evaluated as an average activity. This was also reflected by the number of children that were able to complete the game, in each classroom 3-4 children reached the end of the game, but all of the children were able to find at least half of the colours.

The BugBits set used in case study offered a limited the design space, input and output modalities were restricted to the use of colours and audio but keeping the richness of spatiality provided by TUIs. The difficulties into the design of the toolkit modules were not only related to the specific implementation of the museum case study, but the design process was mitigated by discussions about the flexibility of the design choices. The choice of the colour sensor represented one significant example. At the first look, it could appear decision strictly related to a museum or scholastic setting, but it was considered appropriate for different reasons:

- Colours are widely used by children, they start to know and play with colours since the kindergarten age
- A colour sensor has a limit on the number of colours that can be recognized. But normally it is high enough that in combination with a colour recognition algorithm can achieve easily a very high number of colours. The precision of these type of sensor is high enough to distinguish colours that to the human eyes are appearing as they are the same.
- The use of colours as input enable the designers to use real-life or specifically designed objects to drive the interactive behaviour
- The designers can create multiple designs giving different semantic meanings to the object colour.

For example, a possible alternative use of the colour sensor could be the use of a children xylophone shown in Figure 17.

Figure 17: A traditional xylophone children toy with colour coded musical notes.

These children toys can be easily exploited using the colour sensor; each musical note is recognisable by its colour, the same note but with different octave will have the same colour. A possible application could use the sensor to design a playful, educational game to learn the musical notes and the musical scales.

The data collected from the children showed how the construction of the artefacts was not representing a problem for the children: all of them accomplished the task.

Small difficulties during the building phases fostered the children to help each other's and to dialogue with the researcher and the educator.

The experience at the Mart museum showed episodes of technology appropriation: the use of an internal LED light as alternative visual feedback in a noisy environment, the use of a coloured object to stop an unexpected behaviour of the technology and the use of colours to produce noises intentionally into the museum rooms.

The toolkit design showed some weaknesses in the audio feedback and the fragility of the wires. In particular, the volume levels were sometimes too low in noisy environments, forcing the children to stay close to their pyramid or use the visual feedback of the internal led. Moreover, this limitation fostered the appropriation of the toolkit, showing creative uses of the tool (e.g. the use of led and coloured objects to force the behaviour of the technology). The fragility of the wires demonstrated to be both a factor that slowed the development of the artefacts but also forced the children to be more focused and careful about their actions; at the end, it did not affect the progress of the workshops significantly.

The hardware design of the set was not an easy task to accomplish and also if some of the children showed some knowledge about electronics they were unable to give useful feedbacks or design suggestions regarding the elements of the set: the electronics and the pyramids structures.

The questionnaires and the observations answered well to the questions regarding the engagement of the children. The engagement was estimated by looking at the behaviours of the children, in particular looking at the negative instantiations (e.g. sign of boredom) that were recorded and observed rarely during the workshops (Hanna et al., 1997; Read et al., 2002b). The engagement of this study could be reconducted mainly in the definitions of behavioural and cognitive engagement (Fredricks et al., 2004). Moreover, during the whole building phases of the workshops, both of the electronics and of the pyramids personalisation, children were focused on the task and rarely showed episodes of distraction. For this reason, the teachers rarely needed to intervene to get the focus back on the activities of the workshop.

The questionnaire results mirrored the observations confirming that for the major part of the children that participated in the workshop and rated it as a positive experience, the building activities were appreciated and kept them engaged.

The comments that the children wrote on the questionnaire were a source of data to understand better the important aspects not covered by the other questions. Most of the comments were regarding the engagement and the fun.

A significant percentage of the comments, 39,5% were explicitly giving a good insight into the educational potentiality of the technology. Three of the most interesting comments were the following: a 13 years old girl wrote *"I liked a lot the experience because it was the first time in my life that I had the opportunity to visit the museum and know about the artworks in a not boring way. It was fun."*; a 13 years old boy wrote *"I would skip the last phase of the workshop to have more time to build and decorate the artefact"*; a 13 years old girl wrote "I enjoyed a lot the experience, but often I was in difficulty in understanding if it was my instrument to play. Anyway, this could be a new way to visit the exhibits".

A set of practical advices and reflections emerged from the analysis of the data gathered during the study could be summarised as the followings:

- Integrate theory, practise and technology, to keep the children involved
- Design with an experienced museum educator focuses the design
- Activities should be flexible to accommodate shorter or longer times
- Even if the workshop was designed for the individuals, design the workshop activities to be suitable also for groups
- Leave time and space for creativity and self-expression
- Some weakness in the toolkit could help to let the children paying more attention
- Design an activity that could be debugged while working with simple solutions (use of a spare set of coloured cardboard)
- Frontal lectures should be designed to elicit the curiosity of the children (e.g. the use of non-conventional examples)
- A toolkit based on microcontrollers and sensors with explicit components could help the children curiosity and creativity
- The audio feedbacks could require a low level of volume to be compliant with the museum rules, having a backup feedback mode could be helpful
- A toolkit that can be tweaked and customized using everyday objects and tools could help stimulating the children creativity

- Keeping a good number of spare parts speed up the time to repair the unexpected breakages
- Having tools to hack and repair the toolkit can stimulate the children curiosity about the technology

6. CASE STUDY 2: KINDERGARTEN COLOUR EXERCISES

This case study was designed to test the BugBits technology in a kindergarten, with 3 classes aged between 3 to 6 years old (N=31). The first class composed by 8 children between 3 and 4 ½ years old, the second class of 14 children between 4½ and 5½ years old and the latest class composed by 11 children of 5½ and 6½ years old. The study was conducted in the Livo kindergarten; a rural village located about 50km from Trento.

The design team, in this case, was composed by the author and another researcher in HCI. The focus of the case study was twofold, for the author explore the flexibility of the toolkit in a different context with young children and following structured exercises, the other researcher analysed different evaluation methods with young children. A more detailed description of the case study and its results is discussed in the thesis titled "Drawing the User-Experience of Young Children" by Cristina Core.

6.1. Workshop aims and design

The primary objective of the workshop was to propose a series of exercises based on the Montessori sensorial curriculum exercises (Montessori, 2013), compare them to the traditional ones and collect feedbacks directly from the children. Like the previous study, the design was an iterative process that involved the teachers and the department of education of the Trento province. The study was conducted for a week in June 2017. The study was proposed to all of the children in the school and was structured mainly on two exercises: the first one based on the colour recognition and matching, and the second based on the classification of the shades of the same colour. Each exercise session lasted between 40 and 60 minutes. The non-technologic exercises were proposed following the structure of the traditional Montessori games, but using the same materials, in this case, coloured cardboard and everyday objects. The first exercise asked the children to find the couples of coloured objects (coloured cardboard squares) that had the same colour. For the second exercise, the children were invited to order a series of objects (coloured cardboard squares) of the same colour but with different shades (from the lightest to the darkest). The technologic version of the exercises leveraged the ability of the BugBits technology to augment the exercises giving them interactive audio feedback. For the development of the behaviour of the BugBits, several changes to the internal software were made. The introduction of an exercise based on colour shades required to develop a new algorithm to reach an improved ability in the colour recognition (a more detailed explanation is present in section 4.5.2). Previous experience from an unrelated case study conducted by the two researchers in another kindergarten showed how the speed of the melody revealed to be the most effective musical parameters to change (Core et al., 2017). During this 7-month experimentation, several musical parameters were tested, and results showed that the music speed was the easily perceived one by the kindergarten children (4-6 year old). The study tested different musical styles, changing the musical scales and three musical parameters: speed, volume and articulation. The analysis used behavioural observations, the verbalisation notes on the children drawings, and an expert-based evaluation to determine the most perceived by the children. Observations were taken by three researchers, annotating the reaction of the children to the change of the musical parameters, while the musical teacher evaluated which parameter was clearly understood by the children. For this reason, the algorithmically generated music was replaced by pre-composed music where the colour or the colour shade determined the speed of the melody played. The song played by the BugBits was the melody of Castlevania video game, the researchers chose this melody because revealed to be suitable to be accelerated and decelerated while remaining distinguishable. The primary hardware-related issue identified in the first case study was the low volume level of the music generated, for this reason, the toolkit was improved adopting a different strategy to produce a louder audio level on output. The construction of the BugBits set was excluded from this study due to the very young age of the children. This study aimed at the exploration of the following questions:

- Is the BugBits set usable with/by very young audience?

- Is the interaction metaphor based on colours and sounds, engaging for children of 3-6 years old?
- Can BugBits be used for educational educational purposes with young children?
- Are the young children able to understand the basic functionality of the toolkit?

Not all of the parents agreed with the technological experimentation so the children not authorised, participated in the study only with the traditional exercises. The ethical committee of the university authorised the experimentation but posed several limitations on the data collection allowed in the kindergarten; in particular video recordings and pictures could not always be used in the presence of young children. This excluded the possibility of performing an accurate video analysis of the workshops. Furthermore, pictures were taken only for the final outcomes of the exercises (when children were not in the classroom).

6.2. Context

The kindergarten chosen for this study is located in Livo a very small town of 850 people about 50km from the city of Trento. The kindergarten is a small building near the primary school. The kindergarten was identified and selected as a good candidate by the education coordinator of the province of Trento. The small children of the small villages near Livo are all converging in this structure. The educational offer of the kindergarten follows the ministerial directives, but each teacher has the freedom to include additional topics. The children are divided into three main groups: small, medium and big that are respectively the children of 3-4, 4-5 and 5-6 years old. The education is in charge of 4-5 teachers that are assigned to specific age groups. The classroom sizes are quite small with maximum 14 children per group. The educational offer followed by the teachers make use of traditional materials such as colours, paper, ordinary household objects and toys. The technology was rarely included in the educational practices, limiting it to the use of music and videos.

6.3. Workshop activities design

The researchers defined the format of the exercises. The Bugbits set was used as a Digital MIM interface focused on the teaching of colours characteristics and the musical speed (Zuckerman et al., 2005). The researchers decided to exclude the construction of the BugBits from stretch from the exercises tasks, focusing more on the use and children experience. The activities of both exercises were defined as the following:

Exercise 1

The first exercise started with the introduction of the BugBits artefacts. The researchers showed to the children that by placing the artefact over coloured cardboard, the BugBits produced a melody, after that demonstration a pyramid was given for each child. The first task of the exercise was a game designed to familiarise with the technology: the children were asked to find all the object in the classroom that enabled the BugBits audio feedback, once they found the objects they were asked to bring them and put them on the table.

The colours chosen for this workshop were the 7 colours composing the rainbow. After this initial game children were asked to look at the objects and reasons about their colour. The researchers asked simple questions such as: which colour is this object? Are they all of the same colours?

Figure 18: Some of the objects collected by children.

The objects in **Figure 18** were grouped and ordered by the children following the rainbow disposition in as required by Exercise 1.

The next task was to identify and group all the objects of the same colour using the BugBits to listen to the music produced. At the end of the grouping activities, researchers asked if the children had already previously seen something with those colours, the next activity was to construct a rainbow using a series of arc-shaped coloured cardboards and/or using the objects that the children had found. An example of the outcome of the first exercise is shown in Figure 18. The final activity was to evaluate the activities, for this task, a simple voting system was tested: each child was equipped with one voting coin and could choose between three boxes one with a smiley face, one with a sad face and one neutral. Even if previous studies showed that the neutral face was not fully understood by children, the researchers decided to include the neutral face (Read, 2008). Particular attention was posed to the explanation of the boxes before the children voted, the researchers asked the children to explain what the meaning of each box was, if not clear they explained it again. Furthermore, working with very young children, starting from 3 years old, posed some limitation on the number of vote choices; it was difficult for the children to grasp the meaning of a higher number of boxes. For these reasons researchers kept the neutral box to avoid the use of only two evaluation boxes. Before leaving the rooms to make the drawings, children were asked by the researchers to invent a new game using the BugBits. At the end of the exercise the researchers asked the teacher to fill a simple questionnaire to evaluate the level of attention the children during the workshop.

Exercise 2

The second exercise was based on the classification of the colour shades. The BugBits used in this exercise were programmed differently from the previous exercise to be sensitive only to 1 colour and its shades (a detailed description is present in section 4.5.2). The beginning of the exercise was as the exercise 1 children were asked to find all the objects on which the BugBits produced a melody and bring them on the table.

Figure 19: A typical result of the second exercise.

The coloured cardboard squares depicted in **Figure 19** were ordered from the lightest to the darkest one using the BugBits audio feedback clues as required by the assignments of the Exercise 2.

After the initial “discover the colour” game the children were asked to reason about what have in common all the objects that they found. The next question was to ask the children if the BugBits plays the same music across all the object. After this reasoning, the children were invited to use the BugBits to order a set between 3 and 7 coloured cardboard squares with different shades of the same colour. Figure 19 depicts the typical outcome of the ordering task of the second exercise, some of the colours were not ordered correctly. The possibility to use a different number of cardboards enabled the researchers to tune the difficulty of the task to the children capabilities. As for the previous exercise, the children rated the activities by using the 3 smiley boxes voting system, and the teacher filled the attention questionnaire.

At the end of both exercises, children were asked to draw what they have done in the during the activity, the teacher was supervising the drawing activity and asked each child the meaning of their drawing putting adding a written annotation.

Interaction	Hardware	Function
The children were invited to **use** preassembled BugBits following two exercises. Exercises were designed to leverage the use of audio and objects colors to make the children reason about the colors properties: classification of the same colors and identification of the shades.	Arduino nano microcontroller	Give some computing power to the BugBits
	Piezoelectric transducer	Produce an audio feedback
	Colours Sensor	Use colours properties of objects as input
	Main board	Connect all the component and provide a mechanical structure
	Battery	Power and mobility
	Pyramid kit	Give a shape to the artefacts
Not meant to be used by the children	“hidden” LED	Used as debug indicator of the state of the electronic
Children will grab the objects indicated by the BugBits feedback	Kindergarten objects	Input for the BugBits

Table 4:Second study summary of interactions, components and functions.

Table 4 summarizes how the BugBits toolkit was designed for the second study. In particular, the table describes briefly the designed interaction, the components utilised in the 2 exercises and their intended functionalities.

6.4. Results

The results were collected using multiple methods, in particular: behavioural observations, drawings, voting outcomes and teacher's interviews. This approach was followed to gain a greater amount of data and to have a complete vision of what happened from multiple points of views.

Observations highlighted how the age of the children was a crucial factor, the younger children (3 years old) showed more difficulties in both exercises while the children of 5 and 6 years old revealed to be able to cope with the maximum level of difficulty of the exercises. One significant example was observed with the youngest children group, ordering the colours revealed to be a very challenging task; the 3 years old children were able to complete the task only with 3 shades of colour. On the other hand, the older group of 5 years old children had no difficulties with 4 colours; they showed some difficulty with 7 shades. The researchers tried to propose the exercise starting with 4 colours and then increase the number of colours one at the time. This methodology enabled all of the children to complete the task. A similar result was also obtained by using a by example approach; showing them a different colour scale helped them in the ordering process.

For some of the children especially in the 4 and 5 years old group was easy to understand that the speed of the melody was changing with the colour, and they were able to discriminate up to 5 different speeds. The younger children showed more difficulties in discriminating the music speed, but all of the children were able to group fast and slow speed melodies. In both the exercises all the children noticed that the music coming from the BugBits was not always the same, but they were able to figure out that the music was changing speed. Moreover, even if smaller children showed difficulties with more than 3 musical speeds, the children noticed the cause-effect relationship between colours and melody speed.

The majority of children who used the BugBits showed shyness when they were introduced the first time, but all of the children showed a much more confident behaviour after a few minutes of use. Moreover, the children proved to be confident when they were using the BugBits for the second time. In particular, the first part of the workshop showed clearly this behaviour, most of the children were waiting to play the game of finding the colours in the classroom again. Observations also showed that the activities performed at the beginning of the workshop were particularly appreciated showing the children laughing and collaborating with each other to find and discover more objects. Fun behaviours were observed even during the exercises structured exercises proposed at the table but with less frequency.

One interesting observation showed children having difficulties in inventing new games with the technology. The children were asked to invent a game; only one child was able to create a new game, all the others children ideas were strictly correlated to the physical aspect of the pyramids. For example, one child said: “it’s a mountain” because the pyramid shape resembled a mountain.

The rating boxes were perceived as a game activity and were appreciated, the results showed a general tendency to prefer the technological version of the exercises, which collected more “happy face” votes (see Table 5). An exception was represented by the 3 years old children who rated the traditional exercise with some more votes; this could be reconducted to the fact that exercises for the younger child were difficult. The neutral face of the voting boxes was not always of a clear meaning to the children, for someone was a serious face and for some was between happy and sad but neither of the two. This confirmed the results shown in the literature about the fun toolkit (Read, 2008).

	3-4 years old			**4-5 years old**			**5-6 years old**		
	H	**N**	**S**	**H**	**N**	**S**	**H**	**N**	**S**

Technologic	64.28%	28.57%	7.15%	94.45%	5.55%	0.00%	87,50%	12,50%	0.00%
Non technologic	71.42%	14.29%	14.29%	76.92%	15.39%	7.69%	57.15%	42.85%	0.00%

Table 5: Percentage of smiley faces grouped by children's age.

The values reported in **Table 5** are divided using the three age groups used in the kindergarten, H column represent the votes of the box with the happy smiley face, N the neutral face and the S the sad face.

A total of 82 drawings were collected, and the analysis was performed identifying the most recurrent elements in the drawings: sociability, colours, technology and music.

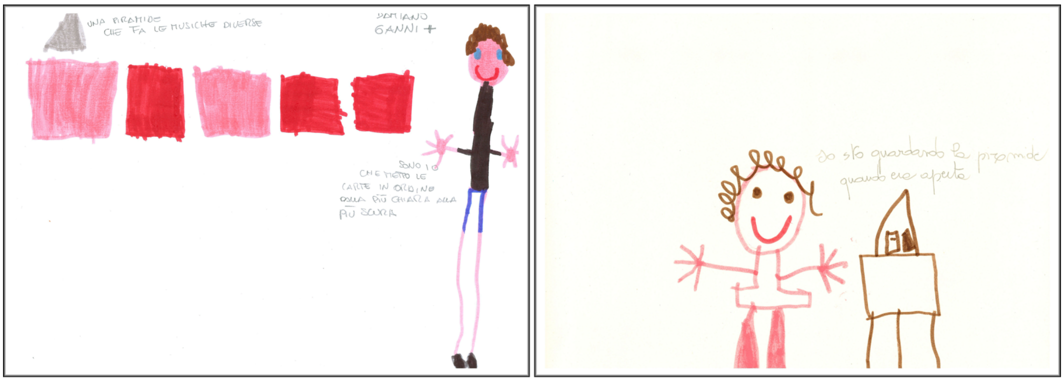

Figure 20: Two examples of children drawings.

Figure 20 shows on the leftmost picture a drawing made by a child of 6 years old depicting the second exercise with the coloured squares and the BugBits. The rightmost drawing made by a 4 years old child depicts himself that was looking at the inner parts of the BugBits.

Sociability refers to the presence of other human figures in the drawing; colours refers to the representation of colours related to the exercise, technology mainly reports if the BugBits were depicted and music refers to the presence of a representation of the music.

To evaluate the results of the drawing analysis 20% of the drawings were analysed by another researcher to assess the intercoder reliability, the agreement between the coding was greater than 80%. The least represented element was the music, where only a few drawings showed the presence of musical notes. Contrarily one of the most reported aspect was the voting boxes that were depicted in 44 drawings. The presence of the technology elements was an essential factor for the children who used the BugBits, in this condition 25 drawings over a total of 45 were representing the pyramids. The second exercise revealed to be more difficult respect to the first exercise, but all the children were familiar with the technology since they all tried it in the first exercise. Figure 20 depicts two drawing samples, on the left a 6 years old child drawn the BugBits and the ordered colours with the following teacher note *"I'm putting the cards from the lighter to the darker. The pyramid makes different music"*. The other drawing, on the right, was drawn by a 4 years old girl, with the following teacher note: "I'm looking the pyramid when it was opened".

The behaviour of the BugBits was programmed in advance, but the use of simple materials as cardboard revealed to be a good choice and enabled the researchers to tune the exercise difficulty accordingly to the children capabilities. The construction of the BugBits was not part of the workshop as evaluating the skills of the children and also asking the teachers the task of building them would have been to complex. Some of the children, about 1 for each age group, was interested and showed curiosity about what was present inside the pyramid. The children that were showing more interest were surprised that the pyramid did not have a button or a switch to start it. The researcher in these cases explained that if the battery was in the BugBits will work. The children demonstrated some level of appropriation of the technology: they used the pyramid as a flashlight or put the pyramid close to their ears to listen to the music when there was a lot of noise in the classroom.

The interview with the teachers confirmed the observations, in particular, the teachers noticed how the second exercise was too difficult for the children of 3 years old. For these reasons, they suggested that the second exercise should be more appropriate for children older than 4 years old. The teachers noticed that sound feedback was sometimes too feeble to ear when there was noise in the classrooms and suggested to increase the volume level for future application in this context. Some of them expressed interest in the technology and hypothesised to be useful in different kindergarten scenarios. Teachers found interesting the way in which the BugBits enabled children to discover the characteristics of the colours. Moreover the shades of the colours were not part of the topics taught in the kindergarten. In particular, the technology was considered interesting to design psychomotor learning activities and activities where there the physical movements were crucial.

The study showed that the interaction paradigm based on colours and audio feedbacks was well accepted by all of the children. They demonstrated to understand the logic of the exercises. However, the younger children showed the most of the difficulties during the studies. In particular, even if the interaction was clear, they struggled to work when more than three shades of colours were utilised. The children older than 3 years did not showed this limitation and they were able to finish the exercises correctly. This difficulties with younger children reflected also on their voting outcomes by showing less happy faces in the 3 years old group. The study demonstrated to be useful to test the flexibility of the toolkit and the interaction paradigm based on colours, the researchers were able to tune the exercises to the children skills and thus avoiding frustrations. Children manifested interest about the technology asking information about what was inside the pyramids. Moreover, children were expecting some form of switch or button to turn on the device. Children demonstrated to be interested about the light feedback that was hidden inside the pyramid. The audio feedback based on one single melody resulted to be efficient in let the children recognise the speed of the music. However, even if the audio levels were improved, when there was a high level of noise in the room children had some difficulty in hearing the audio feedback.

6.5. Discussion

The experience in the kindergarten explored the flexibility of the toolkit in a different context and with a defined educational objective; the colours exercises (learn the colour properties). The experience of the children with the toolkit was not Lego style like the first study, but they used the BugBits as a finished product/tool.

For these reasons, this study investigated the tool flexibility but without evaluating and taking into consideration the construction phases of the toolkit. In this settings children were users and tester of the technology, they were also asked to assess their experience during the workshop (Druin, 2002). The main focus of the study was to twofold: evaluate how the BugBits technologic set was perceived and utilized by very young children and evaluate different methodologies of collection the children's opinions: the drawings and the voting boxes (explained in detail in the PhD thesis titled "Drawing the User-Experience of Young Children" by Cristina Core). As for the first study, the design of the workshop could be categorised as Informant following the IBF, since the children role was mainly to inform the designers through the drawings and their vote (Read et al., 2002).

The use of the drawings highlighted the most important themes for the children identifying how the voting and the technology were perceived as central elements by them (Xu et al., 2007, 2008). This outcome was also reflected in the observations; children demonstrated to be interested even during the voting part of the workshop. This focus on the boxes found in the drawings could be explained since both the experimental condition were using the boxes as data gathering method.

A second theme was represented by the technology, the 55% of drawings coming from the technological experimental condition were depicting the BugBits technology.

Similarly to the previous study, the mainstream view dominated the design of this kindergarten workshop; the children had little or no decisional powers (Kinnula et al., 2017). The participation to the study was imposed by the teachers and parents. While considering the democratic view, they were empowered marginally by giving them the possibility to express their thought about the activities.

Even if the children age was significantly lower compared to the first study but the BugBits set fostered the curiosity of the children, and some of them asked explicitly to know about the toolkit and how it worked.

The workshop was designed to answer and collect information about the BugBits but also methods to evaluate the experience of young children, this latter investigation is explained in detail into the thesis titled "Drawing the User-Experience of Young Children" by Cristina Core.

The workshop was composed of two tasks: a colour recognition game and a colour ordering task; the Montessori exercises inspired both tasks. The TUI implementation changed completely, in particular, the code running inside the toolkit parts.

The feedbacks of the Mart experience suggested and informed the designers to improve the colour recognition algorithm, the new implementation guaranteed a more reliable experience with very few false positive episodes. The audio volume level was increased taking into account the comments of the first study. The major issue was the level of the audio feedback that was sometimes too low when there was noise in the classroom, while it was adequate when the activities were performed on the table. The mechanical design of the BugBits was kept the same, the research team, composed by the author and another HCI researcher, evaluated that the pyramid shape was a good solution to make the artefacts graspable and usable even for younger children.

The construction phase was not part of the workshop, but children were playing the role of tester as in the Mart experience. The observations highlighted that the use of the BugBits technology was an engaging and fun experience for almost all of the children. Laughing behaviour and positive instantiations were often observed during the use of the technology while negative instantiations rarely occurred (Hanna et al., 1997; Read et al., 2002b). The second exercise conducted with the younger children represented the less engaging part of the whole experimentation, this fact emerged from the behavioural observations but even in the post-activity interviews. The researchers tried to overcome this problem by adapting the exercises difficulty adopting an incremental approach in order to match the children skills. During this study, the engagement can be reconducted to the three definitions of Fredricks while the emotional engagement played a more important role when compared to the first study (Fredricks et al., 2004).

The analysis of the drawing showed that the technology was depicted together with the representation of the coloured cardboards, some the verbalisation notes were referring directly to the colour and sound relationship, thus suggesting that for some child cause and effect relation was understood.

The feedbacks collected from the teachers highlighted that excluding an initial reluctance about a new technology they showed interest and possible new educational uses in the kindergarten activities. The children showed curiosity about BugBits, few of them asked the author to open and show them the inner components.

Appropriation behaviour was present also in this case study, some of the children noticed the internal red light as happened during the Mart workshops. They understood that the led light was giving them additional visual feedback when the music was playing.

Even if the volume was increased, a new behaviour emerged: children brought the pyramid closer to their ear to discriminate if the sound was coming out from their pyramid.

The toolkit showed its flexibility in the field particularly during the second exercise, an ordering task of colours according to their shades. This task resulted complicated for the youngest children and barely doable by the 6 years old children. The use of simple materials as coloured cardboard enabled the designers to change on the fly the level of difficulty of the exercises without any particular intervention of change to the code running in the toolkit. By decreasing the number of colours with the youngest children the exercise difficulty was tuned to the children capabilities, but at the same time melody speed of the audio feedback were more differentiated and easier to discriminate.

The use of the toolkit was also experimented in an incremental way by adding one colour at the time; this exercise modality was completely unplanned during the design phases. With this new experimental modality, most of the older children were able to order correctly the whole 7 colour scale. Moreover, this adaptability of the behaviour and difficulty of the toolkit gave to the designers an insight about the ability of the toolkit to be shaped for different purposes.

Some practical advices to improve the study emerged from the data analysis and are summarised as the followings:

- A game-like activity at the beginning could help children to familiarize with the toolkit, the researchers and the activities that are proposed
- Audio feedbacks could require a high level of volume to be clearly understood in noisy environments
- Activities should be flexible to be adapted to some extent to the children capabilities
- The design of the exercises should be taking into consideration different modalities of operation (e.g. changing the exercises using an incremental approach as happened in exercise 2)
- Even if the workshop is designed to use the toolkit as an already built object keeping the ability to disassemble and assembling the parts could help to deal with the children curiosity
- Designing alternative activities to perform additional games and exercises could be helpful when working with older kindergarten children and opens the possibility to explore other design dimensions.

7. CASE STUDY 3: MAKING TOGETHER

The third case study focused on the use of the BugBits toolkit during a participatory design workshop with children between 7-11 years old (N=24). The study aimed at letting the children become design partners, giving them a voice from the ideation, to the creation of technological artefacts and games. Furthermore, the study aimed at discovering how the children will use the BugBits toolkit to develop and create original games. This approach avoided to impose limitations on the design and enabled the children to explore and exploit the toolkit capabilities.

7.1. Workshop aims and design

The primary objective of the workshops was to involve the children in actively and giving them the ability to express their creativity into the creation of new games. The researchers followed an iterative process, with several weekly meetings to design the workshop format and define the materials to use.

The designers chose to explore the capabilities of the BugBits set utilised in the previous two studies. The feedback coming from the previous case studies suggested the researchers expand the toolkit capabilities.

One of the major improvement that the designers introduced was to rewrite the software part of the BugBits set (a detailed explanation is described in the section 4.5.3). The previous version of BugBits, used in the first two case studies, were coded by the author for their intended use (the "museum treasure hunt" and the "Montessori inspired" colours exercises). While the earlier implementations revealed to be effective, the toolkit could not be used in the workshop as it was. The code was working but not flexible enough to be changed "on the fly" during participatory workshop sessions.

These improvements allowed the author to design a general behaviour of the toolkit by writing very few lines of code or adjusting few parameters on the code. For example, it was possible to relate a specific colour to a particular song and at the same time define a light behaviour (e.g. on/off/blinking). The researchers tried to design some behaviour using the new code to familiarise with the new software and identify problems and bugs.

As for the Mart workshop (5 the designers opted to work with materials that are familiar for the children such as cardboard, glue, colours, paper, tape and other scholastic materials. The designers included in the materials also some Lego bricks as they were a good solution to build strong or complex shapes. The researchers chose to avoid the frontal lecture format, as it revealed to be the less engaging part during the museum study. For this reason, the designers decided to introduce the children to the technology using a "learning by example" approach (Dewey and HMH, 1933; Savery, 2015; Schank et al., 1999). This approach will introduce the children to the toolkit elements and their functions, by using the technology in simple practical examples (e.g. demonstrating the reading of a colour).

7.2. Context

The workshop was held in a little rural town called Caldonazzo of about 3500 people, it's located about 20km from the city of Trento. In Caldonazzo there are kindergarten and elementary schools but middle schools are located in the near towns. The location of the study was the "Marchesoni" room a village hall commonly used as a classroom for a local music school (extracurricular) during the afternoon and to hold public events for the community. The hall is strategically located in the center of the town and is known to the majority of people living in town. The room is about 10 meters long and 5 meters wide, equipped with 50 chairs, 2 tables, a piano, a video projector with an audio system. A warehouse room is also available on its side, it was used to store the construction materials and spare parts and rewards for the workshop. The room was booked in advance for all the day by the author to assure consistent progress of the workshop. Before the beginning of each participatory design session the author prepared the room to put the children on the same experimental condition (e.g. avoiding imitation behaviours by looking at the games of the previous groups).

7.3. Workshop activities design

Each workshop session was supervised by the author and a research assistant. It lasted about 1 hour and 40 minutes and was divided into the following main phases: exploration, idea generation, implementation. The workshop ended with a final part of the evaluation. A detailed description of the participants, the procedure and the three workshop phases are described in the following sub-sections.

Participants

The author informed about the workshop teachers of the local elementary school and the staff responsible for extracurricular activities such as local societies (e.g. young football team and scouts). Children and parents who showed interest were successively contacted by the researchers. The researchers introduced and explained briefly by voice about the activities and goals of the workshop. If the parents and children were agreeing to participate a detailed written description of the workshop was provided. A total of 24 children were involved into the participatory design workshops; they were divided in 7 groups sized between 3 and 5 (7-12 years old).

Procedure

The workshop was designed for groups between 3 and 5 children. Parents were contacted 3-4 days before the workshop about the location, the schedule and the intended time of the activity. If there were schedule incompatibilities, we tried to accommodate the timings to minimise difficulties.

The day of the workshop parents were asked to arrive about 10-15minutes before the begin of the workshop. At the beginning, the researcher illustrated again the activities that the children were asked to perform and answered to the questions and doubts of the parents. Before starting the activity, the parents were asked to fill the consent form, authorising the children to participate and the use of data collected during the workshop, all of them agreed the permission to attend to the workshop. Parents were not present during the workshop and before leaving the room were asked to be briefly interviewed some days after the workshop, all of them give to us the availability to be contacted.

The workshops were conducted on the tables area where there was more empty space to work with. During the workshops, some of the unused and spare materials were stored in an adjacent room.

The children groups, composed of 3-5 children, were invited to sit around the table where the researchers introduced themselves. Children were asked about their names, age, if they knew each other and if they liked to build/play with toys like Lego bricks. After the presentations, the researcher informed the children that they will be playing the game of creating new games/ideas and that that would have been prototyped and tried in the last part of the workshop.

Parents interviews were conducted one week after the workshops. Some of the parents were contacted after 2 months. The interviews followed the following question structure:

- Did your son/daughter talked at home about the workshop activity in the days after the experience?
- Did your son/daughter talked about his/her own developed game? What were the main topics discussed?
- Did your son/daughter talked about the BugBits as material?
- What was the most positive aspect of the BugBits workshop (from the point of view of a parent and from the point of view of the child)
- What was the most negative aspect of the BugBits workshop (from the point of view of a parent and from the point of view of the child)
- Did your son/daughter showed behaviours that were influenced by their experience with BugBits (e.g. during the play time or in other situations)? Could you explain and give some details on how the behaviours were changed? How long lasted this change?

Exploration

During this initial phase, the children were introduced to the technology and the BugBits set. The introduction was showing them some examples of the toolkit: using as examples the pyramid-shaped artefacts of the previous studies. The pyramid artefacts were introduced to the children calling them “piramidotteri”. A made-up Italian word combining the words pyramid and beetles. The table was cleaned from the previous sessions, and prepared with: some “piramidotteri”, pencils, white paper, coloured cardboard, glue, scissors, transparent and coloured tape. The researcher showed a “piramidottero” (a BugBits pyramid not active) artefacts and asked the children some simple questions about it such as the following: Do You ever seen something similar? What do You think about it/them? What do you think it/they are/are used to?

After this initial introduction of the artefact the researcher turned on one or some piramidotteri and asked the children to discover how it worked, and what is changed.

The piramidottero behaviours during this phase were fixed and could be one of the following:

- React when one or more specific colours are recognized producing a melody with fixed speed
- React producing a melody when a specific shade of colour is recognised, each shade of colour produces the same melody, but with a different speed. For example, dark shades of blue produced a slow speed music and light shades of blue produced a high-speed music
- React to only one colour producing a random generated melody

Children were asked to explain how the piramidotteri works and they were introduced to the components inside the piramidottero and the others components of the set. The researcher introduced and explained the function of each piece of the BugBits set.

Idea generation

During this phase, the children were asked to create new ideas and games using the BugBits set as the main workshop material. The design space of this phase was almost not limited by the researchers with only a few constraints to respect. The researcher asked the children to think about what they could do with the set presented before. It was not strictly required to use the whole set of components; they could use only some of part of it. Since there were multiple BugBits sets they had the possibility to create games in which combined more than one set. During this phase the role of the researcher was to be a facilitator. When a new idea was generated the researcher asked questions to the children to understand what their idea was and at the same time make them reason about what they wanted. A typical children-researcher dialogue during this phase could be the following a kid said "I want to build an animal that makes music" and the researcher asked "How is this music? Can you explain me how it works in detail? How it looks the animal?" The idea generation was supported by materials such as paper, pens, pencils to allow them to sketch their idea. When ideas were complex, the researcher helped them to sketch on paper what they wanted to design. To keep the focus on the task of idea generation, the "piramidotteri" artefacts were kept on the table together with some disassembled sets as well to inspire them. The researcher switched off the devices when the focus of the children was shifting away from the ideation of new games. The researcher behaviour during this phase was as neutral as possible, to avoid to "drive away" the brainstorming activity from the original ideas of the children. The outcome of this phase was a set of conceptual design sketches accompanied by brief text explanations.

Implementation

At the beginning of this phase, the researcher went through the different conceptual designs by reading them and asked the children to decide what were the best ideas. During this initial phase, the children discussed among them and chose the idea or ideas that they wanted to realise during this phase. The role of the researcher during this phase was two folds: he helped the children to realize and define details about the prototype/s of their idea/s (facilitator); moreover, he filled the gaps between children and the technologies translating the children language into technology-based operations. The children worked with the materials (kit components, cardboards, paper, glue, colours, tape) to give a real shape to their ideas. Figure 21 depict some of the prototypes developed by the children starting from an animal toy to a complex board game to play with an interactive 12 faces dice.

Figure 21: Some of the games and ideas developed by the children.

The pictures of **Figure 21** shows on the left an animated animal game developed by a girl, while on the right the "a dance club for ants" (the red box) developed collectively by the whole group. The big 12 faces solid was an interactive dice to be used in a board game "the pentagame" developed collectively by the whole group.

At the end of the phase of implementation the children test their prototype and they were asked to explain their idea in a self-produced video. With the help of the smartphone, one child played the role of the filmmaker and the others as "actors" showed the prototype in action.

Evaluation

During the whole duration of the workshop, the researcher and the research assistant made structured behavioural observations, a video for each workshop session was recorded. The video recordings were analysed to enrich the field annotations, in particular, the analysis focused on attention/distraction events, frustration episodes, relation with technology, gender differences, collaboration between children, number of ideas/games generated.

Figure 22: Children filling the questionnaire at the end of the workshop.

The table shown in **Figure 22** was used as workbench and is covered by the left-over of the construction materials.

After the implementation phase, children were asked to fill a single page anonymous questionnaire (based on the eSFQ questionnaire and the fun toolkit) to give their feedback about the workshop activities (Moser et al., 2012; Read and MacFarlane, 2006). There are 7 questions focused on the experience they felt during the laboratory of the children. Parents were briefly interviewed after some days from the workshop experience.

Some hardware changes were necessary in order to include some additional features (a detailed description is in section 4.5.3). In particular, the feedbacks and the behaviours of the children suggested to add the possibility to control lights and switches. The observation in the museum and the kindergarten indicated clearly that the presence of light feedback was useful, in both studies children were interested and used the internal lights of the BugBits set. The choice of the designers was to include into the toolkit the presence of coloured LED lights. This introduction required some modification of the mainboard, in particular, the inclusion of some pinheader connectors to attach on the fly the lights. The author implemented the changes and considering the small size of the groups (3-5 children) added 50 LED lights to the toolkit materials. The LED were prepared with a pinheader connector and a rigid wire long about 20cm. The choice of rigid cables was considered because the rigid wires enable the children to shape the wires, while the flexible wires would have required additional tools such as tape or rigid iron wire.

Similarly, the switches were introduced because during the museum experience a lot of children were expecting a switch to turn on and off things on the set. The implementation of the switches followed the same rationale of the LED lights, implemented using rigid wires and pinheader connectors.

The code of the BugBits set was modified to be used with ease during the workshops and included the following characteristics:

- Code based on modules (using standardised data structures for input and output)
- Easy way to implement Boolean conditions (e.g. react to a specific sensor value)
- Possibility to change quickly music melodies
- Easy way to interconnect the sensors and behaviours

The flexibility of the code combined with the adoption of the same type of connectors enabled the possibility to use the LED connectors or Switches connectors to do both the functions. This enabled the children to connect a switch or a LED light in one of the free connectors of the mainboards and assign the correct function editing the code.

Interaction	HW	Function
The children were invited to **invent** and **create games** with the BugBits set. Children play the "game" of being the designers of their own games. Behaviours of the artefacts are imagined by the children and translated into code by the researchers.	Arduino nano microcontroller	Give some computing power to the BugBits
	Piezoelectric transducer	Produce an audio feedback
	Colours Sensor	Use colors properties of objects as input
	Main board	Connect all the component and provide a mechanical structure
	Battery	Power and mobility
	Pyramid kit	Give an example of structure or use the elements in other builds
	LEDs	Coloured LED to be used as light feedback
	Switches & Buttons	Input devices to control the BugBits
	"hidden" LED	Used as debug indicator of the state of the electronic
	Scholastic material	Used as building material for the artifacts

Table 6: Third study summary of interactions, components and functions.

Table 6 summarizes how the BugBits toolkit was designed for the third study. In particular, the table describes briefly the intended interaction, the components utilised during the participatory design workshop and their intended functionalities.

7.4. Results

The children generated a lot of ideas during the workshops, but only some of them were defined with a great number of details and game rules, a lot of ideas were discarded just after the initial proposal. The workshop processes produced 28 different game ideas to be developed with the BugBits technology. The duration of a workshop was about 1 hour and 40 minutes, and at least 1 idea for each group was implemented as a mid-fidelity prototype. At the end of the workshop sessions 20 ideas were implemented by the children, some groups were particularly active and realized the prototypes of more than 3 ideas (a detailed list is presented in Table 8). The analysis and evaluation of the workshop sessions outcomes was conducted comparing different data sources: observations, video recordings, interviews and questionnaires. In particular, the most important sources of information were the structured observations supported by the video recording analysis. A total of about 12 hours of videos were collected and analysed.

The videos of the sessions were analysed following the steps of a thematic analysis (Boyatzis, 1998; Braun et al., 2014). The researcher familiarized with the data and looked at the videos annotating the behaviours of the children during the workshop. After an initial analysis of the behaviours the following themes were identified: distraction, attention, technology, construction, gender differences, fun and boredom. The analysis was performed by two researchers using the themes as lenses, the behaviours were coded by writing a brief description of the event, the time and the children involved.

- Distraction: when children lost concentration and engaged unrelated activities. Most of the distractions were observed when the children knew each other's, in this situation they tended to chat about topics unrelated to the current workshop activity. Only in a few occasions, some child was intentionally distracting the others to show them that they were better in achieving the tasks, this behaviour leads to an active discussion between the children that briefly went off topic. Most of the distractions were concentrated during the first approach with the technology, in particular when the researcher was explaining the functionality of the workshop set. The children after the explanations were excited to put their hands on the technology and they quickly get distracted. Furthermore, even if they were using and familiarising with the workshop material they tended being too focused on fantasy play, thus using the given material as is and not thinking about their own design of the games. A brief intervention of the researcher was needed to bring the attention back to the workshop activities and advance into the creation of their games.

- Attention: when children focused on the "tasks" and were immersed in the activities. The children showed particular attention mainly at the beginning of the workshop and in the latest phases of it. In the beginning, all of the children showed a high level of attention and curiosity when they were introduced to the various activities of the workshop. The part of the workshop that showed the lowest level of attention was immediately after the presentation of the workshop material, the children, in fact, tended to focus more on the play and not to the design of the games. Attention levels increased when some of the children started to draw or explain a game concept. The basic explanation of a conceptual idea drove the attention back on the designing of the games, and most of the children started to contribute to the creation and definition of other games. Similar behaviour was noted at the implementation phase of the workshop when children showed in almost all the groups an increased level of creativity, thus producing new ideas and game concepts on top of what they already built.
- Technology: when children showed an interest in the technology. All the children showed an interest in technology. This interest manifested at the beginning of the workshop when the researcher was explaining the workshop materials briefly, but before showing them the material itself. The interest about of the technology was more evident when they had the possibility to see the technological material, almost all of the children showed curiosity and asked some question about it. For example, the RGB sensor was one of the most asked item during the activities. The children were surprised that the sensor could recognise objects colours. The children that showed a very high level of interest told the researcher that they had seen something similar already and they were interested to know more details. During the implementation of the games, the majority of the children showed an interest in how the technology could be integrated inside

their designs. The laptop used to change the behaviour of the BugBits was one of the most interesting tool for the children, most of them were observing the screen, and few of them were curious and wanted to understand what was happening in the code.

- Construction: when children showed an interest in the physical construction of the artefact. The construction phase of the artefacts was one of the phases in which all of the children showed particular interest. The building phases of the workshop were often characterised by collaboration between children. Children in this phase showed more confidence with the materials that were more familiar to them (cardboard, rulers, scissors, construction bricks, etc.). When children were facing the construction of three-dimensional shapes showed some difficulties and asked help to the researcher: asking how to solve the construction problem or simply asking to perform some basic operation (e.g. taping some cardboard or cutting out some complex shapes).
- Gender differences: when there was an evident difference in the behaviour of the children related to gender. There were some minor differences between gender. The videos showed how some of the girls had some difficulties in participating in the activities because they were thinking of being not able to work with the technologies. Boys contrarily showed a bigger excitement at the beginning they were more confident about their skills. The designing and ideation phase showed a gender difference in the type of idea generated, in particular girls and boys tended to follow stereotypes. For example, boys were proposing to build robots, technologies, cars, football related games, while girls tended to propose games with animals, beauty products, house hold items.
- Fun: when behavioural signs of engagement (e.g. laughing, excitement). The video analysis showed that the most fun parts of the workshop were mainly two: when the researcher presented the BugBits and children used them, and at the end of the workshop when children were building their own game, testing and playing with it.

- Boredom: when children were bored (e.g. yawning). The video analysis showed that the most boring parts of the workshop when the researcher was explaining the electronic parts (during the explanations children did not have the electronics at disposition). The second and most boring part of the workshop was identified at the beginning of the designing phase were children were mostly unsure and showed shyness in proposing their ideas. When some ideas were generated the children showed fewer occurrences of boredom, as they were more active in proposing and improving the newly created game concepts.

The reliability of the video analysis was assessed by using the inter-coder reliability, some 30% of the videos were randomly selected and analysed by another researcher, the analysis showed an agreement greater than 80% on all the coded elements (Holsti, 1969; Neuendorf, 2016).

Coder	Distraction	Attention	Technlology	Construction	Gender differences	Fun	Boredom
Researcher 1	9+11	22+27	16+13	7+11	0+1	5+10	2+3
Researcher 2	10+8	20+24	19+14	8+13	1+2	6+12	3+2
Common events (r1 r2)	8+8	19+21	16+12	6+11	0+1	5+10	2+2

Table 7: An example of the events coded by 2 researchers using the different lenses.

Table 7 refers to the elements coded of 2 groups of children. In particular each cell contains report two different numbers. the leftmost refers to the first group coded, the plus sign is used as a divider, while the rightmost number refers to events coded in the second group.

Table 7 shows the number of events recorded by the video analysis of 2 groups. The behaviours reported were the strong manifestation of the evaluation lenses. For example, an instantaneous distraction was not reported (1-2 seconds), but it was recorded if the child was distracted for a longer time (e.g. more than 15-20 seconds).

The last row represents the common events, the ones that were coded equally by both the researchers. For example, researcher 1 wrote in the technology at minute 26.54 *"the children with the yellow t-shirt was curious about how the pyramid played slow and fast music"*, similarly the other researcher 2 reported at minute 27.00 *"children 2 noticed how the music changed speed changing the colours under the pyramid"*, children 2 was the one with the yellow shirt. To determine the common events, the video was checked to understand if the researchers were reporting the same event or a different one. This additional check was useful when events were close and there were few seconds of discrepancy in the reported time of events.

Observational data

The first part of the workshop served as familiarisation phase with the technology and to let know each other the children and the researchers. Some of the children knew each other, but the groups always had some child that was not knowing all the others. The children showed to be reluctant at the beginning showing shyness, and often they thought to be not able to design a new game. In these occasions, the role of the researchers was crucial to foster them to begin the design process and generate the early ideas.

During the initial phase of brainstorming and idea generation, the presence of the researcher was fundamental to facilitate the first phases of the process (Gutwill et al., 2014). The roles of the researcher in this activity were mainly two:

- Aiming the children to visualise their ideas by sketching briefly on paper what the children were saying
- Asking children simple questions to make them think about their ideas. For example, if they defined a game with lights the question could be: Where do you put the lights? Could you explain how the lights work? How did you play with the lights?

In most of the groups, there was a second phase of idea generation at the end of the workshops. In particular, the children showed to appreciate the implementation phases of the workshop, and while constructing their game a lot of new ideas were proposed, those ideas were not developed to a stage that could be implemented due to the limited time remaining. This behaviour suggests how the “hands-on phase” was useful not only to let them cope with the difficulties of the implementation but revealed to be a useful activity to refine and foster the creation of new games and ideas.

Similarly, at the beginning of the workshop when children could to see and use the BugBits set for the first time, they showed an increased level of interest and attention. This aspect worked well to foster the children creativity, while they were manipulating the pyramids and the other elements of the set they figured out most of the ideas. In the other hand the early introduction of the technology sometimes created distractions, children lose their focus on the design activities in favour of playing and exploring the room with the set. The researcher in these cases acted the role of the facilitator, and his interventions were crucial in bringing their attention back to the design of the games.

At the end of the workshops, children were asked to present their games in a brief video, they recorded the presentations with a smartphone. The activity of video recording revealed to be blocking the children due to shyness, but at the end, all the groups enjoyed the making of the videos. The facilitator role of the researcher was crucial to let them start to present their prototypes. For some of the children, the games were a thing to be proud of and they asked to upload the video presentation online. This latter request was not possible due to the privacy law.

A significant behaviour was observed at the end of workshops when parents came back to bring their children. The kids were spontaneously showing and explaining how they created the games and how to play with them. This behaviour was observed in all seven groups and highlighted how the process of creation of the games was a game in itself and represented a fundamental part of the experience.

All of the sessions of the workshops ended with the implementation, and the collaboration of children was most present in this latest phase. The other phases of the workshops showed a good level of collaboration of the children, only the first minutes of brainstorming were dominated by individual contributions. The group activity worked well and contributed to the creation of more defined ideas. Observations showed how the children instantiated discussions to discard or improve their games. Not all of the groups responded positively to the activities. The last group was the only case in which the children were not engaged, rarely collaborating with each other and unable to generate novel game ideas, episodes of negative instantiations were often observed at the beginning of the workshop. Even if the latest group was the most problematic among the sessions of the workshop, they managed to develop two game ideas, with the help and some suggestions of the researchers. They produced a jukebox like game that played different songs, virtually recorded on coloured discs.

The boys were representing the major part of the children involved into the workshop sessions, boys and girls showed an active collaboration during the progress of the activities. As the first case study there we observed no significant differences in the level of attention and engagement between girls and boys. One interesting case was represented by a girl that at the beginning of the workshop declared to be completely unaware about technology and thought to be not able to help the other in the creation and ideation of new games. The girl was reluctant at the beginning, but at the end of the workshop revealed to be the most important member of the group to develop ideas and reflect about them, she also showed an unexpected interest to the technological part of the workshop where she contributes significantly to the final implementation.

The imitation behaviour was a common problem that occurred during the progress of the workshop. Some level of imitation was present in all the groups involved but was limited. When some child copied from the others, there was always a further process of refinement and improvement of the copied idea. The behaviour observed was more similar to an iterative refinement process, even if some of the games were copied they ended with different implementations and characteristics.

In general, the engaging level of the children resulted to be higher during the last implementation phase, showing an increased level of positive instantiations. This behaviour was similarly observed also in the museum workshops, in particular when children customised their artefact and assembled the electronics. The children showed a particular interest in the programming phase of the technology, some of them tried to understand the rationale behind the coding activity. The majority of them looked interested for some minutes the researcher while it was programming on the laptop and waiting frantically to try their game.

During this phase of coding, the children were collaborating actively with the researcher and asked them to fulfil their needs. Some of the children tried to code on the laptop, but they did not know any concept of programming. For this reason, the children used the researcher as a tool and dialogue with the complexity of the technology. If the game behaviour was not exactly how they imagined they asked the researcher to change the code several times until they were satisfied. During this phase, the role of the researcher was to translate the desired behaviour into code. In 3 groups there were 1 or 2 children that were aware of some basic electronics (e.g. recognising a sensor or a LED), in these children helped the others to understand more quickly what could be done with the toolkit. At the end of the workshop some of the children expressed the desire to include in the toolkit some additional components to let the BugBits move around (e.g. using wheels, motors).

The children's ideas, their amount and diversity could estimate the creativity of the children. A summary of the most relevant ideas is shown in Table 8. The ideas reported are a subset of the whole set of generated ideas, in particular, they were considered game ideas only the ones that were discussed by the children. Some of the ideas were born and forgotten in a few seconds, they were part of the process of the game creation, but they were not significant for the children, and they did not contribute to the development of the final ideas.

Group	N	Idea	Idea description	Imp.
1	1	The dice	A cube with 1 colour sensor for each side (6 colours), the cube is made of a hard material and it's possible to open it. It works like a dice, you can throw it on a special table with colours and when it stops it starts to play a music. The music is different for each colour. The idea was refined and evolved by allowing multiple colours for each side of the cube. They thought about a sphere but they discarded the idea because there are too many sides.	no
1	2	A magic stick	A rectangular shaped stick with some lights on the front. 3 Lights green, yellow and red. On the stick there is the colour sensor. The front lights replicate the colour that is placed under it, when there is a white colour under it all of the lights on the stick will light up. The idea evolved by introducing a blinking feature when white objects are detected (blinking one light at a time).	yes
1	3	PentaGame	Children starting from the first idea proposed to not give the shape of a cube but of a solid with pentagons as faces (12 faces regular solid). The material chosen is transparent like glass or Plexiglas. You throw the dice and when it stops it will be illuminated, if the colour under it is correct it will play a music. The music will be fast or slow according to the shade of the colour. The dice will play a different music for each colour and gives with light feedback. The proposed palette of colour is a gradient between dark blue and pale rose, with respectively the slowest music and the fastest music. To the 12-face dice the player need a table and a game board like "snakes and ladder". Throwing the dice	yes

			over a wrong colour the red lights will be on and the player must go back of some positions.	
2	4	Robot	A robot that "goes on its own and talks and sings. You can control it using a "remote". It can transform itself in a plane.	no
2	5	A lot of robots	A lot of robots !!! they sing when you press a button.	no
2	6	Telescope	A telescope that can play sounds and music when you point a specific house. The children implemented the game by drawing an house on cardboard and placing it over the colour sensor.	yes
2	7	7 Animals with electrical wires	Animals figures enhanced with wires and electronics. The eyes are implemented with Lights. They have the ability to produce sound/music when a specific event happens.	yes
2	8	The train	A little train that moves autonomously. It has the ability to turn on and off the lights, when it stops in a station. No sounds are produced.	no
3	9	The game of lights	A game that turn on and off lights while playing the music and identifies the colours. The lights are controlled by the rhythm of the music blinking. When a determined colour is detected the music changes.	yes
3	10	Turn on and off the light	A simple switch interaction. Children can turn on and off multiple colours lights with a switch.	no
3	11	Talking Lamp	A lamp that is switched on with a switch and could talk.	no
3	12	Lullaby Lamp	An evolution of the Talking lamp, the lamp when switched on starts to play a lullaby. The children wanted to use it to annoy the other children and their mother.	no

3	13	A talking/singing light torch	An augmented torch with a white light on the front, the torch is switched on with a button and the torch plays sounds that resembles the robots sounds.	yes
4	14	A mini piano	A mini piano that has only 2 buttons, it is shaped as a square box. When you press the left button, it plays the C musical note, when the other button is pressed a G note is played. There are also 2 lights one red and one green. Each light is turned on when a button is pressed.	yes
4	15	A loudspeaker	A “super” loudspeaker that plays the music theme of Harry Potter. The game starts when the children place a green object in view of the loudspeaker because the green colour is the favourite of Harry Potter.	yes
4	16	Music cube	An evolution of the loudspeaker idea. Children added to the speaker a set of green lights, it plays the Harry Potter theme, and reacts to the green colour turning on the lights. When is placed over another colour music and lights are stopping.	yes
4	17	Head Dice	It’s a box like a cube with music and lights feedbacks. Three lights are present on the box: green, yellow, red. There is a lever a button and a head can jump out from the box, when this happens the music stops and the light turns on.	yes
4	18	Car game	A toy car driven by a mummy or a monkey that plays a song only when it’s moving.	no
5	19	Jukebox	It’s a rectangular shaped box like a radio, it has a handle on its top and the colour sensor on the bottom. On one side there are a series of holes to make the music pass through. There is a switch to turn the radio on/off. When you put a specific colour under it start playing a specific song. With red the song titled “volare”, with	yes

			yellow the song titled “senza pagare” and with blue the song titled “occidentalis karma”.	
5	20	Replicabox	It’s a cube shaped box, it has the colour sensor attached to the bottom, on the front face there are 3 lights of 3 different colour, on one of the other side faces there is a lever to switch it on/off. When you put the yellow under the sensor the yellow light turns on. The same behaviour happens with green, yellow and red. The box is used to replicate the colours placed under it.	yes
5	21	Oven	It’s a rectangular shaped box, inside of it there is a red and a yellow light inside the box together with the colour sensor. When you put an object inside the box the lights turn on mimicking an oven. An additional light is present on the extern of the oven indicating when something is inside it.	yes
5	22	The fan’s pyramid of the Barcellona football team	It’s like a pyramid shape but with a triangular basis, it has the ability to read colour and produce sounds. The external appearance of the object is coloured with the colours of the football team. When you put the green colour under (that is the preferred colour of one of the football players) it starts to play the team songs.	yes
5	23	The crazy semaphore	It’s like a semaphore, it has the red, yellow and green lights and on its side the rgb sensor to read the cars colour. The semaphore will be red when there are yellow, brown and green cars near it, it will become green with red, blue cars, yellow otherwise. The children play the game with toy cars.	yes
6	24	Discoformiche (the dance club for ants)	It’s a cube shaped box (the initial idea was a pyramid) with 3 powerful lights, 2 red on the sides and one green on the top face. The colour sensor is placed into the bottom face, it's not sensible to the colours but it reacts	yes

			when one hand is under it. If that happen it starts to play a song and the green light will blink following the rhythm of the music. When there are no hands under it the red lights on its sides will be on, off otherwise.	
6	25	Discoformiche passe-partout version	This idea evolved directly from the idea 24. The shape of the artefact is a pyramid made of Lego bricks. The pyramid behaviour is the same as the "Discoformiche" with the additional feature of the passe-partout colour. When the passe-partout colour is detected (blue in this case) the music will be played and all the lights will be on: the green one at rhythm and the other two always on.	yes
6	26	The spider	It's a spider that on its belly has the rgb sensor used as proximity sensor. The spider uses 2 red lights as eyes. When the spider is close to an object or there is an obstacle on its way, the eyes of the spider start to blink. There is no sound feedback.	yes
7	27	A Christmas tree	The game is to replicate a typical Christmas tree, the three is made with cardboard. LED light are used as decoration elements and they are blinking while the jingle bells sounds is played.	yes
7	28	Disc player	The idea is to create a sort of DVD player in which the songs are not on real CDs but coloured cardboard discs. When you put a cardboard disc inside the lector the correspondent song will be played. There is also a status light and a switch. When the player is on and playing a song the status light will be on. The switch turns off completely the disc player.	yes

Table 8: The game ideas generated by the children during the workshop.

For each idea described in **Table 8** a brief functional description of the children's imagined system is given. The last column of the table identifies the ideas that were implemented brought to the end of the workshop and implemented as working prototypes.

The majority of the ideas produced by the children during the workshop were implemented as a final working prototype.

The parent interviews highlighter that the totality of the children talked about the workshop in the 2 days after the experience. Furthermore, some of the parents reported also how their child showed some changes in the behaviours of the children while playing at home. The children were trying to emulate some of the characteristics and features of the BugBits toolkit.

About 2 months after the experience 5 of the parents and 6 children were contacted by the author to be briefly interviewed. The parents reported that sometimes their sons play games at home that are similar to the ones created during the workshop. The interviewed children showed that they enjoyed the activities and asked spontaneously to the researcher if it was possible to organise another cycle of the workshop and play again with the BugBits. All the interviewed children and parents did not report any negative factor regarding the workshop, the only exception was represented by the children that were a little disappointed because they wanted to bring at home the BugBits set after the experience. The children interviewed were also asked if they remembered the components of the toolkit all of them remembered the main components: Arduino Nano, colour sensor and the main board. All of the children recognized and identified the functionalities of the modules when the researcher showed some pictures of the BugBits toolkit.

Questionnaire

The results of the questionnaire showed that almost all of them rated the activity as "extremely fun" (95,7%) with the exception of one child that rated the activity as a "fun".

Figure 23: The words selected by the children to describe the PD workshop.

Figure 23 represents graphically the words that the children selected to describe the activities of the participatory design workshop. In particular, the words were adopted with the following frequencies: fun 29%, exciting 20%, fantastic 19%, easy 13%, intuitive 6%, confusing 6%, difficult 4% and tiring 3%.

As for the observations, the questionnaires suggested the effort required to create a new game from scratch is higher compared to the first case study. A summary of the results of the Likert scale questions can be seen in Figure 33 in Appendix, the questions were defined as the followings:

Q1. I had to work hard to build the game.

Q2. I had to work hard to create and invent the game.

Q3. I was focused in inventing the game.

Q4. While I was inventing and building the games I was curious about what could happen next.

Q5. Building and inventing the games was a challenge

Q6. While I was playing I stopped to notice what was happening around me

The first question was reported by children as an activity that requires a good level of effort (Mdn=3.00, IQR=4.00-2.00). Similarly, the second question rated the effort required to design and invent the games above the average (Mdn=3.00, IQR=3.00-2.00).

The self-reported level of attention during the workshop activities was elevated (Mdn=3.00, IQR=4.00-2.00). The curiosity of the children resulted to be more elevated comparing it with the first case study and the highest score of the Likert scale questions (Mdn=4.00, IQR=4.00-3.00).

The activities were rated as more challenging when compared with the museum study (Mdn=3.00, IQR=4.00-2.00). This could be explained by the fact that the activity of designing a game from scratch without any specific guidelines was objectively more difficult.

The level of engagement of the children could be inferred by the latest question (Mdn=3.00, IQR=4.00-2.00), thus showing that a significant part of the children was engaged in a flow state and losing their attention about the external events. A more extensive representation of the distribution of the answers given by the children to the six Likert-like scales is shown in Table 9.

A detailed analysis of the comments was not possible for this case study because only 6 comments were collected. All of the comments are describing the workshop activities as a positive experience.

Question	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Q1	4.3%	4.3%	30.4%	30.4%	30.4%
Q2	4.3%	8.7%	17.4%	47.8%	21.7%
Q3	4.3%	4.3%	21.7%	30.4%	39.1%
Q4	4.5%	10.4%	0.0%	39.1%	52.2%
Q5	4.3%	13.0%	17.4%	30.4%	34.8%
Q6	13.0%	0.0%	30.4%	30.4%	26.1%

Table 9: Frequencies distribution of the eSFQ answers in the third case study.

7.5. Discussion

The data and feedback coming from the first two case studies informed the design of the participatory design study. In particular, the design of the workshop kept the Lego style approach for the construction phase but did not limit the actions doable by the children; there were no instructions or predefined behaviours on the toolkit provided to the children.

In this workshop the children role was elevated to become design partners (Druin, 2002), the design of the workshop could be classified as in between facilitated and balanced design, the role of the researchers during the workshop sessions was mainly to be facilitators and the children had the decisional powers over the design of the games (Read et al., 2002). On the other hand, the development of the BugBits was strongly influenced by the design experts.

The children empowerment followed a more democratic view since the children had the ability to drive the design of the games from the conceptual up to the prototype implementation, while the researchers facilitated them to reason about their choices and made them refine their ideas (Kinnula et al., 2017a). On the other hand, the children were also empowered from the mainstream view as they were mainly deciding in first person, with very little encouragement from the parents to participate in the workshop. The workshop also offered the possibility to criticise the toolkit and force the researchers and the author to modify the BugBits elements to fulfil their needs (e.g. the use of a large number of lights, or to mimic a proximity sensor).

The children engagement was one of the main design elements of the design process that helped to refine and identify properly the design space (Dodero et al., 2014; Gennari et al., 2017; Tan et al., 2011). In this case the engagement could be characterized mainly as behavioural and cognitive (Fredricks et al., 2004).

This study aimed at answering the following questions:

- Are the children able to design a game with the BugBits set? The results showed that all of the groups developed at least 1 game idea up to the prototype stage. Moreover, 20 games were implemented during the workshops, showing how some of the groups were able to develop more than 3 games during a workshop session.

- Is the set flexible enough to create different types of ideas and games?

  The ideas proposed and then realised by the children were relying on the design space offered by the BugBits set, that focused mainly on colours and audio feedbacks. Even if the children showed some imitation behaviours into the idea generation, the majority of the ideas and games were different. E.g. some of the groups focused more on a board-game with strict rules, some focused more in replicating the world (the Oven or the JukeBox) or augmenting it with unnatural scenarios (Crazy semaphore) (see Figure 21).

- Are the children able to understand the possible interaction behaviours and use them to create non-trivial games?

  Lots of the initial ideas were very close to the example showed by the researchers, but after the initial difficulties to move on children showed more creative ideas. Figure 21 summarises the relevant ideas generated by the children. The table did not contain all of the ideas but only the ones that were discussed among the children. There were examples of non-trivial games like the Pentagame that showed complex game rules and the use of multiple sets at the same time. One significant game idea was the spider that required the children to think about the relationship between light intensity and distance showing a good level of understanding of the mechanics of the set.

- What is the effort required by the children to work as designers with the BugBits set?

  Most of the children struggled to generate new ideas at the beginning of the workshop, but in a few minutes, they were able to think about new games. The children themselves sometimes reported that the effort to invent a new game was quite high. In the other hand, the use of the BugBits during the implementation phases gave them a new perspective, and they were able to reason about new games with less effort, this was noticed in the last part of the workshop when they were able to produce new games in a short period.

- Are the children engaged and enjoying the activities?
  Several aspects of the workshop were appreciated and kept the children engaged, e.g. the implementation phase was an enjoyable and a positive experience for them, the episodes of positive instantiations were prominent in respect to the negative manifestations. The engagement was assessed through the behavioural observations, the video analysis and the questionnaires. The children showed a high level of interest and behavioural observations showed that there were several moments during a workshop where the children were laughing and demonstrating their fun. Even the data collected through the questionnaires indicated that the children rated positively the activities performed during the workshop. Only a few children were not so enthusiastic about the workshop, and they rated the activity with negative marks.

The BugBits set was used by the children to ideate 28 different game ideas showing that the toolkit design space was wide enough to stimulate the children creativity. The children were reluctant at the beginning of the workshop, but the "by example" approach resulted to be a good technique to make them more engaged and fostered their active participation to the activities.

The effort needed by the children to invent the games was higher when compared to the first case study, but all of them, alone or in a group, were able to produce some ideas.

The implementation phase of the workshop helped the children to refine the details of their games and extend the game functionalities. During the implementation phase, the children showed a high level of engagement, and a substantial amount of them thought about new game ideas to develop.

Some of the ideas suffered from the imitation behaviours and ideas were similar or simple extension of other children's ideas.

The level of engagement and fun of the children revealed to be high, and this was confirmed by their request (2 months later in occasion of the parent's interviews) to repeat the workshop activities.

The data analysis and the results found in the study highlighted some practical elements to consider to improve the design of the study.

- Introduce the children to the technology with a "by example" approach could improve the children curiosity and attention
- Having tools to hack and repair the toolkit can stimulate the children curiosity, furthermore enable the children to criticise the toolkit and asking for new features
- Explaining the toolkit capabilities while using it could help to keep engaged the children
- If there are activities that need to be performed by adults, keeping them in front of the children could stimulate their creativity and helps them to understand better what could be done
- The presence of the parents at the end of the workshop could be useful to collect a genuine opinion of the children about the workshop outcomes (e.g. children in study 3 were explaining their creations and games with enthusiasm)
- The hands-on phase after the conceptual design phase could help the children to produce a new series of ideas and games and helps them to understand better the design space
- During the brainstorming activities and conceptual design definition, the presence of an example of the use of the toolkit could help the children to reason about it
- Even if the capabilities of the toolkit can be limited unexpected features could be mimicked (e.g. using the brightness levels to behave like a

proximity sensor). Children expressed their interest in the ability to control and move their artefacts.

- The use of everyday objects puts the children in a position in which they are familiar, and they feel more confident about their actions.

8. DISCUSSION

In this chapter we reflect upon the process that lead to the design of the BugBits set, a generative tool to be used in participatory design workshops and tinkering activities with children. With the BugBits children could explore the design space of TUIs based on visual and audio stimuli.

The possible applications for the TUIs are almost limitless and is very difficult to define the boundaries of the design space of these technologies. A substantial amount of the previous works showed specific examples of TUI prototypes where the objectives and the design space were well defined (Geurts et al., 2014; Horn and Jacob, 2007; Shen et al., 2013). In these cases where the application of TUIs is a narrow application, the definition of a design space and a specific set of requirements could be performed relying mainly to an analysis of the literature. Contrarily, when researchers need to address the creation of a tangible user interface in a wider design space with multiple purposes, such as generative tools for participatory design activities, it is very difficult to cope with the vast amount of possibilities offered by the TUI design space.

This thesis represents the latter situation in which the objective of the TUI is not confined by a single and specific application but aims at designing a tangible-based generative toolkit that can be used in different contexts, reshaped for different purposes, and cope with the peculiarities of children and different levels of participation. In this wide design space is difficult to know in advance all the design factors and limitations that the technology need to address. In this thesis for example, it was not possible to predict the behaviour of the children while using the technology or how the environment factors and limitations were influencing the use of the technology and the progress of the workshop activities. For these reasons there were no easy solutions to define in advance an accurate subset of the large design space offered by TUI. The ideal subset must cover all the requirements needed by the different applications of the toolkit, but several characteristics and feedbacks were discoverable only putting the technology in practice (Dittrich et al., 2002; Schon and DeSanctis, 1986). The “technology in practice” refers to the situations in which the technologies were developed to mid-high level of fidelity and tested in an ecological setting following the design-in-use approach (Barker, 1965; Dittrich et al., 2002). Only in these situations the natural behaviours of the users could be observed and were representing the real interaction between them and the technology. Furthermore the introduction of the prototypes in the early stages of the design helps the children to express their needs, stimulate their creativity and explore the design space (Sanders and Simons, 2009; Sluis-Thiescheffer et al., 2007).

8.1. Design reflections

The design process of the workshops was based on the use the BugBits set starting from the development of an initial version of the set, then tested in different ecological settings (Barker, 1965). The rationale was to develop and test multiple instances of the toolkit, adopted within different contexts and with different purposes. The process of data collection in the field of each instance, aims at instructing the successive phases of development and refinement of the toolkit, following the design-in-use approach (Dittrich et al., 2002). This approach aims at acquiring useful information that is crucial to verify the design hypothesis about the toolkit. In this thesis, the feedbacks collected from the two technology instances demonstrated the flexibility of the toolkit, and its potential to be “shaped’ for different purposes, and thus enabled the author and the designers to move toward the initial design objective of the set. In particular the use of BugBits as a participatory design tool to make the children able to design their ideas and express their needs and dreams.

A more direct approach to the design of using the designed toolkit directly to the participatory design workshops with children, would have been not appropriate. In particular, the direct approach did not give any certainty about the toolkit suitability for the task in a real-world scenario. The identification and tracking of the interaction issues would become more complex. Even the children behaviours and reactions to the technology would have been more complex too understand due too large design space offered by the toolkit.

The first “technology in practice” session was the museum study that explored the use of the BugBits set in an ecological setting (implementation details can be found in section 4.5.1). The study allowed the children to build the artefacts and use them for educational purposes. This approach enabled the children to evaluate and express their thoughts about the toolkit. Moreover, the study served to fulfil some design objectives: assess how the children reacted and used to the technology, find the weakness of the set, offer a meaningful experience. The use of questionnaires and behavioural observations showed how the interaction paradigm based on colours and audio was easy to understand, even if most of the children did not experience similar systems before. The workshop sessions revealed that some weaknesses in the design such as the fragility of some wire connection served to make the children more focused during the building phases. Some minor flaws in the implementation emerged too, in particular, the low volume levels and the accuracy of the colour recognition. Some of the children showed creative solutions to the flaws and manifested interest about the internal lights feedbacks. Moreover, children expected that the BugBits were activated and controlled by means of a button or a switch. The observation and the questionnaires revealed that the level of engagement with the BugBits was high, only a few of the children were not interested in the activities. Children showed interest in the set, and at the end of the workshops they were asking if they could take with them some of the sets. This aspect also emerged in the questionnaires where they expressed their will to use the Bugbits again. The hands-on approach with the technology helped the children to inform the designers about the pros and cons that will be difficult to elicit with other methods.

The second “technology in practice” study was conducted in the kindergarten and helped the designers to evaluate the BugBits in a different context. In particular, the focus of the design shifted more toward the educational aspects. The set was improved following the outcomes of the first study, a detailed description of the changes can be found in section 4.5.2. Children aged from 3 to 6 years old were introduced to BugBits as a playful tool for the exploration of colours (Montessori, 2013), the study focused on two exercises inspired on the Montessori method and following the approach of the Digital MIMs (Zuckerman et al., 2005). The study helped the designers to evaluate the children's relationship with the technology, their experience and the educational potential. The data collected through observations, interviews and drawings highlighted how the experience of the children was in general positive. The drawings showed that the BugBits played an important role in their experience as they were often represented, and some of the children showed interest to discover what was inside the pyramids. The set revealed that the interaction paradigm based on colours and audio was understood by the children, but some of the exercises were too difficult for the younger children. These difficulties helped the designers to explore the flexibility offered by toolkit interaction modality, the exercises were modified, keeping the same colours/audio relationship, but lowering the task difficulties (using very different colours and lowering the numbers of colours). This ability to tune and adapt easily the exercises to the children skills guided the younger children through the tasks and enabled them to finish the exercises.

These difficulties were also reflected in the voting outcomes where the young children showed the lowest level of appreciation. The use of scholastic material such as cardboard enabled the designers to adopt a more straightforward approach to the exercises. The audio feedbacks were improved, but they were not adequate when there was a high level of noise in the room.

This exploration of the technology in the field with different contexts and purposes enabled the designers, with some level of confidence, towards a more complex and complete use of the BugBits set. In particular, the set will be used as the primary material for participatory design sessions, aiming at involving children as partners, giving them decisional powers and widening the design space.

Feedbacks from the previous experiences informed the designers and enabled them to improve the set features introducing coloured LEDs and switches (implementation details in section 4.5.3). These two simple additions widened the possibilities offered by the set but kept all the other components and behaviours as in the previous instances of the technology. The use of the interaction paradigm based on colours and audio feedbacks was retained as the core of the set. The first two studies showed that the children were confident with this interaction modality. Moreover, the children who used the BugBits set (from 3 years old to 14 years old) encountered some interaction difficulties in noisy environments, and with the first version of the colour recognition algorithm. Those difficulties worsened the children's experience but, all of them demonstrated to understand with ease the interaction modality offered by the system. The study explored the level of engagement of the children, their creativity introducing them to the development of TUI systems. Both the BugBits and the tasks were open ended by design in order to not limit the design space exploration. The results of the case study showed how the design activities were perceived by the children as the most difficult part of the workshop. Some of the children struggled to create new ideas. This difficulty was lower when the children were using the BugBits set; they created more game design ideas during the hands-on parts of the workshop (when the researcher firstly introduced the set and during the implementation phases).

The use of BugBits as material in participatory design workshops showed that even if children had no knowledge about electronics the set enabled them to become the lead designers of TUI games. The simplicity of the set enabled them to understand the basic functions of the set and thus stimulated their creativity (Amabile, 1998). Children were able to propose 28 different game design ideas and they realized the working prototypes of 20 of those. The introduction of the BugBits set as design material happened during the early phases of the workshop and helped children to reason on how to invent new games (Gielen, 2008; Sluis-Thiescheffer et al., 2007).

These children design case studies served as design process example and led to the definition of the KPW design process (described in Chapter 9) to enable the designers to develop TUI systems to be used across different contexts and to empowering the children to be real design partners in participatory design sessions.

8.2. Children Empowerment

In this paragraph we provide a summary of the three studies following the proposal by Kinnula et al. analysing the role of the children and their level of empowerment using different lenses (Kinnula et al., 2017a).

The design of BugBits followed a process of iterative co-design. The tool was used in three different case studies. This section analyses the roles assumed by the children and the level of empowerment in these studies.

The first case study was conducted in the modern art museum of Rovereto (Mart); during which the artefacts were used to introduce the children to the concepts of interactive art installations (described in Chapter 5). During the workshop, children assembled the BugBits toolkit to build interactive artefacts and the emphasis was on the tangibility of the interaction.

The second case study was conducted in a kindergarten where children used the BugBits to exercise their knowledge and learn about colours (described in Chapter 6). In the kindergarten setting children did not assemble the BugBits set, but they used it in two educational exercises.

The latest study was a participatory design workshop where children designed from scratch their own games (described in Chapter 7). The latest study gave the children the decisional power to guide the design process and explore the potentiality of the BugBits set freely.

The children's role in the first two case studies was mainly to be testers of the design, in fact the structure of the activities was dominated by the decisions of the designers and researchers. Contrarily in the latest study aimed at empowering the children, to use the technology freely and develop their own artefacts/games without imposing them any predefined schema. Similarly, also the role of the researchers changed significantly in the last study. The first two studies were characterised by the presence of the researchers as observers, collecting the data and helping the children with technical issues. During the third study, the primary role of the researcher shifted to be the facilitator, helping the children not only in solving technical issues but helping them reason about their design choices. This change into the role of the researcher has also reflected in the relationship between them and the children; the children showed more confidence in asking questions respect to the other studies (e.g. asking to modify the set physically or implementing novel features). The researcher in these cases served as a tool for the children to overcome their lack of knowledge. A summary of the children roles and their involvement in the process across the three case studies is reported in Table 10.

	Who set the goals for the project	**What were the goals**	**Decision-making roles**	**Roles of children**	**Practices used for involving children**
Case study 1	Researchers	Introduce children to interactive installations, explore the toolkit characteristics, understanding and supporting children’ s building difficulties, children understanding of technology, evaluate children engagement levels	Designers: developed the toolkit Researchers: initiated the project, defined the workshop activities, defined the game mechanics and toolkit behaviour, facilitated the children in the progress of the workshop; Teachers: groups definition (few times, only in problematic cases) Children: built and personalized the artefacts, used actively their artefact, evaluated their experience and activity	Testers, maker, game and activities evaluator	Teaching interactive installations with multimedia mediums, artefacts making activities, playing with the artefacts, evaluating experience (questionnaires)
Case study 2	Researchers	Exercise the children knowledge about colours, evaluate the toolkit as users, understand the children relation with the technology, evaluate children engagement levels	Designers: developed the toolkit; Researchers: initiated the project, defined the exercises, defined the artefact behaviour; Teachers: children groups definition Children: evaluated the experience, played with the artefacts	Testers, game and activities evaluator	Play with the artefacts with and without rules, playful activities, voting, drawing
Case study 3	Researchers	Let the children explore and design their own games/interactive artefacts, understanding and supporting children’ s participation in game design. evaluate the flexibility of the toolkit, evaluate children engagement levels	Designers: helped the children to build their games, translated the children desired toolkit behaviours into code, facilitated the children in defining the behaviours of the games Researchers: initiated the project, defined a broad workshop structure, facilitated the children in the progress of the workshop Children: defined the games ideas, designed the game, built the games, played with the games, evaluated the experience	Designer (game), maker, design partner, games and activities evaluator	Children fully decided the game design and system’ s behaviours, games/artefact making activities, evaluating experience (questionnaires and interviews)

Table 10: Children involvement and roles in the three case studies.

Similarly the level of empowerment was analysed following the views proposed by Kinnula et al. a summary is shown in Table 11 (Kinnula et al., 2017a).

	Mainstream view	Democratic view	Critical view	Functional view	Competence view
Case study 1	Children were empowered by school, teachers, researchers to participate.	Partially empowered, they could evaluate and customize their own artefact.	Not empowered.	Empowered, they used the toolkit to improve and reflect about interactive art.	Empowered they gained useful skills in critical thinking, interactive arts and practicalities of building electronics.
Case study 2	Children were empowered by teachers, parents, researchers to participate.	Little empowered, they could vote and evaluate the proposed activities.	Not empowered.	Empowered they used the toolkit to improve and expand their skills in colour characteristics.	Empowered they gained useful skills in working in group and voting.
Case study 3	Children were empowered by parents, researchers and themselves to participate.	Empowered, they had a lot of decision making powers: from the ideation to the realization and evaluation of their ideas.	Marginally empowered (they hacked the set functionalities and forced researchers to modify it).	Empowered, they used freely BugBits to improve their (game) design skills.	Empowered, they gained useful skills: game design, understanding of basic programming concepts, and work in groups, and practicalities of building electronics.

Table 11: Children empowerment views across the three case studies.

The third study was developed to give to the children a voice in the design, enabling them to have decisional power in all the phases of the workshop. The analysis shown in Table 11 highlights the increased level of empowerment of the children when compared to the other studies. The analysis highlighted also the difficulties of empowering children during the workshops, in particular according to the Critical View. The choices made by the designers affected the children ability to criticise and arguing the BugBits set, thus leaving little space to radically change the sets. Even the mainstream view highlight how the children were somehow fostered to participate by adults. This could be reconducted also to the way in which children are involved in the studies. Their involvement passes through several layers of institutions and people (e.g. universities, schools, parents) that are deciding for them without asking for their opinions. Even the use of consent forms that are formally requiring the authorization of only the parents. The researchers in the third study tried to open this choice directly to the children, asking them a verbal consent before the beginning of the workshop (one child decided to not participate).

The use of this specific analysis resulted particularly useful for the researcher to be more aware of the effects of the design choices and process on the level of empowerment. In conclusion, the empowerment of the children is a multifaceted aspect, composed and affected by numerous elements. The author tried to obtain a more extensive level of empowerment in the latest study, giving to the children the primary role in the design and giving them the possibility to make their decisions during the whole process, the task revealed to be difficult and was only partially achieved (Iivari et al., 2015; Iivari and Kinnula, 2016).

9. THE KPW PROCESS

The KPW process does not aim at defining a set of precise and detailed guidelines to follow and reach a good design of tangible based making/tinkering tools for children but provides a structured design process to consult and follow. The process guides the designers aiming at empowering and engage the children in the creation of TUIs. The processes help the designers to take into account the difficulties of the realisation of tangible interfaces, from the classical point of view of interaction design and from the design-in-use perspective (Dittrich et al., 2002; Schon and DeSanctis, 1986).

The process addresses the design of tangible-based generative tools that are aiming to let the children become design partners and giving them decisional powers into the design process. Moreover, the processes here described aimed at empowering the children to contribute to the design, making their ideas the primary elements to the development of the tools. The KPW process can be divided into three main phases: building knowledge and limiting the design space, technology in practice, and widening space and technology. A general overview of the phases of the process is depicted in Figure 24.

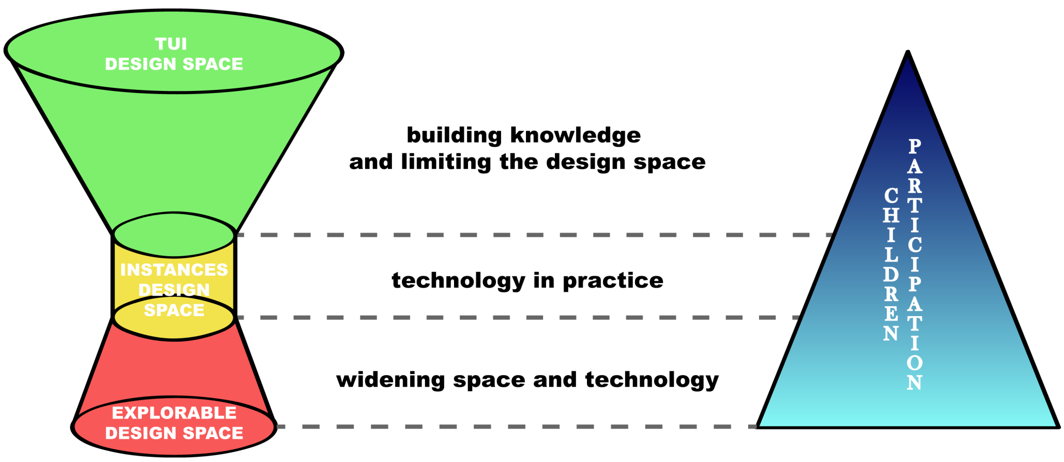

Figure 24: The schema of KWP process.

Figure 24 highlight on the left the three main phases of the process and depicts the changes in the design space. On the right part the blue triangle represent the increasing level of children participation through the process.

9.1. Building knowledge and limiting the design space

The TUI design space is very broad, and this first phase of the KPW process aims at limiting the design space considering different elements and aspects of the TUI design. This initial phase is the most important as it delimits the design space and gives the first and the most important design direction.

The designer team needs to reflect on the desired purposes and the requirements of the tools. Since the nature of generative tools requires to offer different paths and ways to combine its elements. The work of the designers needs to identify the requirements that represent the minimum set that fulfils the desired purposes. This set of requirements needs to be open-ended and ambiguous leaving enough design space to support the children's creativity (Elizabeth and William, 2002). To inform the design and to identify the main requirements, designers could follow and take inspiration from existing frameworks and guidelines. In this thesis for example the CTI framework or the Resnick guidelines and the digital MIMs were considered (Antle, 2007; Resnick and Silverman, 2005; Zuckerman et al., 2005) as the main foundation of the BugBits design (discussed in section 4.1). The phase of identification of the requirements is a process that needs to take into consideration different elements, and designers needs to consider the design implications from multiple point of views. As reference the author started reasoning about the requirements following a PACT analysis schema (Benyon et al., 2005; Preece et al., 2015).

One of the elements to consider is how the choice of a specific **technology** limit the design space of the tool. For these considerations the designers need to cooperate with domain experts. To have useful insights about the practical implementation and take into consideration the pros and cons of each technological solution. A requirement could be satisfied by using different technologies, and the choice of the technology affect directly the design space that the final tool will be able to cover. One example could be represented by Block-Magic (Miglino et al., 2014) in which the technology solution was to rely entirely on a passive RFID technology; the flexibility of the system puts its basis on the ability to augment objects with tags. This flexibility comes at the cost of being extremely difficult to integrate other input/output modalities. Even the BugBits could have been implemented using the same RFID technology; it would have limited the ability of the set of being easy to be modified and expanded. For example, even adding simple light feedback would have severely affected the initial design of the system, requiring the development of secondary systems to add the new features. This example shows how the technology could limit the design space and limit the interaction modalities of the final system but also shows how the technologic choices could affect the ability to modify the tool to fulfil new requirements.

The critical aspect to consider is the **audience**, in this case children. The designers need to evaluate the development stage of the children, their age, what are their characteristics: e.g. their cognitive capabilities and motor skills (Berk, 2000; Piaget, 1951; Vygotsky, 1987). The evaluation of the audience is the central element of the first phase of the KPW process as it affects all the other elements. The inclusion of domain experts in the design team help the designers to have an insight about the children capabilities and characteristics. The inclusion of the domain experts happened in the first and second study presented in this thesis. The third critical element is the **contexts** in which the tool could be utilised. The designers must reason about the physical characteristics of the predicted environments of use, consider the sociocultural influences that could limit the possible scenarios and implementation. Furthermore, the context plays a crucial role as a preliminary way to estimate the children knowledge. For example, if we are targeting children that are part of a fablab or a coderdojo lab we can expect that most of the children will know some basic electronics and programming. In this case, a set with a few elements, such as the one presented in this thesis, could result in a system that is too simple and that is not able to keep engaged the children.

Another element to consider is represented by the **actions**, defined as the intended/non-intended interaction modalities of use of the set. The designers must reason about the actions/steps required by the children to utilise the material, what are the interaction paradigms? The process followed in this thesis started from the general Resnick guidelines and the CTI framework to build the base knowledge about the design space that we needed to address (a more detailed analysis is present in section 4.1) (Antle, 2007; Resnick and Silverman, 2005).

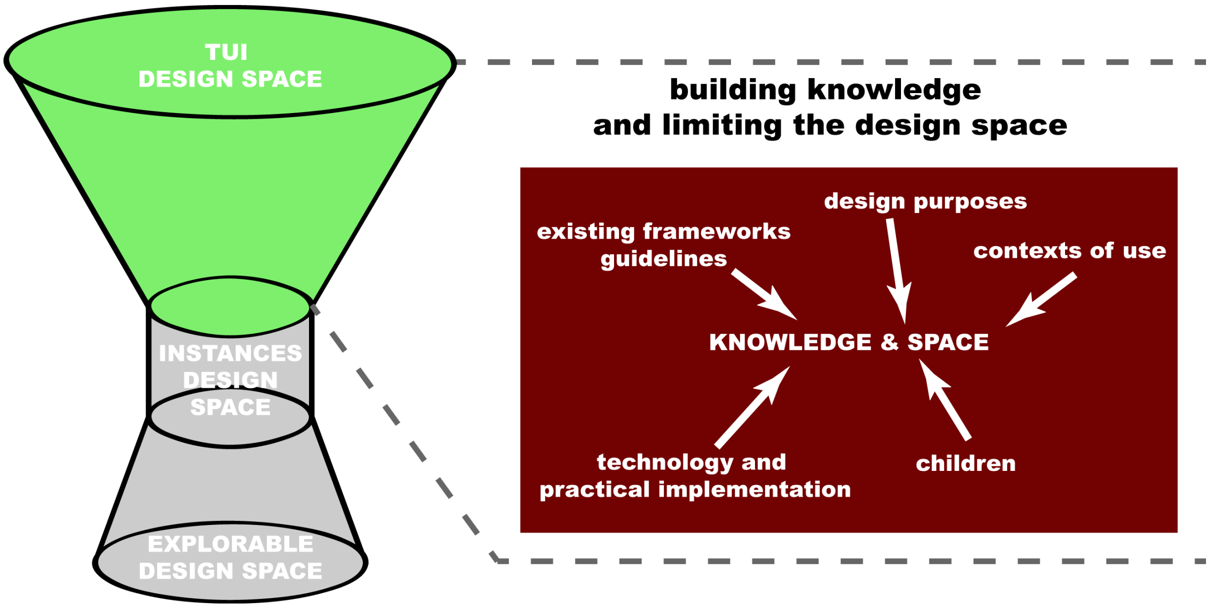

Figure 25: The schema of the first phase (K) of the KPW process.

Targeting children of a very broad age range we needed to deal with very different levels of development of the children, e.g. the designers not expected that all of the children were able to read. Their development stage and knowledge influenced the design, especially when dealing with young children as in the second case study. The abilities of the children were different in each school class and the design needed to include an extended flexibility to adapt the system to the children skills. For example, the role of the children was designated as testers limiting their contribution to their experience and the use of the artefacts. Following the same reasoning BugBits was designed assuming that only few children were knowledgeable about electronics or programming (topics that are not usually part of the educational curricula of the children involved in the studies), and thus keep the system as simple as possible. The socio-cultural aspect was considered, but children involved were normally exposed to the use of digital technologies such as tablets, smartphones or electronics games in their lives, thus the proposed system would not cause issues. The identification of the technology followed a “safe move” of choosing a microcontroller and sensors approach that posed very few limitations on what the set could sense and interact with. On the other hand, this design choice lowered significantly the computing power of the system.

The first stage of this process aims at exploring and informing the designers to make them reason about their design choices. Furthermore, it suggests looking at particular elements to consider. The technology element represents one of the aspects that are limiting and shaping the design space of the tools, but this process fosters the designers to evaluate critically the choice of technologies suggesting the inclusion of a domain expert. The technology is often seen only as a solution to the needs of the users, this process highlights to the designers the need for a deep understanding of the consequences of the technology choices (Lindtner et al., 2016). At the end the first stage of the process limits the design space such that the tools can be implemented and tested in the field.

9.2. Technology in practice

The technology in practice is a central concept of the KPW process. Inspired by the concept of reflection-in-action, the ability to incrementally refine and improve the design while in use (Schon and DeSanctis, 1986). The technology in practice grounds on the Dittrich definition of "design in use" defined as the set of processes able to 'capture practices of interpretation, appropriation, assembly, tailoring and further development of computer support in what is normally regarded as deployment or use'(Dittrich et al., 2002). The idea behind this part of the process is that in order to reach a good level of development of the tools there is the need to locate, test and observe the technology in the field, collecting feedbacks in an ecological environment (Barker, 1965). As emerged in the literature the early adoption of the technology in the field helps the designers to collect meaningful data (Gielen, 2008; Sluis-Thiescheffer et al., 2007). Moreover, the children could have a clearer understanding of the proposed system, thus enabling them to inform the designers with their needs and dreams.

The proposed methodology to collect these information is to adopt several *instances* of the technology. An *instance* in the KPW process is defined as a specific use case of the technology: borrowing the concept from the class-oriented programming languages each variation of an object is an instance of the class (Stefik and Bobrow, 1985).

The "building knowledge and limit the design space" will limit and define the design space in which the designers can move during this central phase. The idea of *instance* is similar to the concept of technology probe (Gaver et al., 1999; Hutchinson et al., 2003), the main difference is that during the technology in practice phase of the process we are targeting not a single specific use case but we are putting deliberately the technology into different scenarios to test its flexibility, pros and cons.

Each instance can be developed to fulfil a specific set of requirements as it happened in the Mart case study but keeping the toolkit open-ended. The ambiguity and flexibility of the tool need to be kept in the design (Elizabeth and William, 2002).

The design of each specific instance of the tool should keep into account the context of use, the audience, physical limitation, technology limits and sociocultural aspects. For these reasons, the design team may need to work with domain experts to cover these design elements.

The development of these specific technology probes can appear as a design direction that is going away from the initial objectives and requirements of the toolkit, but they represent a solution to collect crucial information on the field. In particular each instance is designed to explore a specific subset of the whole design space of the toolkit. In these conditions the researchers can design the instance to collect data and answers to specific questions about the toolkit characteristics. A general representation of the design process proposed for the technology in practice phase is illustrated in Figure 26.

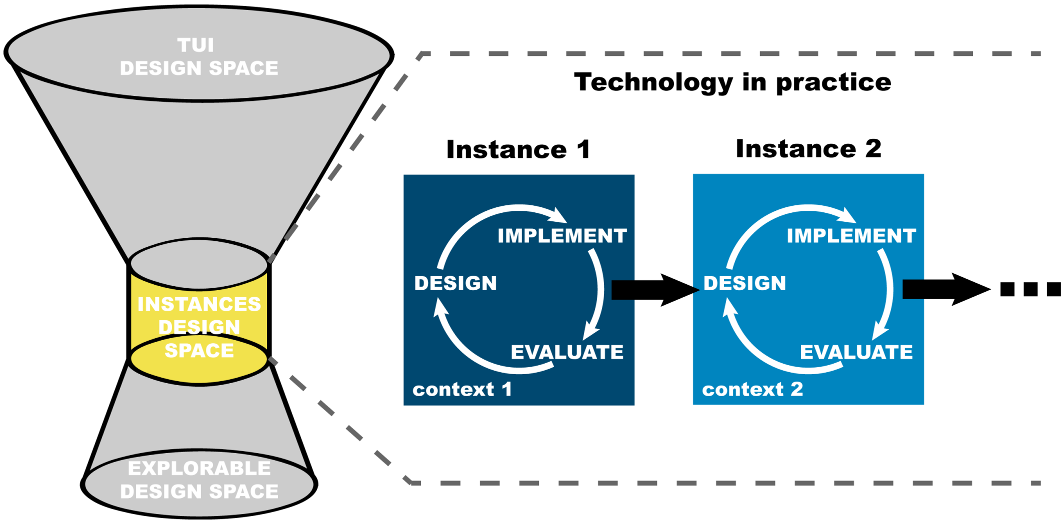

Figure 26: The schema of the second phase (P) of the KPW process.

Designers can also investigate the effect of different levels of participation of the children across the instances. In the first case study the expressivity of the toolkit was limited, with a predefined behaviour and a guided construction phase; children assumed the role of testers (Druin, 2002).

To maximise the data collection the technology in practice phase suggest the designers to target different contexts and purposes for each instance, enabling the designers to capture a more extensive set of information. This process aims at evaluating how the designed tool adapts to different scenarios and how the children react to the proposed interaction modalities. Furthermore, the data and feedbacks collected from the instances gives to designers fundamental insights on how to improve the tool and maximise the flexibility of the system. To design a good instance for of the toolkit, designers needs to identify in advance a set of questions that they want to investigate. The information and feedbacks coming from the previous instances are taken into account into the design of the successive instances, and to test the potentiality of the tool within different perspectives.

As discussed in section 8.1 the BugBits toolkit followed the approach of the design-in-use, putting the technology in the real context and improving it while it is in use. The first two studies presented in this thesis (chapters 5 and 6) are putting the BugBits in the real-world, as an playful educational activity in the art museum and as educational exercise for young children. These two studies are representing two instances of the technology in practice central element of the KPW process.

The first case study of the BugBits was designed to answer specific questions about the physical characteristics of the set, the efficacy of the interaction modalities, the perceived complexity and the level of engagement (e.g. Are the children able to build it? Is the use of the toolkit a fun/engaging activity? Are the children able to understood how the toolkit is working?). This specific instance served to identify that the interaction modality based on colours and audio was clear for all of the children. The children reported that their experience with the Bugbits was engaging and positive, asking for repeating the experience. The construction phases and the exploration of the museum with the BugBits were, accordingly to the children evaluations, the most exciting parts of the workshop. The construction revealed to be easy enough for the children, but some physical weaknesses emerged during the use. The instance resulted particularly useful in identifying two issues: the volume level of the audio that revealed to be sometimes too low when there was noise in the room and the false positives caused by the colour recognition algorithm. Both these issues were not noticed by the designers when they tested the BugBits before the study.

The second case study (discussed in chapter 6 and 8.1), is representing the second instance of the toolkit, it was conducted in the kindergarten investigated how the BugBits responded to a specific learning purpose inspired by the Montessori colours exercises. The second study represents an example of how the designed tool was adopted in a different context and with a different purpose respect to the Museum study. The kindergarten instance involved young children within a scholastic environment where children played the role of tester. In particular, this instance, investigated the following aspects: is usable with/by very young audience? is the interaction metaphor based on colours and sounds, engaging for children of 3-6 years old? can BugBits be used for educational educational purposes? Are the young children able to understand the basic functionality of the toolkit?

The results and discussion highlighted how the experience of the children was positive and engaging. The interaction metaphor based on sound and colours was easily understood by the children, that demonstrated to understand the relationship between the music speed and the colour shade. However, the instance highlighted how the exercises were too difficult for the younger children, and this aspect was reflected in their evaluation where young children rated the experience as less positive respect to the older ones. The flexibility of the toolkit emerged as the designers were able to adapt the exercises of the younger children to their skills. The improved version of the colours recognition algorithm revealed to be more stable, showing rarely false positives. Contrarily, even the improved volume of the audio revealed to be too weak when there was a high level of noise in the classroom. The educational value of the toolkit was appreciated by the teachers that during the interviews manifested interest in using the BugBits for other types of activity. The interviews also highlighted that the colour shades were not treated as part of the curricula and found interesting the interactive approach proposed in the two exercises.

Feedbacks collected from both the instances, at the art museum and the kindergarten, informed the designers and gave them a set of data to reflect on, improve the design of the tool and then move to the final phase of the design process.

Some instances could result less effective to fulfil the requirements when compared with others, showing that the children are having difficulties. The outcomes of the instances in these cases are suggesting the designers that the tool could is too focused and tailored to a specific context or purpose. In this case, the technology in practice approach helps the designers to change and redesign the tool, fostering them to move away from their ideas and following what the children are suggesting.

9.3. Widening space and technology

This phase aims at expanding and exploring the full potentiality of the toolkit and test it for its original purposes. Moreover, the previous phase tailored the tool to be used in a very specific context and use thus limiting the actions and the expressivity of the children. This phase suggests the designers to improve the design of the toolkit and remove the design limitations that were introduced during the technology in practice phase. With the information collected in the technology in practice iterations the designers gained a sufficient level of knowledge about how the children use and react to the technology, this knowledge could help the designers to improve the toolkit to be an open-ended tool for children. The third case study presented in this thesis represent this latest step of the KPW process. A general overview of the third phase and its internal processes is depicted in Figure 27.

Before reaching this latest phase of the process, the design started from the design space offered by the TUIs, the knowledge and reflections acquired in the first phase of the process identified a small subset of the design space to work with.

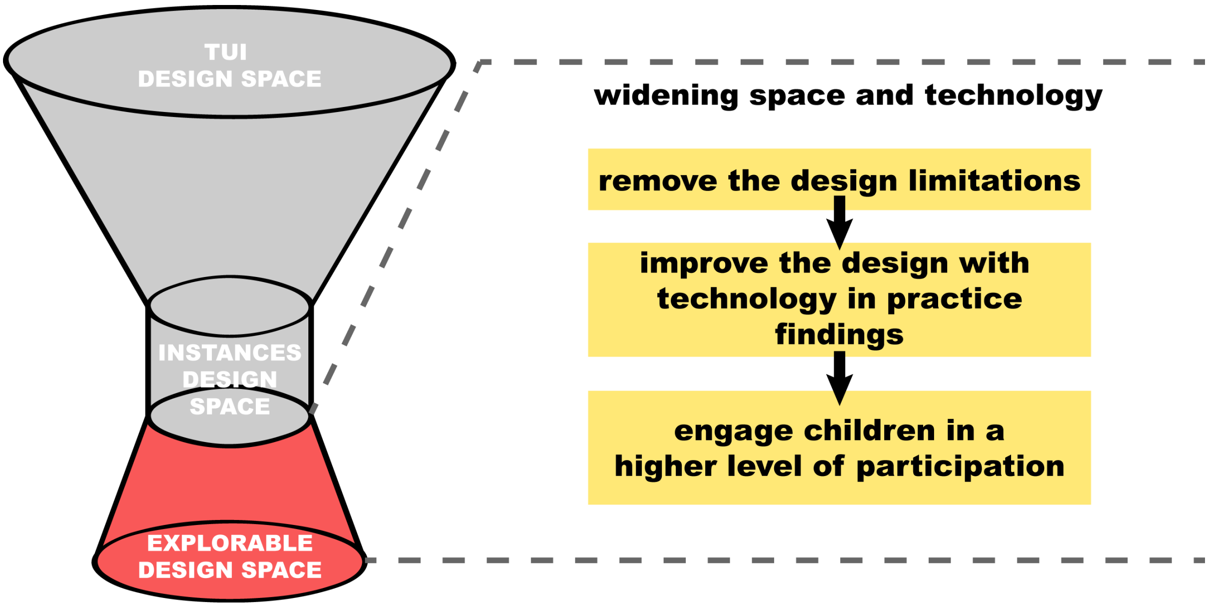

Figure 27: The schema of the third phase (W) of the KPW process.

The technology in practice phase tested the technology in specific scenarios and enabled the designers to collect feedbacks that were taken within an ecological environment. The technology in practice phase and its instances did not exploit the full potential of the toolkit as it aimed mainly to test the flexibility of the technology with children and its adaptability within different context and applications. The technology in practice consolidated the fundamental characteristics of the toolkit. The process structure presented a linear top-down approach it suggesting the designers follow the three steps in order. The KPW does not exclude the designers to go back and forth from the first two phases if the outcomes and the initial design requirements and objectives were not met.

Conversely, the process is aiming at "blocking" the designers to "jump" from the first phase directly to the latest without passing from the technology in practice steps. A direct jump could render a challenging task the identification of the design issues of the tool and their causes. The difficulties of this approach could be attributed to the fact that the jump to the latest phase did not exclude any of the design choices, and all of them can cause the issues.

For these reasons, the technology in practice represents the crucial phase to follow before moving to the last step. This gradual approach ensures the designers that a subset of elements of the toolkit is consolidated and evaluated in different scenarios. Even if this approach could not entirely exclude the issues, it could help the designers to avoid the problems discovered in the central phase of the KPW.

In particular, this latest stage of the design widens the design space, by posing few or no limitations on the toolkit. It takes advantage from of the whole set of information and feedbacks collected to empower the children and give them the possibility to use the toolkit to the full potential.

The third study described in chapter 7, represent the last phase of the KPW process. The BugBits toolkit was improved and widening its the design space. In particular some features were added, restructuring the code to enable the BugBits to be quickly adapted to the needs of the children. These improvements aimed at giving the children the full decisional power to design their own games, ideas or objects.

As discussed in section 8 and, the third study focused on the use of the toolkit to maximize the children empowerment and reaching a high level of participation. In particular the discussion in section 8.2 applied the analysis schema proposed by Kinnula et al. to verify the achieved level of empowerment using several lenses/views (Kinnula et al., 2017a). Despite the designers intention was to fully empower the children, the process of empowering the children revealed to be a complex task (Iivari and Kinnula, 2018). The analysis highlighted that the children were not fully empowered in some of the views (e.g. children were empowered marginally according to the critical view). However, the results of the analysis highlight a significant improvement of the children empowerment in the latest study when compared with the previous two studies. The participation of the children was at the same level as the designers, enabling them to criticise the toolkit, manipulating it and editing its characteristics. The children in this situation will operate at a higher level of participation (in this case design partners), enabling them to express themselves through the toolkit.

The latest phase of the KPW process also enables the designers to verify the findings and the improvement derived by the technology in practice phase. The third case study presented in chapter 7 served as further verification of the toolkit characteristics. The results confirmed that the children were engaged in the process, they were able to exploit and modify the interaction behaviour of the BugBits set. They produced 28 game design ideas, developing 20 of them to the stage of medium-high fidelity prototypes. Their experience was in general positive and at the end of the workshop they were proud to show their creation to their parents, moreover some of them manifested their will to do the workshop again.

9.4. Conclusion

The KPW process aims at providing a high-level structure to inform the design of generative tools for participatory design activities with children, the KPW does not propose a novel approach to the design of tangible interfaces design, but it defines a model to helps the designers to balance the design processes and avoid arbitrary decisions. Furthermore, the process suggests following an incremental approach for the involvement and participation of children into the design process. The final goal of the KPW process is to achieve genuine participation aiming at making the children design partners. The KPW process suggests to include the children with a lower level of participation during the first two phases of the process (e.g. making children the users and testers of the tools) and involve the children with a higher level of participation during the last phase. This approach of passing through a more "controlled" level of children participation, enables the designers to change the design implementation aiming at answering specific aspects of the toolkit design space. Furthermore, these specialised instances help the designers to test the flexibility of the toolkit and at the same time fill the knowledge gaps in the children-technology relationship.

After the initial phases of exploration of the design space of the tool, covered in the first two phases of the process, researchers can move towards the highest level of participation knowing in advance how the children reacted and utilised the technology. The involvement of the children at higher levels of participation in the first phases of the KPW process could represent a valid approach to the design but can result in a complex and resource consuming task (Iivari et al., 2015; Iivari and Kinnula, 2016).

The first part of the process puts its basis on the previous works, frameworks and guidelines and does not impose a particular methodological approach to follow. For example, the BugBits was informed and inspired by the CTI framework, the Resnick guidelines on construction kits and the digital MIMs (Antle, 2007; Resnick and Silverman, 2005; Zuckerman et al., 2005). It aims at guiding the researchers to reflect on the TUI design space and the identification of a set of aspects and requirements that needs to be included in the toolkit. The process suggests looking with particular attention to the elements of the PACT analysis such as people, actions, context and technology as they are influencing the design space of the tools (Benyon et al., 2005; Preece et al., 2015). In particular, the technology element needs to be evaluated carefully as it does help the designers to cover the requirements, but strongly affect the ability of the tools to be flexible and open-ended.

TUI literature showed a large number of application of this interaction paradigm, but very few publications are considering and discussing the practicalities and limitations of the technological choices. For these reasons the central element of the KPW aims at filling and building a knowledge on how technology affects the behaviour of the users and the design space of the toolkit. The multiple instances proposed in the technology in practice are acting as technology probes and hence helping the designers to face the practical implications and limitations of the use of technologies in the real-world scenarios (Dittrich et al., 2002; Gaver et al., 1999; Hutchinson et al., 2003).

This emphasis about technologies does not aims at fostering a more “technology push” vision of the design process, but conversely make the researcher think more on their implementation choices without giving for granted that the technology will satisfy a priori the users and their needs.

Researchers can apply the KPW process and its structure to different purposes of design, by instantiating it on their specific objectives and requirements. The KPW process can adopt and integrate existing methodologies, frameworks and guidelines, rendering it a flexible tool that poses the designers to reflects about the issues of participation and the practicalities of the tools implementations.

The KPW elements and guidelines described in this chapter are flexible and wide enough to be adopted by other designers to develop different tools for participatory design with children.

10. CONCLUSION

Literature in HCI in the last years showed a growing interest about the children as primary users of technologies (Read et al., 2008). In particular, the tangible user interfaces were often adopted to implement new interactive systems for children in several domains (see chapter **Errore. L'origine riferimento non è stata trovata.**). The results found in literature about the efficacy and advantages of TUI over the more traditional interaction modalities are showing an unclear set of results that often are contradicting each other, rendering not clear the effectiveness of using TUIs (Marshall, 2007; Xie et al., 2008; Zuckerman and Gal-Oz, 2013).

This thesis explored the use of tangible interfaces with children to identify the key elements in the design of TUI based toolkits, with a particular attention to the children participations, their roles and the consequences of the practical implementation choices that often are not discussed in details in publications.

To reflect about these themes the author followed a research through design approach applying the design-in-use method (Dittrich et al., 2002; Zimmerman et al., 2007). Three case studies were conducted in order to develop a tangible-based toolkit set called BugBits (chapters 4 5 6 7). The processes of design of the case studies and the results enabled the author to reflect about the results and define a structured design process to inform the design process of tangible-based toolkits. The KPW process presented in this thesis, does not represent a complete solution to the complexities that are inherently present into the development of a TUI based tools for children. The KPW, however, offers a useful design perspective to foster the designers to reflect on the children participation and the practical aspects related to the implementations and limitations of these technologies.

10.1. Contribution

This thesis presented the development of BugBits, a toolkit for participatory design applications, the development of the tool is described in Chapter 4 and tested in three different case studies described in chapters 5 6 7. The results showed that the toolkit was accepted with enthusiasm by the children. In all case studies, children showed a high level of engagement, curiosity and participation. The first and second study demonstrated that the use of the toolkit, even in a different context, was useful for educational purposes. Furthermore, the three case studies highlighted the role of the design team and the need to include specific domain experts in the development of the various instances of the toolkit. The thesis offers a detailed description of the "BugBits" case studies and provides useful information to the research community. Practical design advices and reflections for each case study were summarised as a list at the end of each study (sections 5.5, 6.5 and 7.5).

This thesis aimed at answering the following research question and sub-questions (defined in Section 1.3):

RQ 1. *What are the critical elements of the design process of generative tools for empowering children in making new TUIs?*

- **RQ 1.1.** *Can BugBits be flexibly adapted to different interaction contexts?*
- **RQ 1.2.** *Can BugBits empower the children in participatory design activities?*

RQ 1

The studies presented in this thesis aimed at identifying the key design elements of TUI based toolkits for children. The identification of the key design elements is a complex task that requires a structured design process to inform the designers, supporting them to identify the design elements for their specific application. The thesis suggested a structured design process called KPW, presented in Chapter 9, the process is divided in three main steps that represent the critical step to consider during the design. The three steps "building **K**nowledge and limiting the design space", "technology in **P**ractice" and "**W**idening space and technology" were discussed in sections 9.1, 9.2, and 9.3. The KPW process grounds the exploration of the toolkit design space by fostering the designers to put the technology in the field to collect meaningful data from the children (Barker, 1965). Moreover, the process presented in this work is not the only solution to identify the key elements but highlights some of the crucial design dimensions to take in consideration. The KPW process starts with an initial phase of identification of the design space and requirements, suggesting to consider: technology, audience, context and actions. Furthermore, the initial phase promotes the inclusion of the guidelines and frameworks that could be found in the literature to inform and define the initial design space. The second phase of the process, the "technology in practice", aims at testing the flexibility of the toolkit by developing different instances, developed to cover a more limited design space. The technology in practice push the designers to test the tools across different contexts and purposes, thus each instance covers a different subset of the larger design space covered by the toolkit. This phase represents the critical and most important phase of the proposed process as it enables the designers to gather useful insights about the relationship between the toolkit and the children. The latest phase informed by the previous ones, aims at fostering the children participation empowering them to explore the full potentiality of the designed toolkit without imposing stringent limitations and enabling them to criticize it. This is in line with latest advances in CCI suggesting to reconcile developmental theories (illustrated in Chapter 2) with the design of new interactive tools.

RQ 1.1

The thesis aimed at designing a toolkit that could be adopted in different contexts. The studies presented in this work explored the BugBits toolkit in three different contexts. The solution taken by the author is discussed in Section 9.2. The design space of the tool defined in the first phase of KPW process should not be tailored to a specific application, so that the toolkit could be instantiated in different contexts during the "technology in practice" phase. This second phase aimed at the evaluation of the previous design choices, probing the toolkit under different contexts of use and following the design-in-use approach (Dittrich et al., 2002). This approach is not the only solution to evaluate the ability of a toolkit to be used in different contexts, but the author believes that testing the toolkit within an ecological setting enables the researchers to gather useful data and feedbacks that are representing the real interaction of the children with the technology (Barker, 1965; Gielen, 2008; Sluis-Thiescheffer et al., 2007). The studies presented in chapters 5 6 7 were using the same toolkit but exploring different context and purposes: the Museum study that used the BugBits to offer to the children (13-15 years old) a playful visit to the exhibitions, the kindergarten study that explored the BugBits as enhanced educational exercises with young children (3-6 years old) and the participatory design study that empowered the children (7-11 years old) in designing and making tangible-based games. The first two studies enabled the designers to focus on specific questions about the toolkit flexibility, while the third study explored the ability of the toolkit to be used to implement different artefacts in participatory design workshops with children.

RQ 1.2

The children's empowerment was one of the main objectives of the BugBits toolkit. In the latest study, the author followed the KPW process to develop the toolkit and a facilitated participatory workshop aiming to give the role of design partners to the children (Druin, 2002; Read et al., 2002). The whole process described in Chapter 9 aims at developing a toolkit that could be used with success in participatory design workshops.

In particular, the first two phases were informative about children's behaviour with the technology in real-world settings. Furthermore, these preliminary steps were designed to involve the children with a low level of participation and to facilitate the process of data collection. In particular, they aimed at evaluating the accessibility of the toolkit and identifying the elements that could be improved. The author believes that including the children with a crescent level of participation in the case studies was a good approach to accelerate the data collection and to decrease the difficulties of identifying the toolkit problems during participatory design workshop. The author used the analysis of the children roles and empowerment proposed by Kinnula et al. to evaluate how the studies empowered the children through the process (Kinnula et al., 2017a). This analysis served as a tool to highlight where the design should focus to improve the children empowerment and participation in the further phases of the design. While the approach followed in the studies improved the participation and the empowerment of the children, achieving a genuine participation as design partner, protagonist resulted to be a complex task (Iivari and Kinnula, 2018). The proposed process that follows an approach of incremental refinement of the tools enabling the designers to tune their design, of the toolkit and the activities, and gather data on the field to achieve higher empowerment of the children.

The reflections about the design processes and their description highlighted the strengths and limitations of the implementation choices on the design. The design process highlighted also the necessity to test the technology in the field and the process through which the gradual increase of children's participation in the design phases lead to an artefact that was successfully adopted and well accepted by the children.

Finally, this thesis contributes to the definition of the KPW process and the BugBits toolkit. The process offers a new way to plan the design of TUI based toolkits for children, with a particular focus on their participation and empowerment. The process relies on the previous TUI theories but offers a new perspective to look at. The central part of the KPW process stresses the necessity to test the technologies in an ecological setting and helps the designers to investigate the effects and the implications of the implementation choices and the strategies to cope with the complexities of the design.

10.2. Limitations

The author encountered a series of limitations during the work. One of the main limitations regarded the collection of data when working with young children. In particular, the ethical committee did not approve the use of video recordings inside schools, kindergarten or pictures containing the young children. The first case study presented the same limitation, inside the museum rooms it was not allowed any form of video recording. This limitation imposed to rely mainly on structured observation data, questionnaires and interviews. The availability of video recordings would have enabled a much deeper level of analysis of the behaviours and the relationships between children and technology. The design team was composed by the same people that conducted the three case studies on the field, is both an advantage and disadvantage because they knew well how to deal with the system issues but at the same, it could hide possible flaws.

It revealed to be challenging to manage the special time requirements of some classrooms during the first case study. In these few cases the researchers tried to make the children have a full experience of the workshop but with less time at disposition for the activities. For these reasons questionnaire data were not present for all the workshop sessions and not considered in the analysis presented in this thesis.

During the kindergarten study, the researchers needed to adjust the exercise difficulty to adapt to the children capabilities hence forcing them to considers those changes in the analysis. All of those activities were programmed in advance and dealt with the participant time availability. The limited time of the children sometimes led to the concentration of the sessions into very short periods. This strict schedule of the experimental activities forced the researchers to address the possible problems with quick fixes. Even if the ability to find the solutions rapidly highlighted the flexibility of the toolkit but having some more time between the sessions could have led to more efficient and robust solutions (for example having a louder audio feedback system).

The choice of having an increasing participation approach to the design of the toolkit could have limited the amount the information and consequent reflection coming from the toolkit instances studies. The roles of designers and researchers were twofold during the workshops they covered multiple roles such as facilitators, mediators, observers. This multi-tasking nature of the researchers and designers could have limited sometimes the amount of data collected, for example when all of the researchers were occupied in following the children's requests. For this reason, sometimes, the observations were annotated immediately after the activities.

10.3. Future works

The limitations and issues found during and after the case studies are suggesting to adopt several changes in the design process. The application of the KPW process in a completely different context and with different purposes will help the consolidation of the elements of the process and their definitions. The experimental design of the workshop could be planned to have longer intervals between sessions of each of the instances. Having long intervals between the sessions could enable a detailed preliminary data analysis with the identification of the most critical and relevant elements in each session. This approach will allow the designers to apply the technology in practice phases across the sessions, speeding up the development of the toolkit.

The hardware implementation of BugBits followed the idea of keeping the technology as accessible and explicit as possible, this approach revealed to be a relevant element to stimulate the children curiosity but had the drawback of being a more fragile system when compared to the commercial products. For these reasons a good design direction could be a comparative study between a version with less explicit hardware and one like the one shown in this thesis, this approach will clarify the effects of the technology appearance on children behaviours and actions.

The latest study showed how the children were trying to expand their creativity in designing complex interactive systems with multiple toolkits and sensors. This suggest to develop a form of communication between the sets to enabling an easy implementation interactive and complex behaviours across multiple artefacts. A preliminary exploration of the interest of school teachers and electronics hobbyists at the Rome Maker Faire suggested testing the BugBits as in the latest study as a school extracurricular activity and as a playful individual activity for children. An interview about the first case study and the use of the toolkit for educational purposes is available at the following URL: http://www.appyourschool.eu/bugbits-and-soundscapes/. These suggestions also highlighted the possibility to develop a managing interface to define of the desired behaviour without the use of the code. By doing so, the children could be more empowered and independent in their design choices. For these reasons the BugBits set could be extended in future developing it in a more structured construction kit platform. A preliminary exploration of this evolution was explored by participating to the FabLab2Industry program promoted by the FablabNet Interreg Central Europe. The program aims at the formation and development of innovative projects investigating the opportunities offered by the smart manufacturing and the industry 4.0 (https://www.ufficiostampa.provincia.tn.it/Comunicati/FABLAB2INDUSTRY-dal-prototipo-all-industria).

10.4. Final remarks

This thesis presented the process of creation of a TUI toolkit and its application in three different contexts. The author believes that the reflections and the practical issues exposed in this thesis could be a useful starting point for the similar researches.

The design processes followed by the author highlighted how the practical issues and implementation decisions affected the design of the toolkit, and how some limitations revealed to be useful elements for the design of the workshop activities.

The author strongly believes that the KPW process presented in this thesis could help the designers to instantiate a better design process and support them to reason about the children's role and participation in the process. Furthermore, this thesis and the "technology in practice" phase of the KPW process aims at making the designers reflect more on the implications caused by the implementation choices.

The author covered multiple roles in the design of the BugBits toolkit starting from the designer to the developer of the hardware and software parts of the toolkit. This multidisciplinarity speeded up the process of development but at the same time limited the design space to the expertise and knowledge of the author. Other researchers may consider involving multiple domain experts to accomplish those tasks, increasing the size of the designing team, and at the same time considering more possibilities. Furthermore, the involvement of the domain experts was crucial to expand the design space and include and evaluate different perspectives in the design process. In fact, in this thesis, the contribution of the educator and the game designers were fundamental to design a toolkit that was well accepted by the children.

The research presented in this thesis should not be considered as a definitive solution to the design of toolkits for designing TUIs with children, but a useful set of insights and new perspectives to take in account and discuss while these tools.

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APPENDIX

Figure 28: A set of BugBits pyramids developed by children.

The figure represent the artefacts at the end of the exploration phase of the first case study workshop.

Figure 29: The Bugbits at the Makerfaire in Rome December 2017.

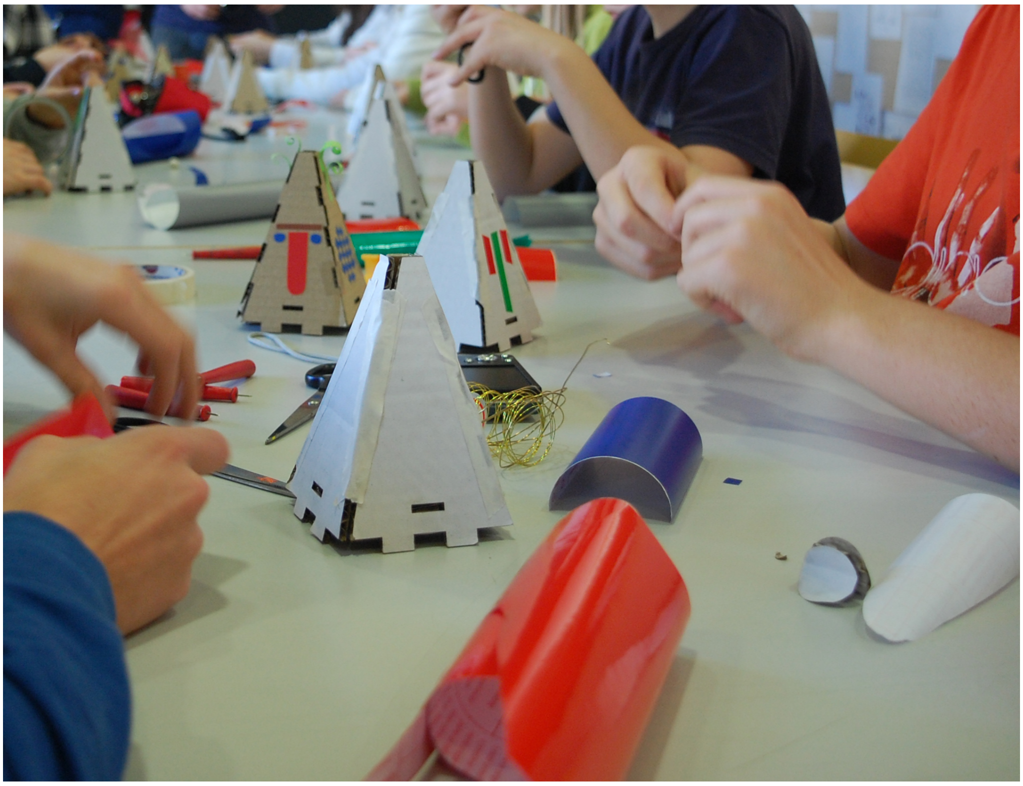
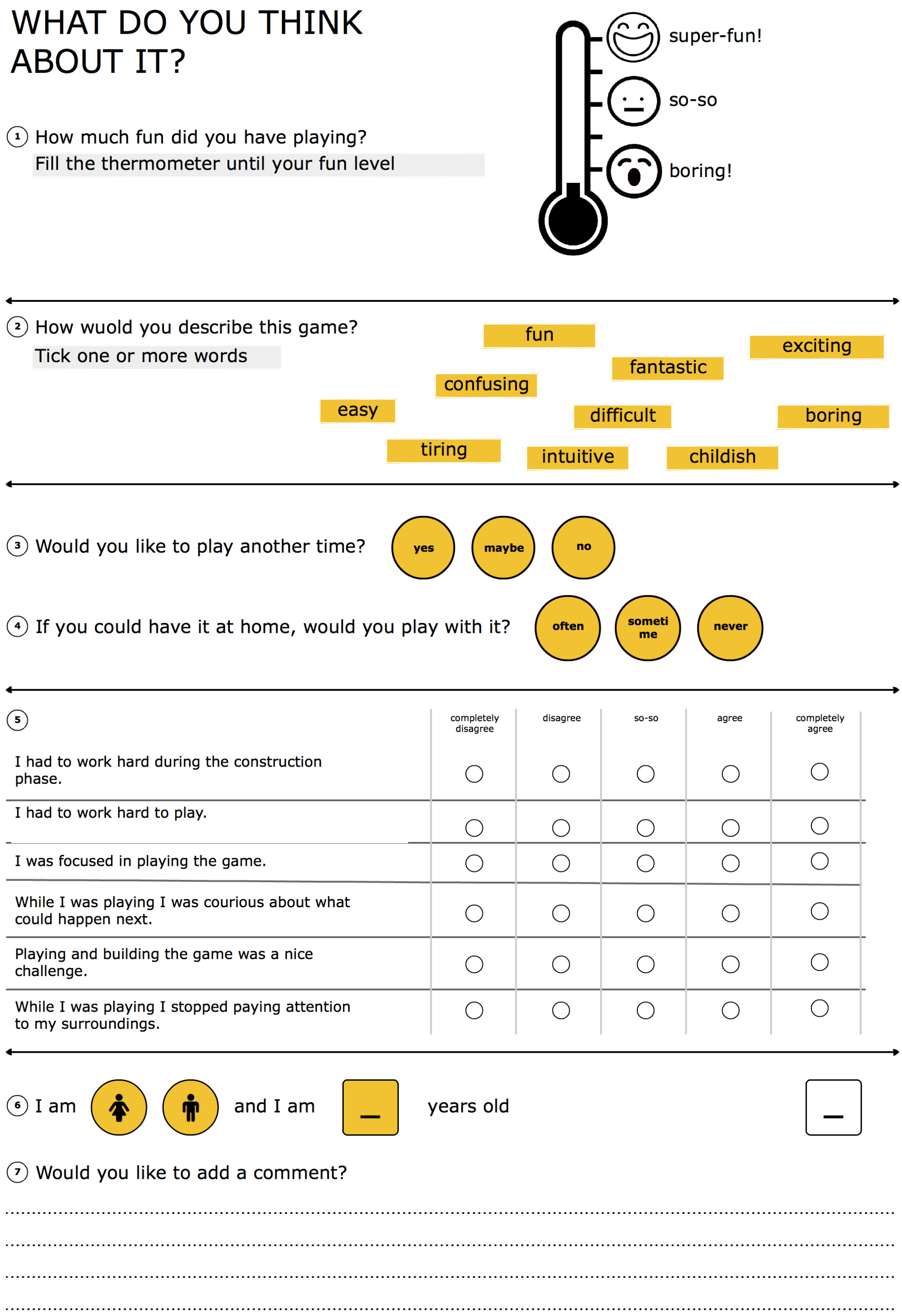


Figure 30: The artefacts during the customisation phase of the first study.

Figure 31: Some of the finished artefacts built by the children during the third study.



WHAT DO YOU THINK ABOUT IT?

1. How much fun did you have playing?
Fill the thermometer until your fun level

super-fun!
so-so
boring!

2. How wuold you describe this game?
Tick one or more words

fun
exciting
fantastic
confusing
easy
difficult
boring
tiring
intuitive
childish

3. Would you like to play another time? yes maybe no

4. If you could have it at home, would you play with it? often someti me never

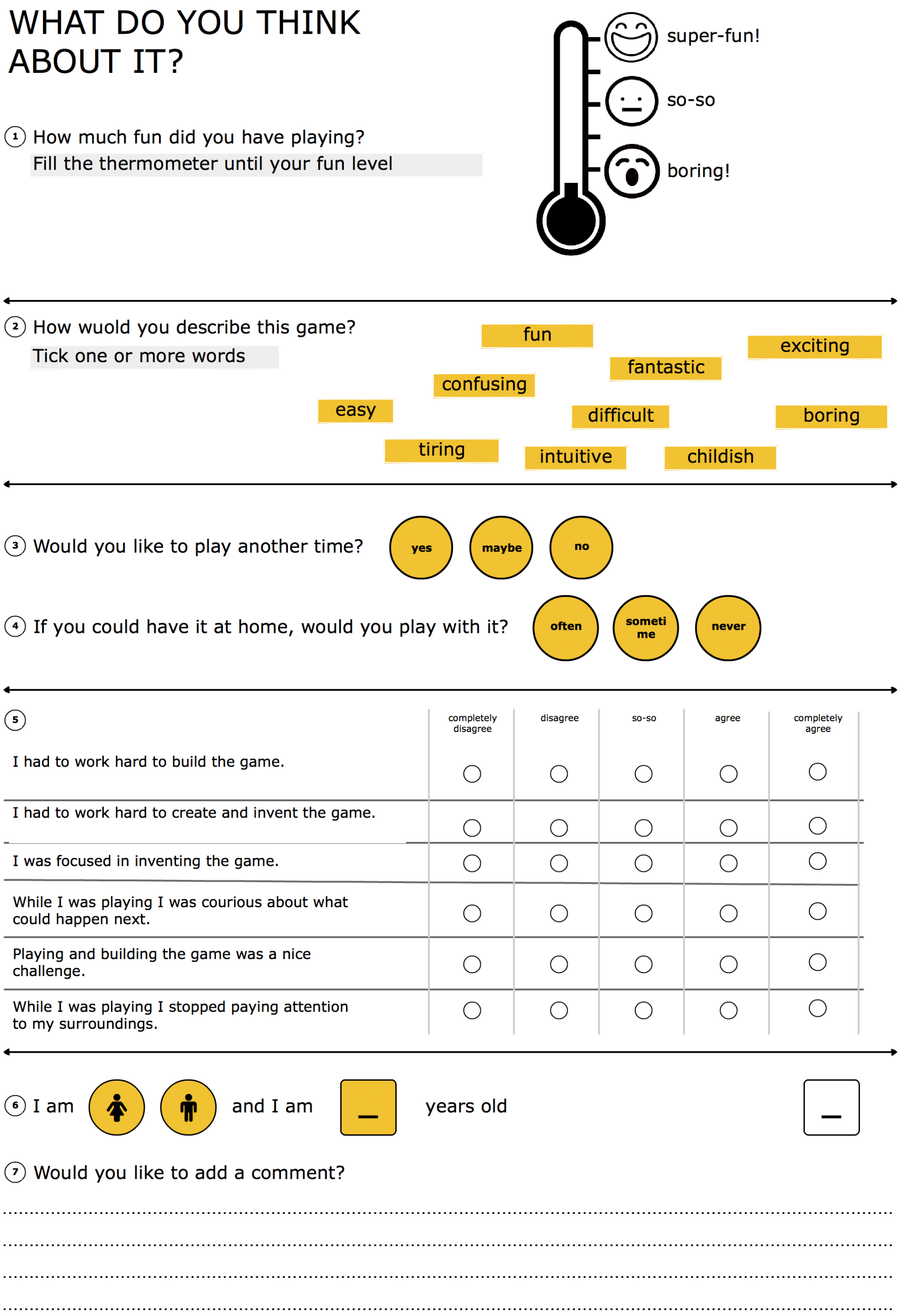
5.

	completely disagree	disagree	so-so	agree	completely agree
I had to work hard during the construction phase.	○	○	○	○	○
I had to work hard to play.	○	○	○	○	○
I was focused in playing the game.	○	○	○	○	○
While I was playing I was courious about what could happen next.	○	○	○	○	○
Playing and building the game was a nice challenge.	○	○	○	○	○
While I was playing I stopped paying attention to my surroundings.	○	○	○	○	○

6. I am and I am _ years old _

7. Would you like to add a comment?

Figure 32: eSFQ-based questionnaire used in the first study (translated in English).



WHAT DO YOU THINK ABOUT IT?

1 How much fun did you have playing?
Fill the thermometer until your fun level

super-fun!
so-so
boring!

2 How wuold you describe this game?
Tick one or more words

fun
exciting
fantastic
confusing
easy
difficult
boring
tiring
intuitive
childish

3 Would you like to play another time?
yes
maybe
no

4 If you could have it at home, would you play with it?
often
someti me
never

5

	completely disagree	disagree	so-so	agree	completely agree
I had to work hard to build the game.	○	○	○	○	○
I had to work hard to create and invent the game.	○	○	○	○	○
I was focused in inventing the game.	○	○	○	○	○
While I was playing I was courious about what could happen next.	○	○	○	○	○
Playing and building the game was a nice challenge.	○	○	○	○	○
While I was playing I stopped paying attention to my surroundings.	○	○	○	○	○

6 I am and I am _ years old _

7 Would you like to add a comment?

....

....

....

....

Figure 33: eSFQ-based questionnaire used in the third study (translated in English).