Universidade do Minho
Escola de Engenharia

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TUIs vs. GUIs: Comparing the Learning Benefits for Kindergarten Children

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Professor Doutor Pedro Sérgio Oliveira Branco
Professora Doutora Clara Maria Gil Pereira Coutinho

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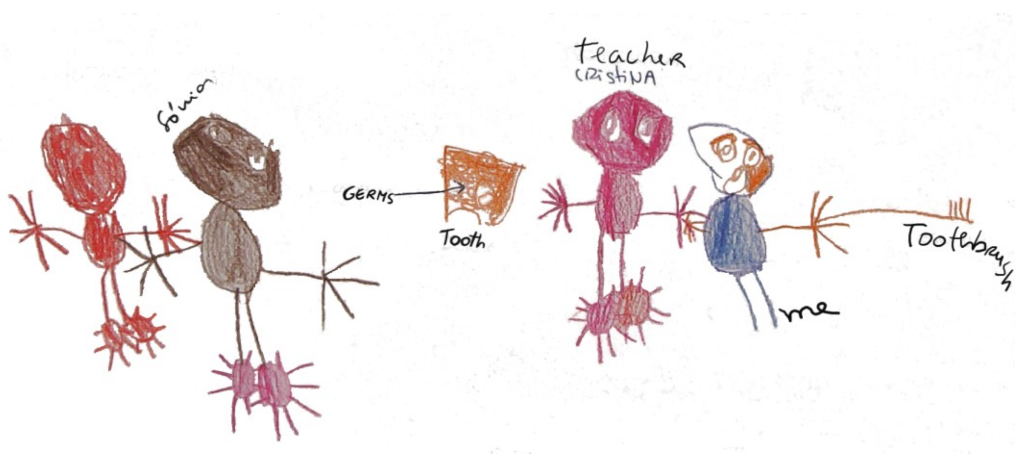
Sónia
GERMS
Tooth
Teacher
CRISTINA
Toothbrush
me

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ABSTRACT

In recent years numerous examples of tangible interfaces have been developed targeting the educational domain, however their impact on learning is not clear when compared to educational software based on a graphical user interface. Most evaluation studies on the benefits of tangible interfaces for learning are rather informal and there are very few empirical studies comparing tangible and graphical interfaces. The evaluation methodology of technology for very young children, 4 to 5 years old, poses some additional challenges given their limited ability of verbal or written expression; the majority of assessment methods are generally suitable for use with older children.

In an effort to better understand the learning impact of a tangible interface we conducted a comparison study between a tangible and a graphical user interface for teaching kindergarten children about good oral hygiene. The study was carried with two groups of children aged 4 to 5 years. Questionnaires to parents, children drawings' and interviews were used for data collection and analysis, and revealed important indicators about children's involvement and preferences on the interfaces. The questionnaires showed a remarkable change of attitude towards tooth brushing for the children that interacted with the tangible interface; particularly children's motivation increased significantly. Children drawings' were used to assess children's degree of involvement with the interfaces. The drawings from the children that interacted with the tangible interface were very complete and detailed suggesting that children felt actively involved with the experience.

Regarding the methodology used, drawing intervention seems to be a promising method to work with pre-literate children; however it is advisable to use it together with other methods, since the evaluation of drawings is rather subjective and can depend on various internal and external factors. The results suggest that the tangible interface was capable of a stronger engagement and impact on children.

RESUMO

Nos últimos anos têm sido desenvolvidos inúmeros exemplos de interfaces tangíveis visando o domínio educativo; no entanto o seu impacto na aprendizagem não é ainda claro quando comparado com software educativo baseado em interfaces gráficas. Os estudos comparativos sobre os benefícios da utilização das interfaces tangíveis versus interfaces gráficas são quase inexistentes, sendo que a maioria é bastante informal. A metodologia de avaliação com crianças dos 4 aos 5 anos de idade coloca desafios adicionais devido à sua limitada capacidade de expressão verbal e escrita; para além disso grande parte dos métodos de avaliação é geralmente adequada a crianças mais velhas.

Com o intuito de compreender melhor o impacto das interfaces tangíveis na aprendizagem, foi realizado um estudo comparativo entre uma interface tangível e uma interface gráfica, desenvolvidas com o intuito de sensibilizar as crianças para uma boa higiene oral. O estudo foi realizado com dois grupos de crianças com idades compreendidas entre os 4 e os 5 anos.

A recolha e análise de dados foi realizada através de questionários distribuídos aos pais das crianças, desenhos feitos pelas crianças após a sua interacção com as interfaces, assim como entrevistas; revelando-se indicadores importantes sobre a experiência das crianças e as suas preferências acerca das interfaces. Os questionários mostraram uma mudança notável de atitude em relação à lavagem dos dentes, no grupo de crianças que interagiu com a interface tangível; particularmente a motivação aumentou significativamente. Os desenhos do grupo de crianças referido revelaram-se muito detalhados e completos sugerindo que as crianças se sentiram activamente envolvidas na experiência.

Relativamente à metodologia utilizada, a análise dos desenhos mostrou ser um método promissor para trabalhar com crianças desta faixa etária, no entanto, é aconselhável utilizá-lo juntamente com outros métodos, dado que a interpretação dos desenhos é bastante subjectiva podendo depender de vários factores internos e externos. Os resultados do estudo sugerem que a interface tangível possibilita um envolvimento mais forte das crianças.

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CHAPTER 1 *Introduction*

1.1 MOTIVATION

Tangible interfaces, a new paradigm of interaction with digital information, free users from keyboards, mouse and displays; instead the users interact with physical objects as interfaces to computer systems and software. While this area has evolved as a field of research exploring a new paradigm in human-computer interaction, technology development and its low cost, has allowed the first steps in the integration of such technology in the process of education. This new systems are less machine-centered, instead more user and task-centered, thus offering new opportunities for different types of public to interact with digital contents, which is especially relevant for young children. The interaction with digital information through direct manipulation, allows children to simulate and create new experiences and perception of the world; thus providing children from an early age a more experimental, participatory, and active involvement with a wide range of learning contents.

1.2 APPROACH

In the field of education, tangible interfaces open new opportunities for making abstract contents graspable and perhaps more understandable for children (Zuckerman, Arida and Resnick 2005). Numerous examples of tangible interfaces have been developed in recent years targeting the educational domain, despite those developments it is not clear their impact on learning when compared to educational software employing the traditional graphical user interfaces (Marshall 2007). In order to meet this issue we conducted a comparison study between a tangible and a graphical

user interface, for teaching children about oral hygiene. The research was conducted with two groups of kindergarten children aged 4 to 5 years.
To better understand the learning impact of the tangible interface we started by developing two similar interfaces one being a tangible and the other a graphical one, for teaching kindergarten children about good oral hygiene. Given that children at this age still lack the ability to clearly express their thoughts and impressions about their experiences, three different methodologies were used for data collection and analysis. First children's attitudes towards tooth brushing were assessed by asking their parents to answer a questionnaire. In order to evaluate if there were any changes in children's attitudes towards tooth brushing, some weeks after the interaction with the interfaces the parents were asked again to fulfill a similar questionnaire. Children's drawings were used after the interaction to assess their degree of involvement with the interfaces and finally the children were interviewed about their preferences.

1.3 SUMMARY OF CONTRIBUITIONS

Usability studies with young children are still a wide research field. Especially studies conducted with children between 4 and 5 years of age are infrequent, and most methods used with children are not suitable to assess children's opinion at this age group. In addition, there are very few empirical studies comparing tangible and graphical interfaces (Fails et al. 2005), the study presented here intents to be a contribution in this area. Drawing Intervention, one of the methods used in this study, is an innovative approach to young children's technology evaluation that consists of asking the children to make a drawing of their experience after interacting with the technology. It seems to be a promising method to work with pre-literate children. The Child Computer Interaction group (ChiCI group) also published studies applying this methodology, as far as we know, they were carried with children older than 4 years of age.

The result of this research suggests that tangible interfaces provide children a richer and more involving experience than traditional graphical interfaces with consequent impact on learning.

1.4 THESIS ORGANISATION

The content of the remaining chapters are summarized below.

Chapter 2 presents Luquet's Drawing Stage Theory, and Lowenfel'd Theory of Artistic Development, discussing how children's development is reflected in their visual representations. That theory supports the development of the Drawing Intervention method used.

Chapter 3 discusses the use of educational interfaces and gives an overview of tangible educational interfaces developed for children.

Chapter 4 presents an overview of different usability methods used to access children's opinions about technology.

Chapter 5 presents a comparative study between a GUI and a TUI for teaching children about oral hygiene.

Chapter 6 discusses the conclusions of the research, and future work.

CHAPTER 2 *Drawing and cognitive development*

> Children's drawings are frequently the result of combinations of different types of knowledge encoded in systems about which we still know little.
> —— Matthews 2003:211-12.

2.1 INTRODUCTION

In this chapter we will discuss the pioneering work of Georges Luquet, his theory of children's Drawing Stages; Lowenfeld's Stages in Artistic Development; as well as more recent research such as the work of Eduarda Coquet, and John Matthews. This discussion is relevant for the analysis of the drawings which is one of the evaluation methodologies used. The methodology will be presented later in Chapter 5.

The first studies of children's drawings were published in the last two decades of the 19th century. Georges - Henri Luquet is the author of one of the first and most influential works, whose theories still continue to influence psychologists and educators today. Luquet's (1927) extremely thorough and detailed longitudinal studies of children's drawings were based on the analyses of over 1700 drawings made by his daughter Simone from the age of 3 years that he collected over a period of ten years.

Lowenfeld was a Viennese art educator; in 1938 he came to America, becoming prominent with the publication of *Creative and Mental Growth* (1947), which became an influential text book in American Art Education. His concepts are still influent, specially his visual-haptic theory (Smith 1989, Matthews 2003). In this work we will refer to the 6th edition of *Creative and Mental Growth*, an influential book where Lowenfeld's theories were updated, including actualized research and its implications, at the time of the publication (Lowenfeld and Brittain 1975).

Coquet has realized a detailed study on the forms of representation that children use to represent graphic narratives. In the whole her study analyses 1461 drawings from 4 to 11 years old children (Coquet 1995, 2005).
Matthews is an artist and an art educator. He realized longitudinal studies over a period of over 10 years of his children's and latter his grandchildren's drawings, as well as studies realized with English and Asian kindergarten children. His work provides valuable information about young children visual representations, taking in account psychomotor, aesthetic and cognitive aspects of drawing development.

2.2 THE STAGE THEORY

A central aspect of Luquet's work is the Stage Theory. These classification is closely related to Piaget's stages of cognitive development[1] (Piaget 1959), being an indicator of the overall development of the children, not only of their art.
Luquet (1927) considered four different drawing stages: *Fortuitous Realism,* from 2 to 4; *Failed Realism*, from 4 to 7; *Intellectual Realism*, from 7 to 9; and *Visual Realism*, beginning at 9 years of age.
The author considered that the boundaries between the different stages were not static and would vary from child to child.
Lowenfeld considered that there is a progression throughout children's drawing development but it is difficult to say when one stage ends and the other begins. He identified six stages in artistic development: the *Scribbling Stage,* from about 2 until 4; the *Preschematic Stage,* from 4 to 7; the *Schematic Stage* from 7 to 9; the stage of *Dawning Realism* from about 9 to 12; the *Pseudo-Naturalistic Stage*, from 12 to 14 and the *Period of Decision* during adolescence.

[1] Piaget calls the first developmental stage the Sensory-motor stage, ranging from birth to two years of age, with little or no capacity for symbolic representation; it follows the Preoperational stage that goes until about seven, characterized by the development of language, symbolic thought and self-centeredness. The stage of concrete operations goes from seven to eleven, in this period children can think logically but not abstractly. This is followed by the stage of Formal operations.

Lowenfeld defines Stages as *typical midpoints* of child's development, *fusing* into one another as children reorganize their thinking competences and develop new relationships with the world around them, indicating the general characteristics of the children at a certain period of their lives (Lowenfeld and Brittain 1975:50).

Matthews, on the other hand, defends that there are no stages in children's drawing development; he sees it as a dynamic continuum process which undergoes transformations that are closed linked to *co-operating, perceptual, and motor systems*.

Unlike the idea that the observation of the environment is reflected in the drawings, Matthews argues that children start to notice shapes in their environment because they first found them in their drawings. "In a real sense, visual reality takes shape on the drawing surface." (Matthews 2003: 109).

2.2.1 THE BEGINNING OF DRAWING

Children's drawings are *unique, personal, visual languages* (Matthews 2003:152). At about two years of age and until four, children begin to experiment the materials and explore their body motion, making random marks on paper; with time children gradually gain control over their scribbles and these become more and more organized. Lowenfeld calls this period *Scribbling Stage.* According to Luquet's terminology it is the period of *Fortuitous Realism*, since he believed to be by accident that the children looking at their random marks noticed a resemblance to something real; for instance a circle would become a head. Matthews sees all children's *mark-making* as intentional, being the result of complex representational and expressive modes; by watching the lines and shapes they have drawn children discover new ways of representation. With time this *mark-making* develops to marking strategies that although reflecting natural movements of children's body, cannot be seen as just *thoughtless, mechanical movements* (Matthews 2003:89).

2.2.2 THE FIRST REPRESENTATIONS

The period, when children begin consciously to draw forms that have a relationship to their environment, marks the beginning of *graphic communication* (Lowenfeld and Brittain 1975:155).

According to Lowenfeld's terminology children's second drawing stage is called the *Preschematic*; it starts at about four years of age and goes until around 7. We will present this stage in more detail, as it is the stage where the children addressed in our research are included.

It is during this period that children make the first attempts to represent their environment, consciously creating forms that have a relationship to the world around them; their drawings reflect how children perceive the reality. Lowenfeld sees drawing as a process that children use to signify and reconstruct the world around them. This exploration of the environment has a strong sensory component. The way children represent things show how they understand them, and that changes with time as they become more aware of the world around them:

> *Perception* means more than just the awareness of the visual appearance of objects; it includes the use of all the senses, such as kinesthetic or auditory experiences.
> —— Lowenfeld and Brittain 1975:168.

> The more involved the child becomes in the art activity, the more he identifies with what he is doing, the more he is actively using his senses, the more the project is really his own, the more meaning it has for him.
> —— Lowenfeld and Brittain 1975:176.

Luquet called this period *Failed Realism*, since children's representations in this stage do not correspond to the way objects look like in reality. This designation goes back to his differentiation between the way adults and children perceive the reality. Luquet speaks of *adult* and *children realism.* For the children *realism* means that the drawing contains all the elements of the object, even the invisible ones, he calls this form of representation *intellectual realism*. For the adult, realism, means that the object is represented in perspective and what is visible depends on the viewpoint, Luquet calls this *visual realism*.

According to the author children's *intellectual realism* is the result of an *internal model* that they have of the objects they represent. Children do not see the same details as an adult; they see them only to the extent that they interest them (Luquet 1927:94). Since children have a great power of abstraction, what does not matter for them is as if it would not exist; thus what children draw had a preponderant weight in their mind:

> the represented object is one that at the moment of the representation occupied an exclusive or preponderant place in the mind of the drawer[2].
> —— Luquet 1927:17.

Children do not draw the details that they find unnecessary or secondary, but they tend to draw all the details even the invisible ones if they believe that these are essential for the representation of the object (for instance, the child draws the head underneath the hat) (Luquet 1927:98).

Matthews considers that children are not interested in realistic representation, since it would interfere with their conception of the structure and characteristics of the object (Matthews 2003:97).

Lowenfeld shares the same view, unlike adults, children do not want to copy their environment, not for lack of ability but because they seem to be satisfied with the way they represent these objects. Instead their drawings show the way children understand the world around them. What children draw at this age is always in relation to them, since at this stage they are very self-centered and understand the world in terms of themselves (Piaget 1959). This means that drawing is much more involving than a mere visual representation, the children themselves become *involved* in their drawings, being at the same time a *spectator and an actor* (Lowenfeld and Brittain 1975:51).

According to the authors the first representation is usually a human figure, apparently the representation of the child them self. This first representations of the human figure is reduced to the head and legs; the head is where eating and speaking takes place (Lowenfeld and Brittain 1975:156) it is where the sense of sight, hearing, and tasting are located[3]; the legs on

[2] Translated from the original by the author.

[3] Piaget (1960) found that some 6 years old children though that thinking occurs in the mouth.

the other hand allow locomotion, being a factor of gained independence (Coquet 1995:91). These first representations should not be seen as immature *since they are an abstraction from complex stimuli and an indicator of an ordered thought progress* (Lowenfeld and Brittain 1975:157).

As children go older their drawings continue to change, according to their priorities. As already mentioned, we shall not dwell on these stages since they fall outside the scope of our investigation. We will just briefly summarize their characteristics. According to the Stage theory by the age of 7 and until around 9 children enter the third stage, characterized by *intellectual realism* in Luquet's terminology. Lowenfeld calls this the *Schematic stage*; it is when children develop a definite form concept; using their drawings in a descriptive way to represent the environment. At this stage the objects are represented in a row across the bottom of the page (Lowenfeld and Brittain 1975:48).

Luquet's fourth and last stage from 9 years of age is called *visual realism;* it is when children are able to reach realistic representations of objects. Lowenfeld calls this stage *Dawning Realism*, going 9 nine to about 11 years of age. At this stage the drawings still symbolize more than represent the objects but they are more detailed and no longer placed in a row at the bottom of the page. Lowenfeld's stages in artistic development include two additional stages: the Pseudo- naturalistic Stage, from 12 to 14; and the Period of decision during adolescence.

2.2.3 SPACE IN THE PRESCHEMATIC STAGE (4-7)

Children's notion of space is very different from the one of an adult and that is reflected in children's drawings. At this stage of development children are self-centered, they conceive space in relation to themselves and their own body, as of *revolving* around the child; they do not yet establish relationships between the objects (Lowenfeld and Brittain1975:161). Children draw everything that is part of their experience, and what is open to their perception (Luquet 1927:15-16). The importance that children give to the details of a particular object often depends on the importance they attach to their role and their function (Luquet 1927:99); this importance given to the details determines the place that they have in the drawing:

> the child does not see the same details as an adult: better, his eyes see them, but his mind only understands them to the extent that they interest him and in proportion to the importance that he attributes to them.
> The relative importance given by the child to the different elements of an object determines the place that they occupy in his drawings[4].
> —— Luquet 1927:94.

Sometimes the exaggeration of a detail reflects the importance it has for the children. Children's drawings are the result of their decisions about which information should go in their representations, and these priorities change with age and the context (Matthews 2003:162).

2.2.4 THE USE OF COLOUR IN THE PRESCHEMATIC STAGE (4-7)

According to Luquet, children can use color in a realistic way or completely random and that can occur separately or in the same draw.
Lowenfeld points out that the use of color often has little relationship with the drawn objects; it may be influenced by psychological reasons and personal preferences. Children can choose their favorite color to color things or persons that they like, independently of the real color of the things they represent. The choice of a color can also have practical reasons, maybe the children choose the pencils that are better sharpened, or a new one, or they may prefer thicker pencils because they are easier to handle, and so on...
Lawler and Lawler [5](1965) carried a study with kindergarten children of 4 years of age. The children choose yellow to color a happy picture, and they colored the same picture brown after having heard a sad story about it. Children's psychological reasons and individual preferences make it difficult to interpret their color choices.

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[4] Tranlated from the original by the author.
[5] In: Lowenfeld and Brittain (1975).

2.3. DRAWING AS A NARRATIVE PROCESS

Luquet identified 3 distinct forms that children use to narrate an event through drawing: the *Symbolic type*, the *Epinal type* and the *Successive type*. In the *Symbolic type* the children draw a single moment from a story, the one that they probably consider the most important and it stands as a *symbol* of the entire story. This form of narrative is widely used among children, especially among children under 7 years of age. Children's potential retention of the narrative is very short, thus they represent only the action or the moment that most impressed them (Coquet 2000:36). Coquet calls this type of representation *single image*, although the child represents only a *single* image she considers that it is not always *symbolic* (Coquet 2000:52). The *single image* is defined by the author as any drawn image that relates a single moment of the narrative. This representation can be complete, including all elements and characters of a narrative moment. It can also be *synthetic*, representing only certain elements or characters in a narrative moment (Coquet 2000:54). In the *single image*:

> the child *clarifies*, at once, the reader, about what seems to her to be the moment or the set of elements most important of the story to retain.
> —— Coquet 2000:207.

The author concluded that most children under 7 years of age focus their representations at the *initial moment* of the story.
In the *Epinal type,* used by older children, the story is represented by several images each one corresponding to a different moment in the story.
In the *Successive type* the child brings together different moments of the story (*Epinal*) in a single drawing (*Symbolic*).

To conclude we can say that children's drawings represent the way they understand the word around them; this is not just a visual process, but it includes all their senses. As we have seen children draw everything that is part of their experience and open to their perception. Children's drawings are the result of a close connection between emotion and reality. Children do not draw what they see; instead they draw what they know that exists and want to transmit. The importance that children give to the different elements in their drawings has to do with personal and individual criteria that children mentally build, whereby affectivity and emotion are the main factors (Coquet 1995).

Evaluation through drawing seems to be an appropriate method, to evaluate children's experience with the interfaces. Drawings are much more than just a visual representation, the children themselves become *involved* in their drawings, being simultaneously *a spectator and an actor* (Lowenfeld and Brittain 1975). Given the previous points we can say that the drawings that children do after the interaction with the interfaces provide important information about the impact that the interfaces had on them. An information that children would otherwise have difficulty in transmitting since, at this age, children are still not able to express themselves through writing, and they still have some limitations in expressing their thoughts through words.

CHAPTER 3 *Physical educational interfaces*

3.1 GIFTS AS A FIRST APPROACH TO TANGIBLE INTERFACES

The importance of using physical objects for the development of the child has been extensively studied. Papert (1980) calls for a new perspective in education research focused on creating the conditions under which intellectual models can take root.

One of the first innovative pedagogical approaches with manipulatives was carried by Friedrich Froebel who created the world´s first kindergarten 1837 in Germany. Froebel developed a collection of 20 physical objects, such as balls, strings, sticks and blocks, called *gifts*. The *gifts* allowed children to create forms which can be found in nature and in their daily lives and were used to help teaching arithmetic, geometry and reading (Brosterman 1997). Each *gift* was designed with the purpose of making the concept accessible and capable of being manipulated by the children.

Maria Montessori developed Froebel's *gifts* and created materials for older children; based on that approach she develop a pedagogical teaching method called *Montessori Method* (Montessori 1912). This method, where manipulatives play a central role, has inspired a network of schools spread over the world.

3.2 LEARNING WITH DIGITAL TANGIBLE INTERFACES

Tangible Interfaces, a new paradigm of interaction with digital information, employ physical objects, surfaces, and spaces as tangible embodiments of digital information (Ishii and Ullmer 1997). In an educational context they are also called Digital Manipulatives, a new generation of computationally enhanced manipulative materials that enable children to interact with digital information (Resnick et al. 1998). In the following, both terms will be used referring to the same kind of interaction with digital information. Tangible interfaces pretend to be simple to use and facilitate the understanding of many complex processes. They go back to the notion of Froebel´s *gifts* taking advantage of the technology; allowing for richer experiences to be developed, expanding the range of concepts that children can understand and dramatically improving accessibility to younger children (Zuckerman, Arida and Resnick 2005). Resnick compares the interfaces developed by his research group, such as Mindstorms and Crickets, to Froebel's Gifts of the 21st century (Resnick 2007).

The pedagogical theories supporting the use of tangible interfaces are provided by a constructionist view of education. An approach supported by Seymour Papert (1980) who sees the child as a constructor. Learning is not a simple matter of transmitting information, but rather an active process, where children build knowledge through learning by doing and by direct, immediate and concrete experiences.

According to constructivism children need materials to explore the world around them in order to construct knowledge. Papert compares the children to builders that, like all builders, need materials for their mental constructions. Therefore the vital importance of the learning tools, because children, as builders, do not build out of nothing. It is only by interacting with the objects that they build their knowledge, and it is this interaction that allows children to internalize knowledge. Papert refers many of the learning difficulties' to the lack of suitable materials that make the concept simple and concrete and therefore *meaningful*.

One of the characteristics of tangible interfaces is precisely that they make abstract concepts concrete and simple; they promote team work, communication and exchange of experiences, as well as stimulating sensory perception such as touch, sight and hearing, thus facilitating content retention (Zuckerman, Arida and Resnick 2005). Traditional educational materials such as Cuisenaire Rods[6] and Pattern Blocks are used in

[6] Cuisenaire Rods, were named after his creator, George Cuisenaire (1891-1976), a Belgian primary school teacher, and are used to teach mathematical and language concepts. The rods are wooden blocks of different size and color.

kindergartens to explore mathematical concepts such as number, size, and shape. Tangible interfaces, though, have the capacity to go behind these traditional materials allowing children to manipulate and to simulate; to develop hypotheses and experience them, thus creating experiences that cannot be shaped by wooden blocks.

At the same time, tangible interfaces bring together the tradition of games and playful activities commonly used in educational activities at kindergarten with the new interactive technological solutions that promote a more experimental, participatory and active involvement; merging the best of computer pedagogic software and traditional learning materials. Resnick refers the importance of interacting with the right materials, which promotes a *creative thinking spiral*; by doing so children:

> imagine what they want to do, create a project based on their ideas, play with their creations, share their ideas and creations with others, and reflect on their experiences.
> —— Resnick 2007.

A process that prepares children for the *Creative Society*, where people continuously need to discover new creative solutions to solve unexpected problems, where knowledge alone is no longer enough (Resnick 2007).

Based on these ideas there has been in the past two decades a growing interest in developing tangible interfaces to support children education, in that context also known as digital manipulatives (Resnick et al. 1998). Groups like the Lifelong Kindergarten[7] at MIT Media Laboratory or the MIT Tangible Media Group[8], among others, have developed a series of tangible interfaces for children.

Inspired by Froebel and Montessori, Zuckerman (2005) proposes the following classification for manipulatives: *Froebel-inspired Manipulatives* (FiMs), manipulatives that enable modeling of objects and structures of the real world; and *Montessori-inspired Manipulatives* (MiMs) that enable

[7] http://llk.media.mit.edu/

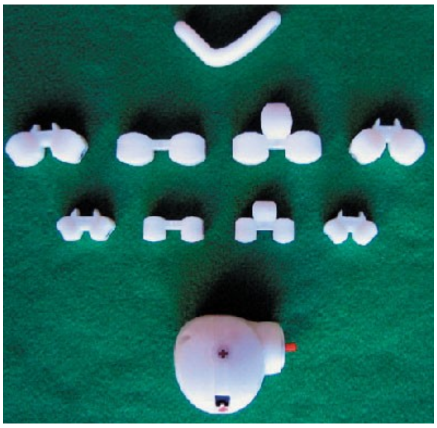
[8] http://tangible.media.mit.edu/

modeling of abstract concepts such as the representation of numerical proportions, and relationships between quantities.

Marshall (2007) gives a good overview about what has been done in the area of learning with tangible interfaces providing an analytic framework of six perspectives: typical learning domains, learning activity, integration of representations, concreteness and sensory-directness, effects of physicality and possible learning benefits. Although he questions that many tangible interfaces offer more cognitive advantages for learning over traditional graphical interfaces he admits that *exploratory and expressive activitie*s might be *particularly well supported* by tangible interfaces. Through an exploratory process of discovery the learners interact with an existing model of the world trying to understand the underlying mechanisms; whereby the model can reflect the learners own experiences and his *existing level of understanding*, or in the other hand conflict with it, which can lead to a process of reflection and consequent learning. In *expressive activities* the learners can give physical form and materialize their ideas thus making them concrete and clear having the possibility of reflecting upon how accurate their models are in their representation by comparing them to the real world (Marshall 2007).

3.2.1 EXAMPLES OF EDUCATIONAL TANGIBLE INTERFACES

Topobo (Raffle, Parkes and Ishii 2004) is an example for *expressive* learning (fig. 3-1). It is a 3D building system with kinetic memory able to record and play physical movements. The physical input and output of the movement is made in real time. Topobo combines passive and active components, which can be fit together to form models of animals, geometric or abstract shapes. It allows children to build their toys and associate them with movements that they then play. Children can compare the movements of their constructions with their own movements or from various animals, making it easier for children from the age of 4-5 years old to learn concepts of movement and locomotion. Topobo is already being commercialized.



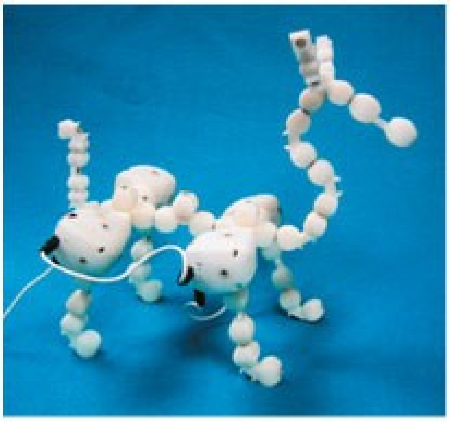


FIGURE 3-1 The Topobo system and an animal built with Topobo, reproduced from (Raffle, Parkes and Ishii 2004).

In 2006 the same researchers from the MIT Tangible Media Group (Raffle, Yip and Ishii 2006) developed Robot Topobo a controller that allows users to store and reproduce up to four recordings created with Topobo, which can then be played using a joystick controller. The system allows reversing the sequence of movements, change the speed and its extent.

One of the first TUIs developed for young children, from 4 years of age, was Curlybot (Frei et al.2000) (fig. 3-2), an autonomous two-wheeled vehicle with embedded electronics that can record the way it is moved on a flat surface and afterwards play that movement in an absolutely accurate mode and repeatedly. The interface is very simple allowing children to create complex movements, whereby they learn concepts of movement, space and repetition as well as about points of origin, direction and magnitude.

FIGURE 3-2 Top and Bottom of curlybot, reproduced from (Frei et al. 2000).

A domain that has also been addressed by tangible interfaces is the narrative. TellTale (Ananny 2001) (fig. 3-3) is an example of a collaborative interface that aims to support the language development by encouraging children, through storytelling, to develop oral language skills that are important for the development of literacy. It gives children control over the structure and content of their verbal exteriorization. The interface resembles a worm with the body consisting of five pieces and a colored head. Children can record audio into each part of the body, and hear it by pressing a button. The pieces are independent of each other, can be randomly sorted and rearranged, or a new story can be created at any time. TellTalle can be used by one or several children simultaneously, allowing a group experience that can be very motivating for the development of the language.

FIGURE 3-3 TellTale Prototype, reproduced from (Ananny 2001).

Another interface that targets the narrative domain is the Jabberstamp (Raffle et al. 2007) (fig. 3-4), an interactive tangible interface that aims to help developing children's literacy by enhancing their creativity, the ability to develop stories, and capacity of communication. The interface allows children, from the age of 4 and older to add sounds and voices to their drawings. To use the Jabberstamp children make drawings, collages or paintings on normal paper, placed on a Wacom tablet[9]; by pressing a special rubber stamp on the sheet they can record sounds in their drawings. Using a small trumpet, a device created by the authors, children can hear the stories they created. The authors found that children integrated direct speech (speech of the characters), indirect speech (presentation of the characters),

[9] http://www.wacom.com/index.html

provided additional contextual information (narrator), besides enriching their stories with ambient sounds and sounds they created and invented.

FIGURE 3-4 Children creating an interactive story with Jabberstamp, reproduced from (Raffle et al. 2007).

An example of a Tangible Interface to promote children's creativity is the I/O brush (Ryokai, Marti and Ishii 2004) (fig. 3-5), a *brush* that allows children from 4 years of age to explore colors, textures and materials from their daily life. Like a brush it captures patterns of the world allowing children to paint with them. The I/O brush has the appearance of a physical paintbrush but has a small webcam embedded with light and touch sensors. It allows children to take samples of color, textures or patterns, which are present in their personal objects and their environment and use these elements to create their own paintings.

FIGURE 3-5 Exploring different patterns of an object (Ryokai, Marti and Ishii 2004), reproduced from http://web.media.mit.edu/~kimiko/iobrush/).

Several other educational tangible interfaces have been developed for primary school children and older; we will shortly refer some of these interfaces.

A group well known for his work in this area is the Lifelong Kindergarten group at MIT. The group developed a family of programmable bricks, which led to the development of the "LEGO Mindstorms" product, a robotic construction kit. Crickets (Resnick et al. 1998) (fig. 3-6) are a more recent version in the programmable bricks family. They are small Programmable Bricks, containing a Microchip PIC processor and are capable of two-way infrared communications. Children can use Crickets to create robotic constructions that interact with one another. This helps children learning general communication principles. Crickets have been used with elementary-school children, as a mean of incentivizing them to science activities.

FIGURE 3-6 Robotic construction with two built-in Crickets, which communicate with one another to synchronize their motion, reproduced from (Resnick et al. 1998).

The BitBall (Resnick et al. 1998) (fig. 3-7) is a transparent, rubbery ball with a Cricket, an accelerometer, and colored LEDs embedded inside. It can be programmed by children to change its lights according to acceleration or deceleration. For instance children can program the BitBall on a computer, to turn on its LEDs based on its motion; or to flash its light according to its acceleration or deceleration, or the Ball can begin to flash if there is no acceleration. The Cricket allows the BitBall to receive infrared signals. Thus children can than send their program to the BitBall via infrared, as well program them to communicate with other electronic devices. BitBalls can also be used to store data such as acceleration. The handle of the ball can lead to deeper understanding of kinematics.

FIGURE 3-7 The BitBall, reproduced from (Resnick et al. 1998).

Programmable Beads (Resnick et al. 1998) (fig. 3-8) are used to create dynamic patterns. Each Programmable Bead has a microprocessor and a LED, it communicates with the neighboring beads by inductive coupling. Depending how they are combined the Beads produce different dynamic patterns of light.

FIGURE 3-8 A necklace of Programmable Beads, reproduced from (Resnick et al. 1998).

Beginners can create their necklaces by stringing together pre-programmed beads and observe the dynamic patterns that arise from the interactions. More advanced users can write new programs and download them into the Beads. Beads can help children exploring and understanding probabilistic behaviors.

System Blocks (Zuckerman 2004) (fig. 3-9) is a physical interface that children can explore to learn about dynamic systems. It is composed by a set of computationally enhanced blocks with embedded electronics. System Blocks can be used to learn complex concepts of system dynamics and causalities. These concepts include stocks and flows, linear dynamics, and positive feedback (Zuckerman 2004). It can be used with 5^{th} and 6^{th} graders.

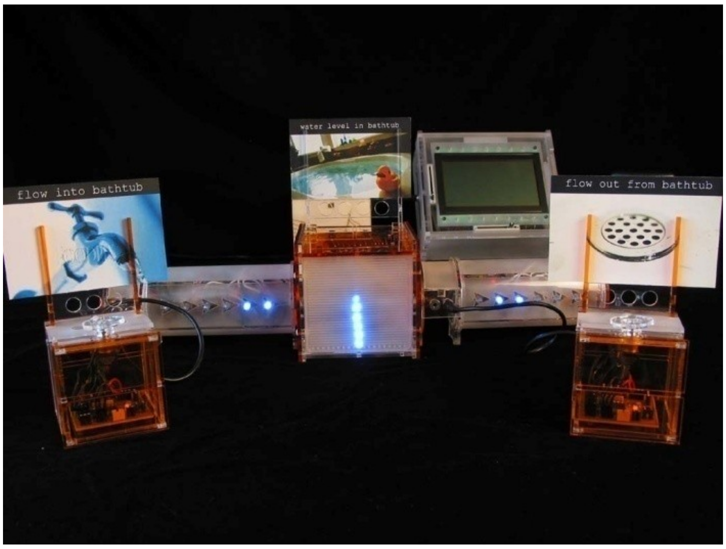


FIGURE 3-9 System Blocks simulating water flow through a bathtub, reproduced from (Zuckerman 2004).

Thinking Tags (Resnick et al. 1998) (fig. 3-10) were inspired in traditional badges, through embedded electronics they can communicate via infrared with one another and change its displays according to those communications. Thinking Tags have been used in educational applications with pre-college students, especially by engaging students in playing simulations. For example, Thinking Tags were used to simulate the spread of an epidemic disease, with an electronic *virus* jumping from one student's Thinking Tag to another. Students were challenged to develop theories to explain the spread of the virus.

FIGURE 3-10 Thinking Tags, reproduced from (Resnick et al. 1998).

Table (3-1) presents an overview of some educational tangible interfaces that address children from 4 years of age.

TABLE 3-1 Examples of TUIs for young children.

TUI	Learning domains
Topobo	Concepts of movement and locomotion
Curlybot	Concepts of movement, space and repetition as well as points of origin, direction and magnitude.
TellTale	Children's literacy, creativity, ability to develop stories, and capacity of communication, language development.
Jabberstamp	Children's literacy, creativity, ability to develop stories, and capacity of communication, language development.
I/O brush	Exploration of colors, textures and materials.

Table (3-2) presents some examples of educational tangible interfaces that address older children.

TABLE 3-2 Examples of TUIs for older children.

TUI	Learning domains
Crickets	General communication principles, development of science activities.
BitBall	Deeper understanding of kinematics.
Beads	Exploration and understanding of probabilistic behaviors.
Thinking Tags	Social network simulations
System Blocks	Concepts of system dynamics and causalities

CHAPTER 4 *Evaluating technology for and with young children*

4.1 HISTORICAL OVERVIEW

In parallel with the development of new interfaces for children, there has been, in the last 12 years, a growing interest on the evaluation of interactive technology for children. Special emphasis is given to the work of Hanna, Risden and Alexander (1997). Despite the growing interest in this field, most evaluation studies of the benefits of tangible interfaces for learning are rather informal (Marshall 2007) and there are very few empirical studies comparing tangible and graphical interfaces. One of these studies was carried by Fails et al. (2005) with children aged 4 to 5 years old comparing a tangible and a graphical version of a Hazard Room Game that teaches children about environmental health dangers. The results of the study suggest that the physicality of the tangible interface has advantages over the graphical interface in terms of learning outcomes.

Jensen and Skov (2005) conducted an extensive survey of research methods in paper publications, reviewing 150 papers on children's technology design; their results show a strong focus on engineering of products and on evaluation of developed products; they also found out that most research is conducted in natural setting environments with strong focus on field studies. The evaluation methodology with children 4 to 5 years old, poses some additional challenges given their limited ability of verbal or written expression. In addition the majority of assessment methods are generally suitable for use with older children. For a good overview of evaluation methods used with children, see Markopoulos, Read, Macfarlane and Höysniemi (2008).

In the next section we will discuss some of the evaluation methods that have been used with children.

4.1.1 THE VISUAL ANALOGUE SCALE

One of the methods that have been adapted for children is the Visual Analogue Scale (VAS), a psychometric response scale which can be used to measure the level of agreement with a statement by indicating a position along a continuous line between two end-points. Wong and Baker adapted the (VAS) creating the Wong-Baker FACES Pain Rating Scale (fig. 4-1), a visual analogue scale to access pain in children. The scale presents a series of faces ranging from sad to happy. It was originally developed to evaluate children's pain, due to the difficulties of young children in understanding how to use a traditional scale.

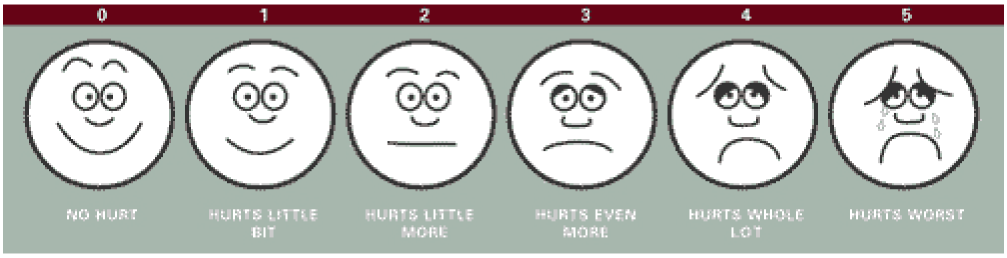


FIGURE 4-1The Wong-Baker FACES Pain Rating Scale, reproduced from (Wong on Web Archive).

The scale is extensively used in research and clinical practice with children for the assessment of pain and it has also been used to rate preference and other feelings.

Some researchers find the scale appropriate to be used with children older than 7 (Shields et al. 2003). Other researchers, nevertheless, think that it can be used with younger children, although if children are evaluating software or hardware products younger children tend to choose the highest score (Read MacFarlane and Casey 2002).

4.1.2 THE STICKY-LADDER RATING SCALE

In a study on children's use of electronic toys and related software, Airey et al. (2002) developed a scale (fig. 4-2), to be used with children 4 to 6 years old. The scale consists of a tangible object that children can handle to express their opinions, by sticking the objects to a Velcro ladder, according to their preferences.

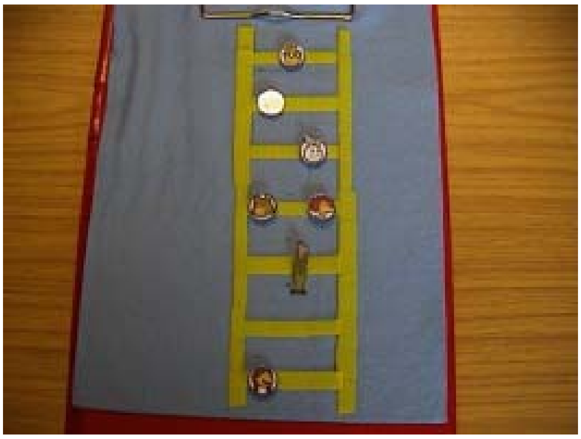


FIGURE 4-2 The sticky-ladder rating scale, reproduced from (Airey et al. 2002).

The method was found suitable for that age rank since children did not have to deal with difficult vocabulary or instructions; however the authors claim that further research has still to be done to validate the method.

4.1.3 THE FUN TOOLKIT

Janet Read and Stuart MacFarlane have extensively investigated the measurement of the fun component as a method of evaluating children's preferences. They defined three dimensions of fun: *Expectations*, *Engagement*, and *Endurability* (Read and MacFarlane 2000). The Fun Toolkit is a set of tools by Read, MacFarlane and Casey (2002) specially designed to measure children's opinions about technology. The Toolkit is composed of four tools: a Funometer, a Smileyometer, a Fun Sorter, and an Again-Again table. The tools are intended to be very simple and clear using pictures and only essential vocabulary.

The Funometer (fig. 4-3) is a variation of a tool developed by Risdan, Hanna and Kanerva (1997) consisting of a vertical scale with a smiley face on the top and a sad one on the bottom joined together by a vertical ruler. Children can draw a vertical line inside the ruler showing the amount of fun they had. The Funometer can be used even by very young children 3 and 4 years old (Markopoulos et al. 2008); but it seems to be more useful to be used with older children (Read, MacFarlane and Casey 2002).

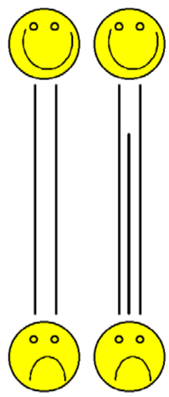


FIGURE 4-3 The Funometer – before and after completion, reproduced from (Read, MacFarlane, and Casey 2002).

The Smileyometer (fig. 4-4), a Likert type scale adopted for children, is a variation of the Funometer designed with the participation of children; it has five faces that go from *awful* to *brilliant*. Children mark the face that better suites their preference; since the faces are labeled, the Smileyometer gives extra information when used with children that can read.

FIGURE 4-4 The smileyometer, reproduced from (Read, MacFarlane, and Casey 2002).

Research on the Funometer (Read MacFarlane and Casey 2002, MacFarlane, Sim and Horton 2005, Read and MacFarlane 2006) showed that the *Smileyometer* is of limited value when used alone with very young children as they tend to choose the highest score. Kam (2007) in a study evaluating mobile gaming with children in Indian, aged 6 to 7 years old, found out that children tended to always pick *brilliant* and *very good*, because these emoticons were esthetically more appealing to them than *frowns*.

The Fun Sorter (fig. 4-5) is used to measure different types of things, such as fun, likes and dislikes or grade of difficulty. The tool consists of a grid with activities or things to be rated. Children are asked to rank these in order to their preferences. The Fun Sorter seems to work better when comparing a small numbers of activities. This method can also be used with younger children, if only one construct is used and picture cards instead of words. Older children can write their preferences. Very important is that the children understand what they shall evaluate, thus being necessary to use simple words (Read, MacFarlane and Casey 2002).

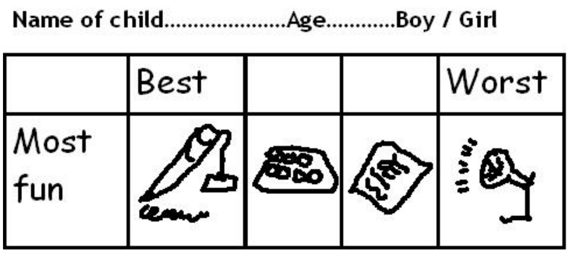


FIGURE 4-5 A completed Fun Sorter with only one construct, reproduced from (Read and MacFarlane 2006).

The Again-Again table (fig. 4-6) can be used to measure *endurability*, based on the Pollyanna principle that people are more likely to remember things that they liked to do, and the belief that people would like to do things again that were fun (Read, MacFarlane and Casey 2002).
The table consists of a grid with the activities listed on the left, and it has three columns on the right. Children mark their answers to the question *would you like to do it again?* in different columns with yes, maybe and no according to their opinion.

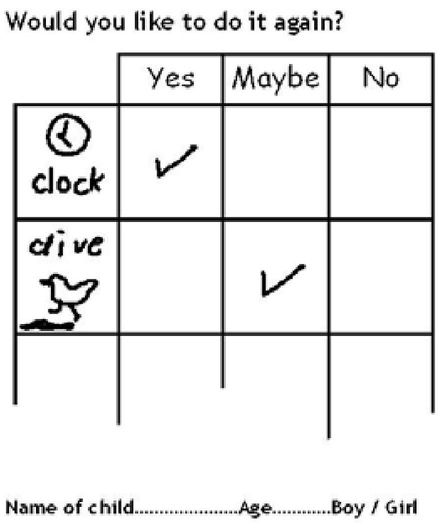


FIGURE 4-6 A Completed Again - Again table, reproduced from (Read and MacFarlane 2006).

4.1.4 THE THINK ALOUD METHOD

Other usability testing methods such as the Think Aloud method, where children verbalize their thoughts while interacting with a product, are appropriated to be used with children 8 to 14 years old. Younger children may have difficulties in expressing themselves clearly through words (Donker and Markopoulos 2002). Donker and Markopoulos (2002) found out that children have difficulty, or don't like to speak while exploring the technology. They had to be constantly encouraged in order to keep verbalizing their thoughts; however by thinking aloud children provide much more relevant information about their interaction than if they are asked specific questions.

Children's capacity of verbalizing their thoughts depends not only on their language skills but also on children's experience in talking to adults; on the other hand, as logical reasoning and abstract thinking are not yet fully developed in children, they might have difficulties doing multiple tasks and abstract task formulations (Markopoulos and Bekker 2002), and this is specially truth for children 4 to 5 years old.

4.1.5 THE TALK ALOUD METHOD

Talk Aloud (Donker and Reitsma 2004) is a variation of the Think Aloud method where children are instructed but not prompted to talk about what they are doing during their interaction. In a study carried with kindergarten children 6 to 7 years old, the authors found the children very quiet, even though they had been asked to verbalize their thoughts. Nonetheless the few comments that children made were very useful, identifying important problems about the software, and giving opinions about the design.

4.1.6 PEER TUTORING

One method specially designed to assess children's opinions is the Peer Tutoring method (Höysniemi, Hamalainen and Turkki 2002) whereby one child teaches another how to use a product. This test undergoes two phases, first the tutor child becomes familiar with the product and learns how to use it, and then in a second session, the tutor teaches a tutee child how to use it. The method allows checking to what extent the child giving the instructions understood the functioning of the product and is able to convey it to his peer.

van Kesteren et al. (2003) carried a study about children's ability to provide verbal comments in usability evaluation sessions applying six evaluation methods to test an interactive toy with children aged 6 and 7 years old. They concluded that children are able to verbalize their thoughts during usability evaluation, but the results depend on the method used and on children's personality. The most comments were provided using the Active Intervention method, where children are asked questions while interacting with the technology, the Think Aloud method showed that children were able to provide useful comments during their intervention and managed to explain their peer the functioning of the tested product when using Peer Tutoring.

4.1.7 DRAWING INTERVENTION

> Making drawings gives young children opportunities to represent intricate personal narratives and use them to communicate with significant others in their lives.
>
> —— Anning and Ring 2004:116.

A new evaluation method is Drawing Intervention (Xu, Mazzone, and MacFarlane 2006, Xu, Read and Sheehan 2008, Xu et al. 2009). Drawing is one of the essential activities undertaken at kindergarten, it is often used as a method to appraise the degree of what children have learned after a particular activity, and it has shown to be useful and generally worthy of credibility (Coquet 2000). Drawing allows children to represent their thoughts, feelings and interpretation of their lived or imagined experiences. Children retain visual elements and details that they are able to draw; however, they may have greater difficulties if they have to describe these elements in spoken or written words. Despite the difficulty in evaluating drawings they may give important additional knowledge about children, complementing other quantitative and qualitative data thus providing a method of self expression that verbal measures may not allow (Malkiewicz 1994).

Drawings have an historical tradition as a method of evaluating cognitive development. William and Reilly (1996) give an excellent overview of research works on this matter: authors such as (Golomb 1992, Burns 1982, Klepsch and Logie 1982, Koppitz 1968) have shown that children's drawings can reflect self- concept, attitudes, wishes, and concerns. Buck (1948), Burns and Kaufman (1970), Knoff and Prout (1985), Koppitz (1983), Rubin (1984), Burns (1982), Allan (1978) have developed methods to interpret children's drawings. These methods have been used mostly for diagnostic purposes in clinical or educational context, including a variety of assessment purposes, as intellectual development (Harris 1963, Goodenough 1926), learning disabilities (Cox and Howarth 1989), personality (Prout 1983, Wade et al. 1978, Hulse 1951, Machover 1949), emotional adjustment (Koppitz 1968); art therapy (Malchiodi 1998); art education (Lowenfeld and Brittain 1975, Matthews 1999, 2003) as well as program evaluation and communication (William and Reilly 1996).

Children's drawings are also part of the mixing ideas method, an additional Cooperative Inquiry[10] design technique used when involving young children as design partners (ages 4-6) (Guha et al. 2004).

More recently the Child Computer Interaction group has used Drawing Intervention as an evaluation method to rate children's approach to technology, particularly to measure the amount of fun that the children experience by interacting with different interfaces (Xu, Mazzone, and MacFarlane 2006, Xu, Read and Sheehan 2008, Xu et al. 2009).

As we have seen, the evaluation of technology with children 4 to 5 years old poses some difficulties since they are not yet able to express themselves clearly through words; in addition the great majority can neither write nor read. Most evaluation methods are of limited value when used alone; therefore it is worthwhile to combine more than one evaluation method. Young children tend to choose the highest score when using the Smileyometer; the Fun Sorter poses some difficulties when used with pre-literate children. The Think Aloud method seems to be more appropriate to

[10] A method developed in the project: *Classroom of the Future,* at the University of Maryland (Druin 1999, 2002).

be used with children aged 8 to 14, younger children have difficulty, or do not like to speak and explore the technology at the same time. They also seem not to be very motivated to talk while interacting with technology, when using the Talk Aloud method. Peer Tutoring is difficult to be used with children 4 to 5 years old, since they may have difficulties in expressing themselves through words.

Drawing Intervention, although it has limitations like other evaluation methods, seems to be a promising method to work with 4 to 5 years old children, since it is easier for children to express their feelings through drawings rather than through words. In the study that will be presented in the next chapter Drawing Intervention was one of the methods used to assess children's experience.

CHAPTER 5 *Comparing TUIs vs. GUIs*

5.1 INTRODUCTION

As stated in the introduction, the motivation behind this work was to compare the learning impact of a tangible versus a graphical user interface in kindergarten children. Tooth brushing was chosen as the kindergarten curricular topic to address. At the age of three, children begin to acquire the habit of brushing their teeth and it is part of the kindergarten's educational program to promote this practice. Our research question was: *do children learn more about oral hygiene with a tangible than with a graphical interface?*

Learning in this context means not only factual knowledge acquisition but a change in behavior and/or attitude resulting from an effective learning.

To answer this question we developed two similar interfaces differentiated only by one being a tangible and the other a graphical interface.

5.2 TWO INTERFACES FOR TEACHING ORAL HYGIENE

The graphical interface consists of a tooth with germs moving on its surface that children can clean by moving the mouse over the germs (fig. 5-1).

The tangible interface consists on a large physical tooth with a projection of virtual germs on its surface (fig. 5-2). Children interact by cleaning the germs with a 70 cm long toothbrush. They brush the tooth and the germs disappear with the pass of the brush.

FIGURE 5-1 Two screenshots of the graphical interface.

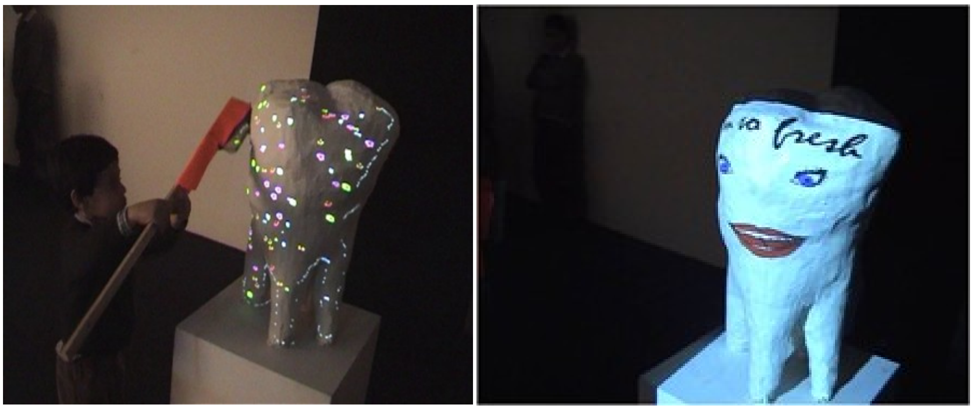


FIGURE 5-2 A child interacting with the tangible interface and the cleaned tooth.

In both interfaces, the germs are *laughing*; when the children begin to brush them away they react by *saying*: *ai*, *ui*. When all the germs are cleaned the tooth turns into a pleasant face with a big smile and a little voice says: *I'm so fresh*! The audio effects and the *smiling* face are common to both interfaces; the sound effects were recorded with children's voices.

The final system consists on a video projector, a webcam, the tooth, the brush and the software developed in Processing[11] and JMyron[12] an image processing library.

The projection of the virtual germs is front projected on the tooth from an elevated point in order to avoid the obstruction of the image by the users (fig. 5-3). The webcam is positioned between the tooth and the projector to capture the image of the toothbrush. The webcam tracks the 2D position of

[11] http://processing.org/

[12] http://webcamxtra.sourceforge.net/

the red brush. When the position from the red brush and from the germs coincide, they disappear.
To build the brush we have adapted a cleaning brush with a long wood handle, covering the backside with red cardboard, to allow for easier image detection by the webcam.

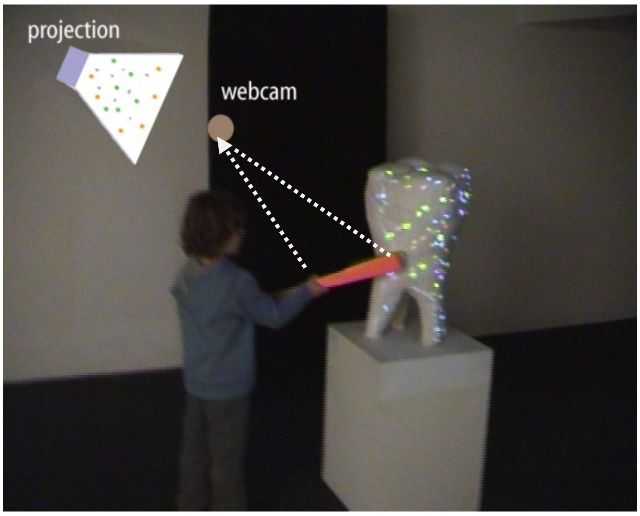


FIGURE 5-3The system setup.

The lengh of the brush handle (70 cm) leads the children to position themselves on the side of the tooth in order to clean it, avoiding that way obstructing the front projection .
Since the system can be moved between different locations, it requires an initial calibration to make the alignment between the projection of the virtual germs and the physical tooth (fig. 5-4).

FIGURE 5-4 System alignment and calibration.

A small program developed in Processing allows painting the area of the tooth directly in the projected image using the mouse, creating a mask that defines the area where the germs move around. Given that the light conditions influence the RGB values that are captured by the webcam, it is necessary to calibrate these as well.

In both interfaces the software and the game functionality are the same, the only difference is that one is projected on the physical tooth (tangible interface) and the other on the computer screen (graphical interface).

5.3 METHODOLOGY

The study was carried with two groups of kindergarten children 4 to 5 years old. Group A was composed of 18 children, group B was composed of 23 children. The groups were from two different Portuguese kindergartens and had no contact with each other. Both kindergartens can be considered to be located within a middle class social economic context.

5.3.1 QUESTIONNAIRES

Since we are dealing with pre-literate children that can neither read nor write, and since most usability tests aren't appropriate to be used with that age group, as discussed in the previous chapter, three different methodologies were used.

First children's attitudes towards tooth brushing were assessed before and after being exposed to the interfaces by having their parents answer a questionnaire. This was a Likert type scale composed of four questions which provided information about children's motivation for brushing their teeth, their opposition to it, children's notion of the importance of tooth brushing and finally about the degree of knowledge children had of the consequences of a poor oral hygiene.

5.3.2 DRAWING INTERVENTION

Drawing Intervention was used after children's interaction to assess their degree of involvement with the interfaces. This was divided in three assessment phases. First group A interacted with the tangible interface and group B interacted with the graphical interface. After the interaction both groups of children were asked to draw their experience.

The second interaction followed five months after the first one, in this phase the interfaces were changed; thus group A interacted now with the graphical interface, while group B interacted with the tangible interface. Again after the interaction the children were asked to draw their experience.
Between these two phases, three weeks after the first interaction, a follow up was carried with both groups; without seeing the interfaces children were asked to draw what they still remembered from their experience.
To evaluate the drawings two evaluation grids were created; one with the elements common to both interfaces; the other with elements that were not necessarily equally present in both interactions, but that were related with the experience itself, such as for instance elements of the set up. Each element was scored a point. Such approach pretended to see if the different experiences would be reflected in children's drawings by measuring the number of elements children represented, assuming that the more detailed and complete the drawings are, the more involving the experience was. As discussed in chapter 2 children only draw what is important for them, the details of the objects depend on the importance that they give to them.

5.3.3 INTERVIEWS

Finally, the children were interviewed about their preferences and expressed their likes and dislikes of the interfaces. The time table bellow gives an overview of the different moments of data collecting (table 5-1).

TABLE 5-1 Time table of the user study.

Distribution of the 1st questionnaires	group A + group B	20. 11. 2008
1st interaction	***group A*** interaction with the tangible interface	27.11.2008
	group B interaction with graphical interface	19.11.2008
Follow up	group A + group B	16.12.2008
Distribution of the 2nd questionnaires	group A + group B	18.12.2008
2nd interaction	group A interaction with the graphical interface	27.04.2009
	group B interaction with the tangible interface	29.04.2009
Interview with the children	group A	06.05. 2009

5.4 COLLECTING CHILDREN'S ATTITUDES TOWARDS ORAL HYGIENE

Before testing the interfaces and to gather background information about children's motivation for the oral hygiene, the parents were asked to fulfill a questionnaire about their children's resistance to tooth brushing (table 5-2). The questionnaires were distributed by the kindergarten teachers in children's backpacks following the usual procedure for communication with parents. The parents were informed that it was a long term study, and that the evaluation was not about how good they teach their children about oral hygiene, but rather to know their children's attitudes towards it. The questionnaire was a Likert type scale composed of four questions with punctuation from one to five, one being the minimum score and five the maximum.

T ABLE 5-2 Questions given to the parents.

a	Motivation of their children for tooth brushing
b	Children's opposition to tooth brushing
c	Children's notion of the importance of tooth brushing
d	Children's knowledge of the consequences of a bad oral hygiene

In addition, parents were asked to state the arguments that their children gave in case they did not like to brush the teeth.

Sixteen parents from group A and 17 parents from group B returned the fulfilled questionnaire (table 5-3). The results were quite similar in both groups. They revealed that the children were motivated for tooth brushing, and knew the importance of it. The differences between both groups have no statistical significance for the level of probability $p < 0.5$, which means that they are similar, necessary condition to infer the differences later assigned to the experimental treatment (Macmillan and Schumacher 1997).

TABLE 5-3 Questionnaire results before the interaction.

	Degree of motivation	**Degree of opposition**	**Notion of importance**	**Knowledge of consequences**
Group A	3,56	1,87	3,60	3,87
Group B	3,82	1,71	3,94	3,69

5.5 FIRST INTERACTION WITH THE INTERFACES

One week following the collection of the first questionnaires from the parents both interfaces were tested (fig. 5-5). The tests were carried in two consecutive days, one day for each group and took place during the morning at each respectively kindergarten. The tests were conducted at the reading room or the activity room, which were familiar to the children. Group A composed of 18 children, interacted individually with the tangible interface, which took about 30 minutes. While one child was brushing the tooth, the others sat around and were giving advice. Group B, composed of 23 children played the computer game in their activity room, which took about 40 minutes. The children sat around while one at a time was handling the mouse making the germs disappear.

In both groups children were successful in brushing all the germs, turning the tooth into a smiling face for their enjoyment: laughing and clapping hands.

After the interaction the children from group A went to their activity room, so that they could not see the tangible interface and were asked to draw what they had seen. Group B stood in their room, the computer was turned off and the children were as well asked to draw what they had seen.

FIGURE 5-5 Children from group A interacting with the tangible interface and children from group B interacting with the graphical interface.

5.5.1 DID CHILDREN'S BEHAVIOUR TOWARDS ORAL HYGIENE CHANGED AFTER THE INTERACTION?

In order to assess and compare the TUI versus GUI in respect to their ability to change children's attitude towards tooth brushing and verify if that change was a lasting one, we waited three weeks after the initial interaction and asked parents to fill once more a questionnaire similar to the first one. Parents were also encouraged to write any possible comments their children had made at home about the tooth brush activity that had been carried at kindergarten. The parents had no prior information on the interaction of their children with the interfaces, all they knew was told by their children at home. This was important for data collecting in order to minimize their interference influencing children's answers.

5.6 ANALYSIS OF THE QUESTIONNAIRES

We received the second questionnaires five weeks after children's interaction with the interfaces. Thirteen parents from group A and 14 parents from group B answered the questionnaire (table 5-4).

TABLE 5-4 Questionnaire results after the interaction.

	Degree of motivation	Degree of opposition	Notion of importance	Knowledge of consequences
Group A	4,46	1,38	3,85	3,92
Group B	3,92	1,77	3,79	3,43

The results of the questionnaires before the interaction with the interfaces (table 5-3) showed that although in mild terms, group B scored a higher punctuation than group A. The results after the interaction show group A (tangible interface) relatively to group B (graphical interface) having a higher motivation for tooth brushing (0, 54 points), decrease of opposition (0, 39 points), higher notion of the importance of oral hygiene (0, 06 points) and higher notion of the consequences of a bad oral hygiene (0, 49 points). In order to test the significance of those differences found between the results of both groups after the interaction, a non-parametric Mann-Whitney U test for independent groups was chosen because the conditions for normal distribution weren´t fully guaranteed due to the presence of some outliers in some of the variable distributions (Gibbons 1993). As shown in (table 5-5), the variations found of the degree of motivation are significant at the level of p<0, 5 but not for the other three dimensions.

TABLE 5-5 non-parametric Mann-Whitney U test for independent groups.

Ranks

Group		Mean Rank	Sum of ranks
Motivation	Group A	16,54	215,00
	Group B	10, 46	136,00
Opposition	Group A	11,58	150,50
	Group B	15,42	200,50
Importance	Group A	14,23	185,00
	Group B	13,79	193,00
knowledge	Group A	15,38	200,00
	Group B	12,71	178,00

Test Statistics[b]

	Motivation	Opposition	Importance	Knowledge
Mann-Witney U	45,000	59,500	88,000	73,000
Wilcoxon W	136,000	150,500	193,000	178,000
Z	-2,204	-1,482	-,157	-,931
Asymp. Sig. (2-tailed)	,028	,138	,875	,352
Exact Sig. [2*(1-tailed Sig.)]	,044[a]	,204[a]	,905[a]	,402[a]

a. Not corrected for ties.
b. Grouping variable: Group

Looking at the questionnaires of each group before and after the interaction with the interfaces it is noticeable that in group B (table 5-6), there is no noticeable change in children's attitude towards tooth brushing.

TABLE 5-6 Group B: results before and after the interaction with the graphical interface.

	Degree of motivation	Degree of opposition	Notion of importance	Knowledge of consequences
before the interaction	3,82	1,71	3,94	3,69
after the interaction	3,92	1,77	3,79	3,43

Instead, group A (table 5-7), which interacted with the tangible interface shows a general increase of score.

TABLE 5-7 Group A, results before and after the interaction with the tangible interface.

	Degree of motivation	Degree of opposition	Notion of importance	Knowledge of consequences
before the interaction	3,56	1,87	3,60	3,87
after the interaction	4,46	1,38	3,85	3,92

The increase of motivation in group A is statistically significant as verified when applying the Wilcoxon Sign Rank Test for related samples whose results after the Interaction (AI) are shown in (table 5-8). For the other three dimensions of the questionnaire no statistical significance was found.
On the contrary the results of group B are not statistically significant.

TABLE 5-8 Wilcoxon Sign Rank Test for related samples.

Test Statistics[c]

GroupA	Motivation AI	Opposition AI	Importance AI	Knowledge AI
Z	-2,142[a]	-1,279[b]	-1,127[a]	-,649[a]
Asymp. Sig. (2-tailed)	,032	,201	,260	,516

GroupB	Motivation AI	Opposition AI	Importance AI	Knowledge AI
Z	-707[a]	-,073[b]	-,491[b]	-,355[b]
Asymp. Sig. (2-tailed)	,480	,942	,623	,722

a. Based on negative ranks
b. Based on positive ranks
c. Wilcoxon Signed Ranks Test

5.6.1 QUALITATIVE RESULTS

The questionnaires gave parents the opportunity to write their comments and the remarks done by their children about the experience. According to the parent's of both groups most children justified the lack of willingness to brush the teeth with arguments such as: *I am very tired; I did it yesterday; I have no time; I want to play; I am too sleepy; my teeth are not yellow; the tooth paste is too spicy*.
In group B (table 5-9), most comments were given by the parents explaining why their children don't like to brush their teeth; there were only two comments from the children themselves referring to the experience with the interface. In group A (table 5-10) there were 5 comments from the children

referring to the experience. The comments from the children and their parents (table 5-11) suggest that the tangible interface had a stronger impact on the children. In fact, while only two of the children who interacted with the graphical interface talked about the experience at home, five children from the other group talked about the tooth at home. This difference is significant since group A was composed by 18 children and group B by 23 children.

TABLE 5-9 Remarks made by the children from group B.

group B graphical interface	*Mum, we have to brush the teeth; otherwise they will get rotten and start to hurt.*
	In the computer we had to rub the germs really good to get rid of them.

TABLE 5-10 Remarks made by the children from group A.

group A tangible interface	*Liked to see a big tooth and to brush it.*
	Told us that there was a big tooth with germs that he cleaned with a big brush, to show how important tooth brushing is.
	Liked to see a tooth speaking.
	Told us that he made a draw about a tooth and the germs. If we don't brush the teeth they will get dirty and ugly.
	You'll have to brush the teeth after lunch otherwise they will fall.

TABLE 5-11 Comments from the parents group A and B.

parents group A	*I've noticed a big change; when I answered the first questionnaire my son didn't like brushing the teeth, now he is the one who takes the initiative to brush them!*
	A very important initiative, thank you!
	Since that experience she brushes the teeth before and after meals!
parents group B	*These initiatives are very good and important; children get advice from other persons besides the parents about habits that are for life.*

It seems that children were mostly impressed by the tooth, the brush and their size. Another mentioned aspect seems to be the cleaning of the tooth with a brush, perhaps because it is a richer experience than just handling the mouse. The children had to move around it searching for hidden germs, since the tooth is almost as big as the children themselves. In fact, while one child was handling the big brush, cleaning the tooth, going around, examining it, trying to remove all the germs from its surface, the other children were helping by giving advice and instructions. They just could not sit still and watch, very often, the child that was cleaning looked around asking for help, thus the experience became a group experience. This aspect supports Zuckerman (2005) view that the handling of tangible interfaces promotes team work, communication and exchange of experiences, aspects that also promote learning.

5.7 DRAWING INTERVENTION AS AN EVALUATION METHOD

In addition to inferring children's change of attitude towards tooth brushing indirectly through their parents, we used drawings to assess the ability of the graphical and tangible interface to engage children. The more involved the children were with the task at hand, the most likely they would be influenced by it and assimilate the change of attitude towards oral hygiene that was being promoted.

As we have seen in chapter 2 drawings can be highly complementary to other evaluation methods since young children might have difficulties expressing themselves through words. Building on theories that children's drawings portrait how they understand the word, what is important for them, and children do not represent objects that they find unnecessary or uninteresting (Luquet 1927, Lowenfeld and Brittain 1975, Coquet 2000, Matthews 2003), our approach was to determine the number and nature of the elements children represented - the more detailed and complete the drawings are, the more involving the experience was.

The process was divided in two assessment phases. First group A interacted with the tangible interface and group B interacted with the graphical interface. After the interaction both groups of children were asked to draw their experience.

The second interaction followed five months after the first one, in this phase the interfaces were changed; thus group A interacted now with the graphical interface, while group B interacted with the tangible interface. Again, after the interaction, the children were asked to draw their experience.

To evaluate the drawings, the elements present were grouped into two groups: elements common to both interfaces and other elements (table 5-12). Each element was scored a point. The score of elements for both groups was than compared.

TABLE 5-12 Elements scored.

Common elements	tooth	germs	brush	fresh tooth	
Other elements	self drawing	PC	researcher	other persons	other

The Computer (PC) was not classified as an element common to both interfaces; it was not considered an integrant part of the tangible interface since it was in the background and did not made part of the interaction. The researcher was considered as an element given that it was present in several drawings, especially in the first interaction.

Since young children do not always hold the necessary skills to represent (in terms of the adults' standardized models) what they want to, but because what matters is their intention (Coquet 2000, Luquet 1927), children were asked individually about the elements they had drawn and annotations were added to the pictures so that it was possible to code them without ambiguity. According to the methodology used the average results of group A and group B (table 5-13, 5-14)[13] show that both groups drew the elements common to both interfaces. Group A scored an average of 3 points/child against 2, 69 points/child from group B. However the significant differences between both groups concern the other elements. Thus the average total score achieved by the children from group A was 5 drawn elements against 3 from group B.

TABLE 5-13 Group A: interaction with the tangible interface (1st interaction).

common elements		**other elements**			
score	Average/child	Score	Average/child	Total score	Average/child
56Points	3,1 Points	34Points	1,88 Points	90Points	5 Points

[13] This tables replaces the tables presented in (Sylla, Branco, Coutinho, Coquet 2009)

T ABLE 5-14 Group B: interaction with the graphical interface (1st interaction).

common elements		other elements			
Score	Average/child	score	Average/child	Total score	Average/child
62 Points	2,69 Points	10 Points	0,43 Points	72 Points	3 Points

To confirm if these differences were statistically relevant, a non-parametric Mann-Whitney U test for independent groups was applied to the results. This test was chosen because the conditions for normal distribution of the high value of skewness weren't fully guaranteed due to the high value for skewness (Gibbons 1993). The mean rank of each child in group A was 29, 89, against 14, 04 from group B. These differences are statistically significant for $p<0.01$ (table 5-15[14]).

TABLE 5-15 Non-parametric Mann-Whitney U test for independent groups (1st interaction).

Ranks

1st interaction	N	Mean Rank	Sum of Ranks
Group A	18	29,89	538,00
Group B	23	14,04	323,00
Total	41		

Test Statistics

	1st interaction
Mann-Whitney U	47,000
Wilcoxon W	323,000
Z	-4,543
Asymp. Sig. (2-tailed)	,000
Total	41

a. Grouping Variable: Group

Looking at the drawings from the children that interacted with the tangible interface (fig. 5-6/5-8), we see that some of them represented not just a static situation but various phases of the action, for instance, some children drew the tooth with the germs and also the cleaned tooth. Other children even drew several images of the tooth showing the different stages of the

14 This table replaces the table (Mann-Whitney test) presented in (Sylla, Branco, Coutinho, Coquet 2009)

action. This indicator suggests a high level of children's involvement with the experience (Coquet 1995).

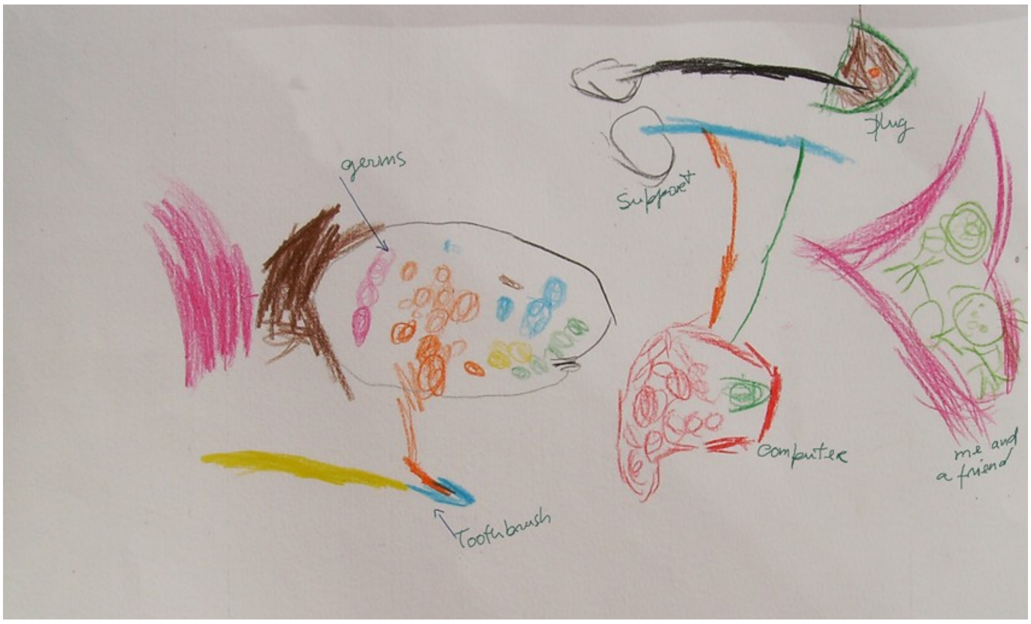


FIGURE 5-6 Example of children's drawings about the experience with the tangible interface.

FIGURE 5-7 Example of children's drawings about the experience with the tangible interface.

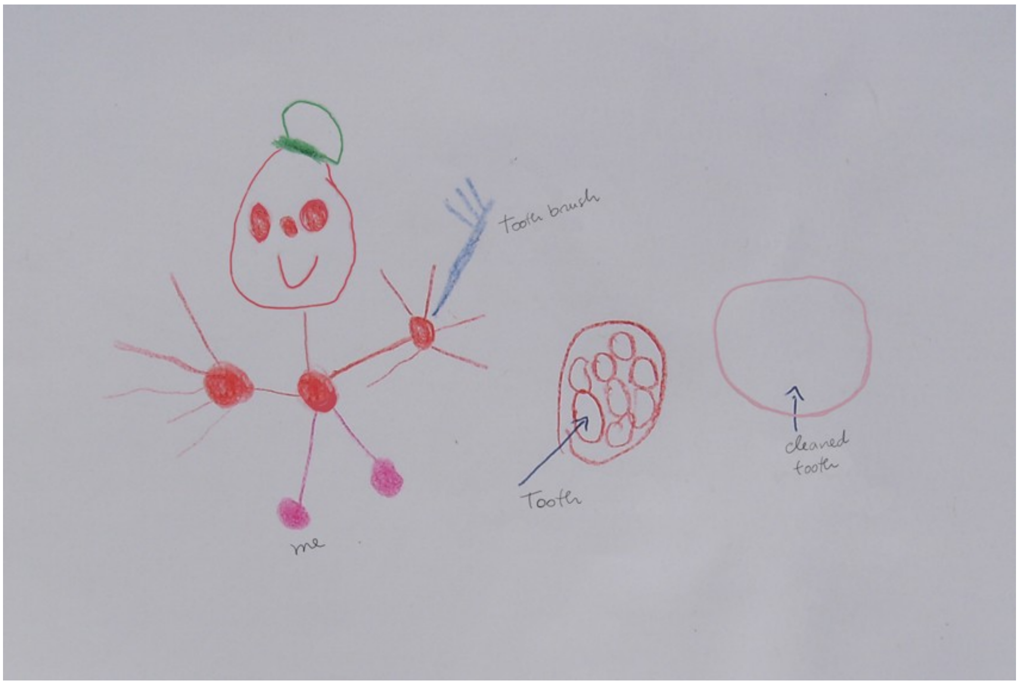


FIGURE 5-8 A drawing showing the tooth with the germs and the cleaned tooth.

The children that interacted with the graphical interface drew mostly just the tooth with germs and sometimes the brush (fig. 5-9/5-11).

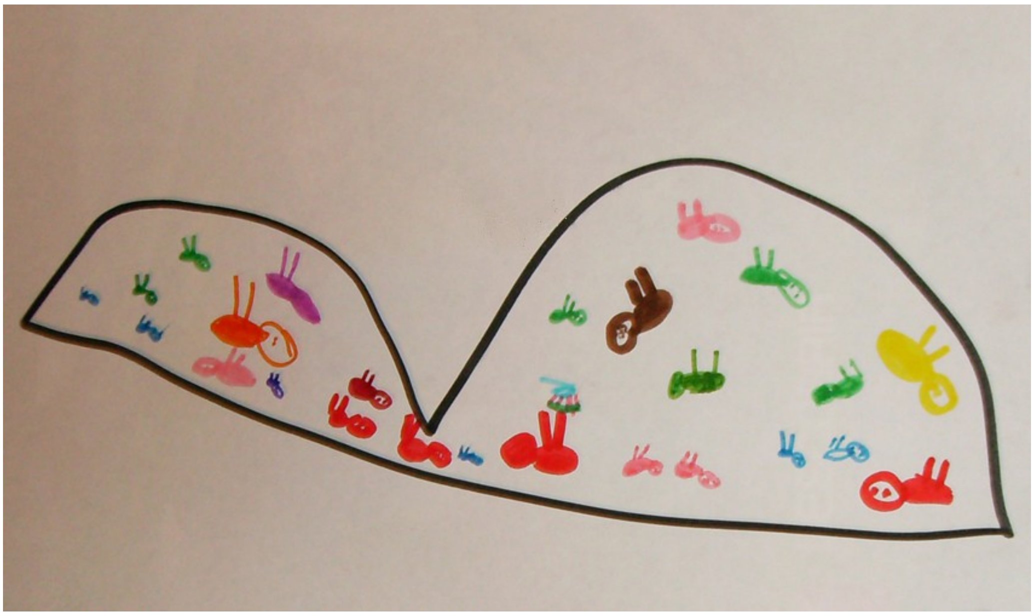


FIGURE 5-9 Drawing from a child that interacted with the graphical interface.

FIGURE 5-10 Drawing from a child that interacted with the graphical interface.

FIGURE 5-11 Drawing from a child that interacted with the graphical interface.

5.8 FOLLOW UP

In order to infer what children had retained from their interaction with the interfaces, three weeks after the first interaction the children were asked again to draw what they had seen (fig. 5-12). There had been no more contact with the interfaces, thus children had to recall their experience.

FIGURE 5-12 Children from group A and from group B drawing what they still remembered.

The number of elements that the children still remembered and drew after the period of time elapsed can be seen as an indicator of the deepness of their experience. Children and adults as well, tend to forget the things that they do not find interesting or important, and in opposition according to the Pollyanna principle, people are more likely to remember things that they liked to do (Read, MacFarlane and Casey 2002). The drawing activity lasted for about 25 minutes in both groups and it took place in the morning at each respectively kindergarten in the activity room. All the children from group A and B were present. In the following tables it is possible to compare the percentage of drawn elements of each group, with the results from the follow up activity, group A (Table 5-16, 5-17) group B (table 5-18, 5-19).

TABLE 5-16 Percentage of drawn elements: group A /interaction with the tangible interface.

% common elements				**% other elements**			
Tooth	germs	brush	fresh tooth	self portrait	researcher	other children	PC
100	100	83,3	27,7	61	16,6	27,7	38,8

TABLE 5-17 Percentage of drawn elements: group A /follow up.

% common elements				**% other elements**			
Tooth	germs	brush	fresh tooth	self portrait	researcher	other children	PC
94,4	94,4	61	16,6	77,7	5,5	0	33,3

TABLE 5-18 Percentage of drawn elements: group B /interaction with the graphical interface.

% common elements				**% other elements**			
Tooth	germs	brush	fresh tooth	self portrait	researcher	other children	PC
100	100	69,5	0	0	0	21,7	21,7

TABLE 5-19 Percentage of drawn elements: group B /follow up.

% common elements				**% other elements**			
Tooth	germs	brush	fresh tooth	self portrait	researcher	other children	PC
95,6	95,6	69,5	0	0	4,34	0	21,7

The results show that the children from both groups still remembered the interaction very precisely.

5.9 SECOND PHASE – EXCHANGING THE INTERFACES

In the second phase of the study the interfaces were swapped for group A and B, to control for any bias in the children that could justify the drawings' differences. Group A, now composed by 21 children, interacted with the graphical interface (table 5-20); group B, composed by 23 children, interacted with the tangible interface (table 5-21). This second interaction was conducted under the same conditions as the first. The score shows the number of drawn elements by the children after interacting with the interfaces.

TABLE 5-20 Group A: interaction with the graphical interface (2nd interaction).

common elements		**other elements**			
score	Average/child	score	Average/child	Total score	Average/child
43 Points	2 Points	24 Points	1,1 Points	67 Points	3 Points

TABLE 5-21 Group B: interaction with the tangible interface (2nd interaction).

common elements		**other elements**			
Score	Average/child	Score	Average/child	Total score	Average/child
69 Points	3 Points	68 Points	2,95 Points	137 Points	5,95 Points

Again the results show that the group that interacted with the tangible interface, now group B, scored (total score) an average of 5, 95 points/child on the total, against 3 points/child from the group that interacted with the graphical interface. In order to confirm if these differences were statistically relevant a non-parametric Mann-Whitney U test for independent groups was applied to the results. Now the mean rank of each child in group A was 12, 38 against 31, 74 from group B. These differences are statistically significant for $p<0.01$ (table 5-22).

TABLE 5-22 Non-parametric Mann-Whitney U test for independent groups (2nd interaction).

Ranks

2nd Interaction	N	Mean Rank	Sum of Ranks
Group A	21	12,38	260,00
Group B	23	31,74	730,00
Total	44		

Test Statistics[a]

	2nd interaction
Mann-Whitney U	29,000
Wilcoxon W	260,000
Z	-5,141
Asymp. Sig. (2-tailed)	,000
Total	44

a. Grouping Variable: Group

5.10 DO GRAPHICAL INTERFACES LOSE THEIR INTEREST AFTER INTERACTING WITH TANGIBLE ONES?

Another interesting data provided by the drawings is that the only group that drew any external elements to the experience was group A, after the interaction with the graphical interface (fig. 5-13/5-15). This group had interacted with the tangible interface almost 5 months ago, and as seen before, their drawings showed a high involvement with the task. Interesting is the fact that their drawings after the second interaction (graphical interface) show external elements to the experience. Eleven drawings out of 21comprise elements[15], such as: Clouds (1), sun (9), flowers (3), grass (2), a hedge (1), rain (1), bird (1), father (2), mother (2), house (1), and the sky (1). Given the variety of different elements drawn it is less likely that they are the result of the influences of the partner.

These results could maybe be understood as a decline in the interest, concentration or motivation of the children. While the drawings made after the interaction with the tangible interface showed that the children focused on the experience that they had (there were no external elements represented), the drawings after the interaction with the graphical interface seem to show a shift of child's attention.

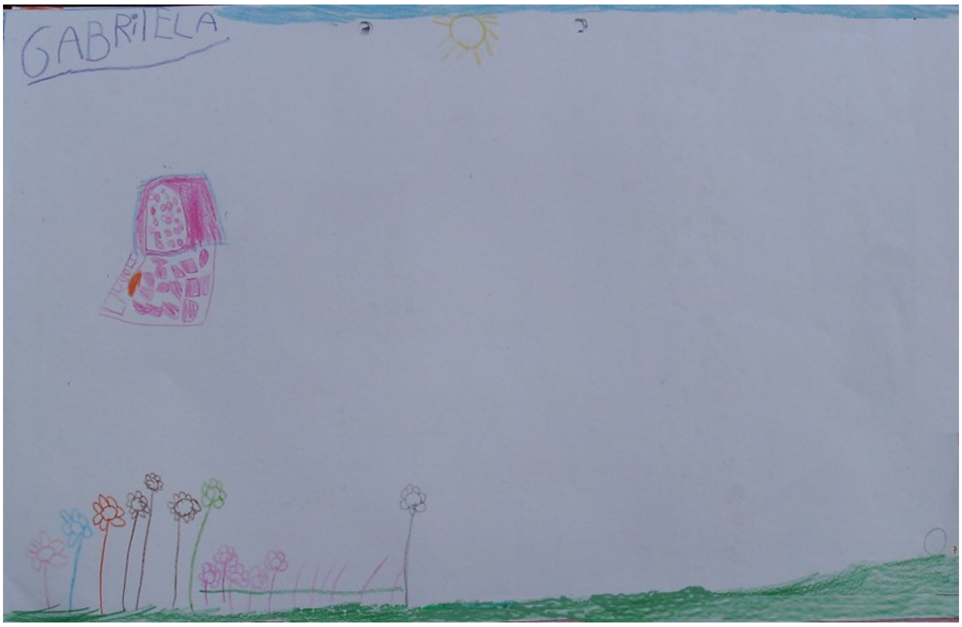


FIGURE 5-13 Drawing showing the graphical interface and elements of nature.

[15] The number in brackets after each element indicates the number of drawings that contain such element.

FIGURE 5-14 Drawing showing the graphical interface and elements of nature.

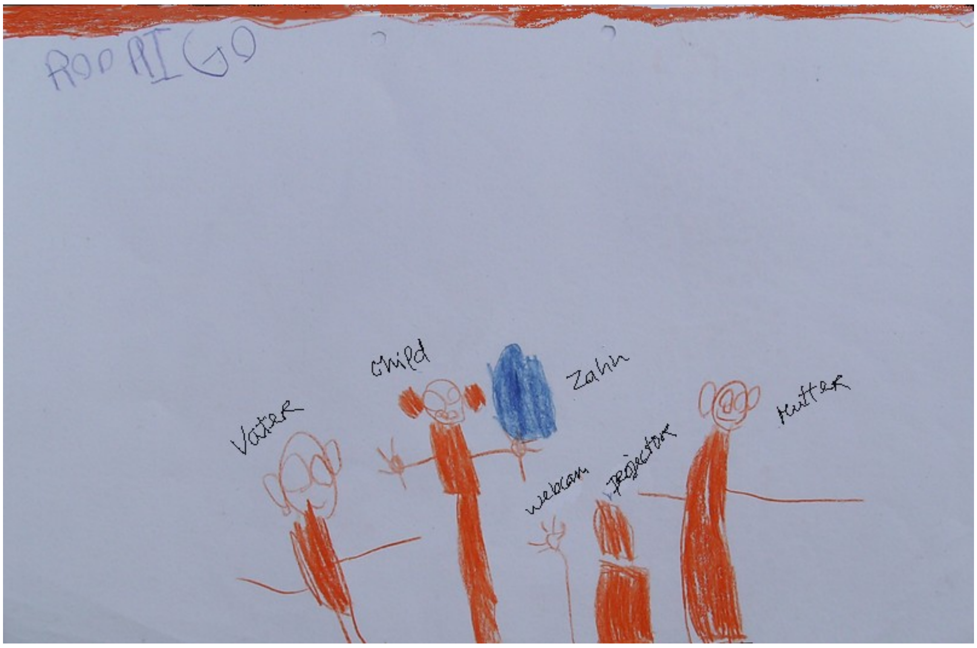


FIGURE 5-15 A drawing showing the tangible tooth (blue) and the family.

Interesting is that one of children's drawings from group A, after interacting with the graphical interface represents the experience he had with the tangible interface showing a boy cleaning the physical tooth and his family around it (fig. 5-15).

5.11 OVERALL COMPARISON OF DRAWINGS TUIs vs. GUIs

Looking at the final results and comparing the score obtained by the two groups together interacting respectively with each of the interfaces (table 5-23, 5-24) in the total 44 children interacted individually with the graphical interface (table 5-23) and 41 children interacted individually with the tangible interface (table 5-24). There is an average advantage of 2 points/child for the tangible interface, showing a preference independently of any of the groups.

TABLE 5-23 Total score obtained by both groups: Group A+B /interaction with the graphical interface (44 children).

common elements		**other elements**		**total score**	
105 Points	average/child 2,38 Points	34Points	average/child 0,77 Points	139 Points	average/child 3,15 Points

TABLE 5-24 Group A+B: interaction with the tangible interface (41 children).

common elements		**other elements**		**total score**	
125 Points	average/child 3 Points	102Points	average/child 2, 48 Points	227Points	average/child 5, 53 Points

5.12 TALKING WITH THE CHILDREN ABOUT THEIR EXPERIENCES

Some days after the second interaction the children from group A (18 children) were interviewed individually about their preferences on the interfaces. Meanwhile there was a time gap of 5 months between the first and the second interaction[16]. The children were asked 3 short questions. The first question was if they still remembered both interfaces, 2nd which interface they preferred and 3rd what they liked most about the experience. We talked with the children in their environment at kindergarten while the other children were painting and doing constructions. The interviews were carried in the reading corner at a small table using children’s chairs. We avoided that way being in a physically superior position (Keats 2000) and

[16] The first interaction took place in 27.11.2008, the second in 27.04.2009.

interviewed one child at a time to avoid children's mutual interference. We tried to be as briefly as possible so that they could quickly join the other. The children seemed to be quite at ease with our presence, since they already knew us from the previous visits to the kindergarten.

Although children's interaction with the tangible interface had been long ago, all answered yes to the 1st question; 13 children preferred the tangible interface, 3 preferred the graphical interface and 2 liked both interfaces. What they liked most about the experience was the big tooth and the brush and that they had to hold a big brush to clean the germs. As mentioned before, the more senses an experience involves, the more involved the children become in it, the more meaning it has for them (Lowenfeld and Brittain 1975:176).

5.13 DISCUSSION

When children make a drawing of a story, they draw the main characters or the scenery that most captured their attention. The vast majority of children between 4 and 6 years (about 70%) draw a *single image*. The concept of the *single image* represents the most important moment of the graphic narrative, and it acts as a symbol for the all story (Coquet 2000:52). It is where the children define the moment or set of elements that they have retained, that most impressed them, and they transmit it through their drawings.

A story can only capture children's truly interest if it raises children's curiosity, stimulating their imagination and really capturing their attention (Bettelheim 1976).

The majority of the children that interacted with the tangible interface drew themselves holding the toothbrush (fig. 5-16, 5-17). They drew not only the tangible objects but also the surrounding scenery, their friends or the other children (fig. 5-18/5-20). Actually some of the drawings are so detailed, that someone, who does not know the system setup, can reconstruct it based on the drawings. This could be an indicator for the level of interest that the experience raised on them; the setup seems to have really captured children's attention and interest. The group of children that interacted with the graphical interface concentrated most in drawing the elements represented on the computer screen.

FIGURE 5-16 Example of children's drawing showing themselves holding the brush.

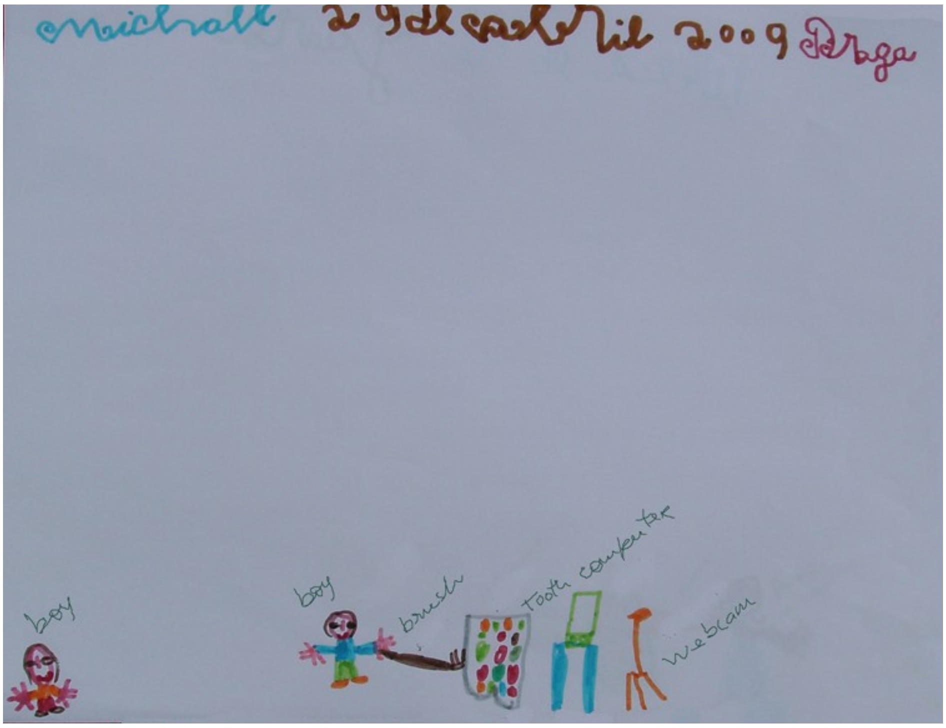


FIGURE 5-17 Example of children's drawing showing themselves holding the brush.

FIGURE 5-18 Example of children's drawing showing themselves, the other children and the surrounding scenery.

FIGURE 5-19 Example of children's drawing showing themselves, the other children and the surrounding scenery.

FIGURE 5-20 Example of children's drawing showing themselves, the other children and the surrounding scenery.

The children seem to be impressed by the size of the interface, by its tangibility; not only most children expressed this during the interviews, but also the percentage of the drawn elements suggests this preference for the big brush and the big tooth.

Concerning the size, it is possible to argue that a graphical interface can also provide a *big size* experience, for instance through the graphical projection of the interaction in the wall. Nonetheless this would still be provided by the mouse, being a two-dimensional instead of a tridimensional experience.

Children seem to be most motivated and to perceive the world around them, if this knowledge is experienced through their own body, with as many senses and sensory experiences as possible, including: thinking, feeling and perceiving (Lowenfeld and Brittain 1975:175).

> Since the child himself is the center of his environment in what may be called a stage of egocentrism[17], those experiences that are directly related to him become the most meaningful.
>
> —— Lowenfeld and Brittain 1975:163.

[17] This is a characteristic of the preoperational stage, which occurs between ages two and six (Piaget 1960).

5.14 SHORTCOMINGS AND LIMITATIONS OF THE WORK

We could not finish without referring some limitations of the study. The conclusions regarding the effectiveness of learning by graphical versus tangible interfaces have to take in account the nature of the content conveyed, a physical, concrete activity. For this type of content and for the age group addressed we can say that the results of the study suggest that the physicality of the interface has advantages over the graphical interface in terms of learning outcomes. The evaluation through Drawing Intervention was not conducted under ideal conditions, due to space limitations it was not possible to seat the children individually, thus it was not possible to avoid potential influences of the partner. In any case, the same conditions applied to the drawings with the TUI as well with the GUI.

The interpretation of the drawings is always subjective, they can be influenced or determined by internal and external factors that we do not know, and therefore it was important to use more than one evaluation method such as the questionnaires and the interviews. The three methods together seem to give reliable information about children's learning outcomes.

Despite these limitations, Drawing Intervention seems to be a promising method to work with children of 4 and 5 years of age, therefore we plan to continue to validate and optimize it.

CHAPTER 6 *Conclusions and future work*

Cleaning the physical tooth, and holding a real brush in their hands provides children a multiple sensory experience, whereby they are integrant part of it. Children are spatially situated inside of the experience itself, being the main actors in a story, whereas by cleaning the virtual tooth they do not have this sensory experience of holding the brush in their hands, and moving around the tooth. Here children are not an integrant part of the experience; they are a kind of spectators rather than actors.

Another important aspect provided by tangible interfaces can be seen in terms of how they meet children's conception of the word, which is still animistic at this age.

> A child's conception of his world may be so bound up with himself that he may even confuse his own thoughts and feelings with those things around him. If a chair falls over, he is concerned about the chair's being hurt (Piaget1960). It is as almost as though he were the chair. We can say, therefore, that the child at this stage is emotionally involved in his spatial relationships.
>
> ——Lowenfeld and Brittain 1975:163

We are convinced that the novelty of the tangible interfaces, their capacity of transforming inanimate daily life objects into animated things, *the tangible magic* (Xu, Read and Sheehan 2008) meets children's conception of the world, raising their interest, curiosity and willingness to try out and explore new materials, through which they can experience the world in a new way.

The results of the questionnaires and the interviews support and validate the conclusions suggested by the drawings. Since the questionnaires were given to the parents before exposing children to the interfaces it was possible to infer children's attitudes towards tooth brushing. After the interaction the questionnaires showed a remarkable change of attitude, from the children that interacted with the tangible interface, towards tooth brushing; particularly children's motivation has significantly increased. This was not just a temporary effect since the questionnaires were distributed three weeks after the interaction.

On the contrary no remarkable change was noticed in the group that had interacted with the graphical interface.

As previous investigation in HCI has demonstrated, usability studies with young children are still a wide research field. Although several studies have been done with very young children, few studies have been conducted with 4 years old children. The majority of assessment methods are generally suitable for use with older children. Drawing Intervention seems to be a credible and promising evaluation strategy to work with pre-literate children. It is advisable however to use it in combination with other methods, since the evaluation of drawings is rather subjective and can depend on various internal and external factors, such as motivation (Xu et al. 2009). The combination of the 3 methods: Drawing Intervention, questionnaires and interviews seems to be rather convincing.

6.1 FUTURE WORK

In future work we pretend to continue validating Drawing Intervention as a method for evaluating tangible interfaces with kindergarten children.

We intent to develop a set of small tangible interfaces together with the children themselves, through which they can explore the world around them. These children will be accompanied till they reach primary school; their learning skill and school performance will be than compared with children that never worked with tangible interfaces.

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Questionnaire on preschool children's resistance to the practice of oral hygiene.

On a scale from 1 to 5 please answer the following questions
Regarding that ***1 is the minimum and 5 the maximum score***

1. How would you classify your child's motivation for tooth brushing?

2. How would you classify the degree of your child's opposition to tooth brushing?

3. How would you classify your child awareness of the importance of a good oral hygiene?

4. How do you classify/evaluate the degree of knowledge that your child has about the consequences of a bad oral hygiene?

5. If your child does not like brushing his/her teeth, what are the arguments that he/she gives to avoid doing it?

APPENDIX II

CHILDREN'S RESISTANCE TO TOOTH BRUSHING / ***before the interaction with the interface***

Group A: 16 answers

Score from 1 to 5: 1 minimum 5 maximum

Nº.	Degree of motivation					Degree of opposition					Notion of the importance					Knowledge of consequences				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1			x						x				x					x		
2				x				x						x					x	
3					x	x								x					x	
4				x		x									x					x
5			x					x					x					x		
6	x						x					x								x
7				x																
8		x					x						x						x	
9			x					x				x					x			
10		x						x						x					x	
11					x	x									x					x
12					x	x								x					x	
13			x			x							x					x		
14					x	x									x					x
15				x		x							x					x		
16				x		x								x					x	
sum	**1**	**4**	**12**	**20**	**20**	**8**	**4**	**12**	**4**	**0**	**0**	**4**	**15**	**20**	**15**	**0**	**2**	**12**	**24**	**20**

APPENDIX II

CHILDREN'S RESISTANCE TO TOOTH BRUSHING / ***before the interaction with the interface***

Group B: 17 answers

Score from 1 to 5: 1 minimum 5 maximum

Nº	Degree of motivation					Degree of opposition					Notion of the importance					Knowledge of consequences				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1			x				x							x					x	
2			x			x									x				x	
3				x		x								x					x	
4				x					x					x						
5			x				x							x					x	
6				x		x									x					x
7			x			x							x			x				
8			x				x						x					x		
9				x			x							x					x	
10					x	x							x				x			
11				x		x								x					x	
12					x	x									x					x
13				x		x							x					x		
14			x							x				x					x	
15			x				x					x					x			
16					x	x									x					x
17					x	x									x					x
sum	**0**	**0**	**21**	**24**	**20**	**10**	**10**	**0**	**4**	**5**	**0**	**2**	**12**	**28**	**25**	**1**	**4**	**6**	**28**	**20**

APPENDIX II

CHILDREN'S RESISTANCE TO TOOTH BRUSHING / ***after the interaction with the interface***

Group A – interaction with the tangible interface: 13 answers.

Score from 1 to 5: 1 minimum 5 maximum

Nº	**Degree of motivation**					**Degree of opposition**					**Notion of the importance**					**Knowledge of consequences**				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1					x	x							x					x		
2					x	x									x					x
3				x			x							x					x	
4		x							x				x						x	
5					x	x									x					x
6				x			x							x					x	
7				x		x							x					x		
8				x		x								x					x	
9					x	x								x					x	
10					x	x							x					x		
11					x	x									x					x
12					x	x								x					x	
13					x	x							x					x		
sum	**0**	**2**	**0**	**16**	**40**	**10**	**4**	**0**	**4**	**0**	**0**	**0**	**15**	**20**	**15**	**0**	**0**	**12**	**24**	**15**

APPENDIX II

CHILDREN'S RESISTANCE TO TOOTH BRUSHING / ***after the interaction with the interface***

Group B – Interaction with the graphical interface: 14 answers

Score from 1 to 5: 1 minimum 5 maximum

Nº	**Degree of motivation**					**Degree of opposition**					**Notion of the importance**					**Knowledge of consequences**				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1			x				x						x						x	
2			x				x						x			x				
3					x	x								x					x	
4				x				x					x					x		
5				x		x								x					x	
6				x		x								x					x	
7				x			x							x					x	
8									x						x					x
9				x		x								x				x		
10			x				x						x			x				
11				x		x								x					x	
12					x								x					x		
13				x		x								x				x		
14				x			x								x					x
sum	**0**	**0**	**9**	**32**	**10**	**6**	**10**	**3**	**4**	**0**	**0**	**0**	**15**	**28**	**10**	**2**	**0**	**12**	**24**	**10**

APPENDIX III

Drawing grids after the interaction with the graphical and the tangible interface

FIRST INTERACTION

Group A – Local: college Teresiano   Date: 27.11.08

Interaction: tangible interface
18 children   age: 4 years

Group B – Local: college D. Diogo   Date: 19.11.08

Interaction: graphical interface
23 children   age: 4 years

FOLLOW UP

Group A – Local: college Teresiano Date: 16.12.08

Without interaction
18 children   age: 4 years

Group B – Local: college D. Diogo   Date: 16.12.08

Without interaction
23 children   age: 4 years

SECOND INTERACTION

Group A – Local: college Teresiano Date: 27.04.09

Interaction: graphical interface
21 children age: 4 / 5 years

Group B – Local: college D. Diogo   Date: 29.04.09

Interaction: tangible interface
23 children age: 4 / 5 years

APPENDIX III

First Interaction: *Group A – Interaction with the tangible interface: 27.11.2008 / 18 children*

Common elements						**other elements**						
nº	tooth	germs	brush	fresh tooth	**score**	self port	res.	other child.	PC	*	**score**	**total**
1	x	x	x		3			x	x	x	3	6
2	x	x	x		**3**			x			**1**	**4**
3	x	x	x		3			x	x	xx	4	7
4	x	x			**2**				x	x	**2**	**4**
5	x	x	x	x	4	x			x		2	6
6	x	x			**2**	x					**1**	**3**
7	x	x	x	x	4	x					1	5
8	x	x	x	x	**4**	x					**1**	**5**
9	x	x	x		3				x	xx xx	4	7
10	x	x	x		**3**	x	x	x		x	**4**	**7**
11	x	x	x	x	4	x	x		x		3	7
12	x	x	x		**3**	x	x				**2**	**5**
13	x	x	x		3	x					1	4
14	x	x			**2**	x					**1**	**3**
15	x	x	x		3	x			x		2	5
16	x	x	x		**3**			x			**1**	**4**
17	x	x	x	x	4	x					1	5
18	x	x	x		**3**						**0**	**3**
sum	18	18	15	5	**56**	11	3	5	7	9	**34**	**90**

Legend: res. - researcher
*other elements from the setup

APPENDIX III

First Interaction**:** *Group B – Interaction with the graphical interface: 19.11.08 / 23 children*

Common elements						**Other elements**					
nº	tooth	germs	brush	fresh tooth	score	self port	res.	other child.	PC	score	total
1	x	x	x		**3**					**0**	**3**
2	x	x	x		**3**					**0**	**3**
3	x	x	x		**3**					**0**	**3**
4	x	x	x		**3**					**0**	**3**
5	x	x	x		**3**					**0**	**3**
6	x	x	x		**3**					**0**	**3**
7	x	x			**2**				x	**1**	**3**
8	x	x			**2**				x	**1**	**3**
9	x	x			**2**				x	**1**	**3**
10	x	x			**2**				x	**1**	**3**
11	x	x			**2**				x	**1**	**3**
12	x	x	x		**3**					**0**	**3**
13	x	x	x		**3**					**0**	**3**
14	x	x	x		**3**					**0**	**3**
15	x	x	x		**3**					**0**	**3**
16	x	x			**2**					**0**	**2**
17	x	x	x		**3**					**0**	**3**
18	x	x	x		**3**					**0**	**3**
19	x	x	x		**3**			x		**1**	**4**
20	x	x	x		**3**			x		**1**	**4**
21	x	x	x		**3**			x		**1**	**4**
22	x	x			**2**			x		**1**	**3**
23	x	x	x		**3**			x		**1**	**4**
sum	23	23	16	0	**62**	0	0	5	5	**10**	**72**

Legend: res. - researcher

APPENDIX III

Follow up - no interaction*: Group A - 16.12.2008 /18 children*

Common elements						**Other elements**						
nº	tooth	germs	brush	fresh tooth	**score**	self port	res.	other child.	PC	*	**score**	**total**
1	x	x	x		**3**						**0**	**3**
2	x	x	x		**3**	x	x			xx	**4**	**7**
3	x	x	x		**3**	x					**1**	**4**
4	x	x			**2**	x					**1**	**3**
5	x	x	x		**3**	x				x	**2**	**5**
6	x	x			**2**						**0**	**2**
7	x	x	x		**3**					x	**1**	**4**
8	x	x	x		**3**	x			x		**2**	**5**
9	x	x			**2**	x					**1**	**3**
10	x	x	x		**3**	x			x		**2**	**5**
11	x	x	x		**3**	x					**1**	**4**
12			x	x	**2**	x			x	x x x	**5**	**7**
13	x	x	x		**3**	x			x		**2**	**5**
14	x	x			**2**	x					**1**	**3**
15	x	x			**2**	x					**1**	**3**
16	x	x	x	x	**4**	x					**1**	**5**
17	x	x			**2**				x		**1**	**3**
18	x	x		x	**3**	x			x		**2**	**5**
sum	17	17	11	3	**48**	14	1		6	7	**28**	**76**

Legend: res. - researcher
*other elements from the setup

APPENDIX III

Follow up- no interaction*: Group B - 16.12.2008 /23 children*

Common elements						**Other elements**					
nº	tooth	germs	brush	fresh tooth	**score**	self port	res.	other child.	PC	**score**	**total**
1					0				x	1	1
2	x	x			2				x	1	3
3	x	x	x		3					0	3
4	x	x	x		3		x		x	2	5
5	x	x			2					0	2
6	x	x	x		3					0	3
7	x	x	x		3					0	3
8	x	x	x		3					0	3
9	x	x	x		3					0	3
10	x	x	x		3					0	3
11	x	x			2					0	2
12	x	x			2					0	2
13	x	x			2					0	2
14	x	x	x		3					0	3
15	x	x	x		3				x	1	4
16	x	x	x		3					0	3
17	x	x	x		3					0	3
18	x	x	x		3					0	3
19	x	x			2					0	2
20	x	x	x		3					0	3
21	x	x	x		3					0	3
22	x	x	x		3					0	3
23	x	x	x		3				x	2	5
sum	22	22	16	0	**60**	0	1	0	5	7	67

Legend: res. - researcher

APPENDIX III

Second Interaction *:Group A – Interaction with the graphical interface: 27.04.09/ 21 children*

Common elements						**Other elements**							
nº	tooth	germs	brush	fresh tooth	**score**	self port	res.	other child.	PC	*	**score**	**total**	external elements
1	x	x	x		3						0	3	
2	x	x			2					x	1	3	
3	x	x			2				x		1	3	
4	x	x			2				x		1	3	clouds, sun
5	x	x			2				x	x	2	4	sun
6	x	x			2				x		1	3	flowers, sun, grass
7	x	x			2				x		1	3	flowers, sun, grass
8	x	x			2				x		1	3	flowers, sun, hedge
9	x	x			2			x			1	3	sun
10	x	x			2				x		1	3	
11	x	x			2						0	2	
12	x	x			2				x		1	3	
13	x	x			2			x			1	3	sun
14	x	x			2			x	x		2	4	
15	x	x			2			x			1	3	
16		x			1			x			1	2	
17	x	x	x		3			x		x	2	5	father, mother
18		x			1			x		x	2	3	father, sun, rain, mother, house,
19	x	x	x		3			x	x		2	5	sun, bird
20	x	x			2				x		1	3	
21	x	x			2				x		1	3	sky, sun
sum	19	21	3	0	**43**	0	0	8	12	4	**24**	**67**	

Legend: res. - researcher
*other elements from the setup

APPENDIX III

Second Interaction :*Group B – Interaction with the tangible Interface: 29.04.2009 / 23 children*

Common elements						Other elements						
nº	tooth	germs	brush	fresh tooth	**score**	self port	res.	other child.	PC	*	**score**	**total**
1	x	x	x		3			X			1	4
2	x	x	x		**3**		x	x			**2**	**5**
3	x	x	x		3			x			1	4
4	x	x	x		**3**			x			**1**	**4**
5	x	x	x		3	x					1	4
6	x	x	x		**3**	x					**1**	**4**
7	x	x	x		3			x			1	4
8	x	x	x		**3**			x			**1**	**4**
9	x	x	x		3			x			1	4
10	x	x	x		**3**	x		x	x	x,x xx	**7**	**10**
11	x	x	x		3	x		x		xx	4	7
12	x	x	x		**3**			x	x	xxx x	**6**	**9**
13	x	x	x		3			x	x	xxx x	6	9
14	x	x	x		**3**				x	xxx	**4**	**7**
15	x	x	x		3	x		x	x	xx	5	8
16	x	x	x		**3**			x	x	xxx x	**6**	**9**
17	x	x	x	0	3			x	x	xx	4	7
18	x	x	x		**3**		x	x			**2**	**5**
19	x	x	x		3	x				x	2	5
20	x	x	x		**3**			x	x	xx	**4**	**7**
21	x	x	x		3	x			x	xx	4	7
22	x	x	x		**3**	x				x	**2**	**5**
23	x	x	x		3	x				x	2	5
sum	23	23	23		**69**	9	2	16	9	32	**68**	**137**

Legend: res. - researcher
*other elements from the setup