TUIs vs. GUIs: comparing the learning potential with preschoolers

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Abstract: In an effort to better understand the learning potential of a tangible interface we conducted a comparison study between a tangible and a traditional graphical user interface for teaching preschoolers[1] about good oral hygiene. The study was carried with two groups of children aged four to five years. Questionnaires to parents, children's drawings and interviews were used for data collection and analysis, and revealed important indicators about children's change of attitude, involvement and preferences for the interfaces. The questionnaires showed a remarkable change of attitude towards tooth brushing in the children that interacted with the tangible interface; particularly children's motivation increased significantly. Children's drawings were used to assess their degree of involvement with the interfaces. The drawings from the children that interacted with the tangible interface were very complete and detailed suggesting that the children felt actively involved with the experience.
The results suggest that the tangible interface was capable of promoting a stronger and long-lasting involvement having a greater potential to engage children, therefore potentially promoting learning. Evaluation through drawing seems to be a promising method to work with pre-literate children; however it is advisable to use it together with other methods.

Keywords: Tangible Interfaces, Interaction Design, Children and Technology, Oral Hygiene, Learning, Education.

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[1] In Portugal, children enter preschool at the age of three and they attend it till entering school, normally at the age of six.

Introduction

Tangible interfaces allow users to interact with digital information through physical objects, in contrast with traditional graphical user interfaces* where the interaction is done through the keyboard, mouse and display. Tangible interfaces are less machine-centered, more user and task-centered, offering new opportunities for different types of public to interact with digital content. In the field of education, tangible interfaces open a new opportunity for making abstract contents graspable and perhaps more understandable to children [1]. A multitude of technological developments, such as projection systems, cameras and processing power at increasing lower prices will enable in a near future the integration of tangible interfaces in the process of education.

Following this trend, numerous examples of tangible interfaces have been developed in recent years targeting the educational domain, however their impact on learning when compared to educational software employing traditional GUIs is still not clear [2]. Most evaluation studies of the benefits of TUIs are rather informal [2] and more empirical studies are needed [3]. This study aims to better understand the learning potential of a TUI versus a traditional GUI. We have compared children's attitude, involvement and preferences relatively to both interfaces, assuming that these are key elements in the process of learning, and may positively influence children's willingness to learn. Both interfaces address the topic of the oral hygiene.

The research was conducted with two groups of four to five years old children, an age group that poses some evaluation challenges given their limited ability of verbal or written expression, making the majority of assessment methods more appropriate to be used with older children. In order to outwit these difficulties and to get reliable data as possible three evaluation methodologies were used to assess children's involvement and preferences with the interfaces: questionnaires - the parents were asked to fulfill a questionnaire about their children's attitude toward tooth brushing before and after the interaction; interviews - the children were asked about their preferences, and drawings - the children draw their experience after interacting with the interfaces.

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* Traditional graphical user interfaces is used to distinguish from other graphical interfaces that still rely on a display but incorporate novel interactions such as voice, gestures, and so on.

Drawings have an historical tradition as a method of evaluating cognitive development; recently they have been used to evaluate children's approach to technology [4,5,6,7]. In the process of comparing a TUI versus a GUI this study investigated the reliability and the potential of drawings as an evaluation methodology and whether it is a reliable tool to work with preschoolers.

Physical educational interfaces

The importance of using physical objects for the development of the child has been extensively studied. Piaget [8] and the *constructivism* showed that learning is a dynamic process whereby children actively construct knowledge from their interaction and experiences with the word, people and things. Papert and the *constructionism* added the idea that children need concrete materials to interact with in order to *construct* knowledge, thus the vital importance of the learning tools [9]. Interacting with the right materials originates a *creative thinking spiral*: 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* [10].

This pedagogical approach goes back to Friedrich Froebel who developed a collection of *gifts*, 20 physical objects, such as balls, strings, sticks and blocks. The *gifts* represented forms that can be found in nature and in daily life and were used to help teaching arithmetic, geometry and reading [11]. Building on Froebel's *gifts* Maria Montessori developed materials for older children, developing a pedagogical teaching method named *Montessori Method* [12]. The method, where manipulatives play a central role, has inspired a network of schools spread over the world.

Inspired by Froebel and Montessori, Zuckerman et al. [1] propose 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) manipulatives that enable modeling of abstract concepts such as the representation of numerical proportions, and relationships between quantities.

In the past two decades there has been a growing interest in developing digital manipulatives [13] - also known as TUIs - to promote learning. Groups like the

Lifelong Kindergarten at MIT Media Laboratory or the MIT Tangible Media Group, among others, have developed a series of TUIs that allow children to explore, to simulate and to create knowledge through direct manipulation. These digital manipulatives go back to the notion of Froebel´s *gifts* taking advantage of the technology, allowing for richer experiences to be developed.

The challenges of evaluating technology for and with preschoolers

In the last 12 years, in parallel with the development of new interfaces for children, there has been a growing interest on the evaluation of interactive technology for children. Special emphasis is given to the work of Hanna, Risden and Alexander [14]. Despite the growing interest in this field most evaluation studies of the benefits of tangible interfaces are rather informal [2] and there are very few empirical studies comparing tangible and graphical interfaces. One of these studies was carried by Fails et al. [15] with children aged four to six years old comparing a tangible and a graphical version of a Hazard Room Game to teach 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.

One of the greatest difficulties in evaluating technology for/with young children relies on the fact that most usability methods that are commonly used with children - think aloud [16], talk aloud [17], peer tutoring [18], the fun toolkit [19] - are more appropriate to be used with older children since younger children may have difficulties in expressing themselves clearly through words. Additionally as logical reasoning and abstract thinking are not yet fully developed children might have difficulties doing multiple tasks and abstract task formulations [20]. Some methods that can be used with younger children, where they can express their opinions without using words, are the funometer [19], the sticky-ladder rating scale [21], or the this-or-that method [22].

Drawing intervention

More recently, drawing intervention has been used as an evaluation method to rate children's approach to technology, particularly to measure the amount of fun that children experience by interacting with different interfaces [4,5,6].

At about four years of age and until around seven children enter the *Preschematic Stage*; a period that marks the beginning of *graphic communication* [23], children make the first attempts to represent their environment, consciously creating forms that have a relationship to the world around them. At this stage children are not interested in realistic representations, since it would interfere with their conception of the structure and characteristics of the objects [24:97]. They do not see the same details as an adult; they see them only to the extent that they interest them [23]. What does not matter for them is as if it would not exist; thus what children draw had a preponderant weight in their mind.

Drawings allow children to represent their feelings, thoughts and preferences, and may give important additional knowledge about children's approach to technology. In this work we employ drawing intervention as a method to capture what caught children's attention and their level of involvement with each interface.

Comparing TUIs vs. GUIs

At the age of three, children begin to acquire the habit of brushing their teeth and it is part of the Portuguese kindergarten's educational program to promote this practice. We chose this topic as the curricular subject to address and compared the learning potential of a tangible versus a traditional graphical user interface. Our research question was: how does the interaction with two different interfaces – a TUI and a GUI - reflects on children's attitude towards oral hygiene?

To answer this question we developed two similar interfaces differentiated by one being a TUI and the other a traditional GUI.

Two interfaces for teaching oral hygiene

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

Fig.1 - Two screenshots of the GUI.

The TUI consists of a large physical tooth with a projection of virtual germs on its surface (fig. 2). Children interact by cleaning the germs with a 70 cm long toothbrush; they brush the tooth and the germs disappear with each pass of the brush.

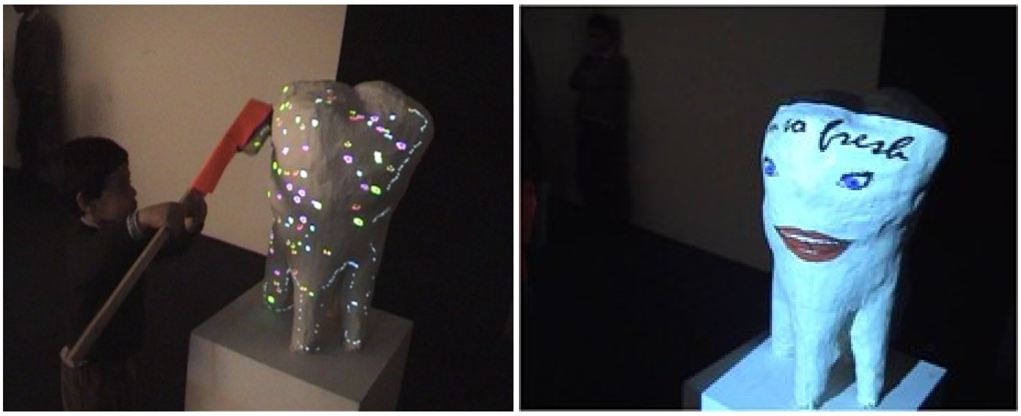

Fig. 2 – A child interacting with the TUI (left) and the cleaned tooth (right).

In both interfaces the software and the game functionality is the same, 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 of the germs and the *smiling* face are common to both interfaces.

Methodology

The study was carried with two groups of preschoolers aged four to five years; 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.

Three different methodologies were used to access how the interaction with the interfaces reflected in children's attitude relatively to the topic addressed. First, children's attitude toward tooth brushing was assessed before and after being exposed to the interfaces by asking their parents to answer a questionnaire. Drawings were used after children's interaction to assess their degree of involvement with the interfaces. Finally, the children were interviewed about their preferences and expressed their likes and dislikes about the interfaces.

The drawing evaluation was divided in two assessment phases: first group A interacted with the TUI and group B interacted with the traditional GUI; five months later there was a second interaction whereby the interfaces were changed, group A interacted now with the traditional GUI, while group B interacted with the TUI. After both tests the children were asked to draw their experience.

Collecting children's attitudes towards oral hygiene

Before testing the interfaces the parents were asked to answer a questionnaire about their children's resistance to tooth brushing (table1). With those questionnaires the researchers intended to ensure that both groups of children had similar motivation for the oral hygiene and also to collect a baseline to assess changes in children's behavior.

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 and five the maximum score.

Table 1- 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. 16 parents from group A and 17 parents from group B returned the fulfilled questionnaire (table 2).

The comparison of the two groups showed that they were quite similar; in both groups the children were motivated for tooth brushing, and knew its importance. The Non-parametric Mann-Whitney U test, revealed that there were no statistical significant differences between the two groups for the level of probability $p < 0.5$, which means that the groups were similar, necessary condition to infer the differences later assigned to the experimental treatment [25].

Table 2 - 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

First interaction with the interfaces.

One week following the collection of the first questionnaires both interfaces were tested (fig. 3). The tests were carried in two consecutive days, one day for each group and took place during the morning at each respectively kindergarten. Group A - 18 children - interacted individually with the TUI, which took about 30 minutes, while one child was brushing the tooth, the others sat around and were giving advice. Group B - 23 children - interacted with the GUI, which took about 40 minutes. The children sat around the computer while one at a time played the computer game.

Fig. 3 - Children from group A interacting with the TUI (left) and children from group B interacting with the GUI (right).

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 TUI was taken away, the GUI was turned off and in both groups children were asked to draw what they had seen.

Using questionnaires to collect data after the interaction

In order to assess and compare the TUI versus the GUI in respect to their ability to influence children's attitude toward tooth brushing and verify if that influence was a lasting one, we waited three weeks after the initial interaction. After that time the parents of the children that had interacted with the interfaces were asked once more to answer a questionnaire similar to the initial one. Parents were also encouraged to write any possible comments their children had made at home about the toothbrush 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.

Analysis of the questionnaire results

The second questionnaires were received five weeks after children's interaction with the interfaces: 13 parents from group A and 14 parents from group B answered it (table 3).

Table 3 - 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 comparison of the two groups after the interaction shows group A (TUI) relatively to group B (GUI) having a higher motivation for tooth brushing (0, 54 points), a decrease of opposition (0, 39 points), a higher notion of the importance of oral hygiene (0, 06 points) and a higher notion of the consequences of a bad oral hygiene (0, 49 points). In order to test the significance of those differences, a non-parametric Mann-Whitney U test for independent groups was chosen because the conditions for normal distribution were not fully guaranteed: high values of kurtosis indicate that we should be cautious in using a statistical test that assumes a normal distribution [27]. The only statically significant difference found was the degree of motivation with a value of $U=45$ and a value of $p=0, 044$, which is significant at the level of probability of 5%.

The comparison of each group before / after the interaction shows that in group B (GUI) there was no noticeable change in children's attitude toward tooth brushing (table 4).

Table 4- Group B, results before and after the interaction with the GUI.

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

On the contrary, group A (TUI) shows a general increase of score (table 5). Children's motivation increased significantly (0,90 points), their degree of opposition to tooth brushing decreased (0,49 points) suggesting a change of attitude.

Table 5- Group A, results before and after the interaction with the TUI.

	Degree of motivation	Degree of opposition	Notion of importance	Knowledge of consequences
before interaction	3,56	1,87	3,6	3,87
after interaction	4,46	1,38	3,85	3,92

Applying the Wilcoxon Sign Rank Test for related samples showed significant statistical differences for motivation (z = -2, 142; p = 0, 032), but not for the other three dimensions of the questionnaire. On the contrary the results of group B are not statistically significant for any variable considered.

Qualitative results

The questionnaires gave parents the opportunity to write their comments and the remarks done by their children about the experience. In 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 most comments were given by the parents explaining why their children do not like to brush their teeth. There were only two comments where children referred the experience with the interface (table 6). In group A (table 7) there were five comments from the children referring to the experience. The comments from the children and their parents (table 8) suggest that the TUI had a stronger impact on the children. In fact, while only two of the children who interacted with the traditional GUI talked about the experience at home, five children from the other group talked about the TUI at home. This difference is significant since group A was composed by 18 and group B by 23 children. Certainly one can point out the novelty effect to justify at least partially the preference for the TUI. In either condition this game was new for the children, but certainly a computer game would be more familiar than the tangible interface. This issued is discussed later when presenting the limitations of the work.

Table 6 - Remarks made by the children from group B at home (translated from Portuguese).

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 7- Remarks made by the children from group A at home (translated from Portuguese).

group A tangible interface	*She liked to see a big tooth and to brush it.*
	He told us that there was a big tooth with germs that he cleaned with a big brush, to show how important tooth brushing is.
	He liked to see a tooth speaking.
	She told us that she 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 8 - Comments from the parents: group A and B (translated from Portuguese).

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.*

Using drawings to evaluate children's experiences

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 the 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 content that was being promoted.

Building on theories that children's drawings reveal how they understand the world, what is important for them, and that children do not represent objects that they find unnecessary or uninteresting [23, 24, 26], our approach was to determine the number and nature of the elements that children represented – assuming that the more detailed and complete the drawings were, the more involving the experience had been.

As previously mentioned, the data collection was divided in two assessment moments: first group A interacted with the TUI and group B interacted with the traditional GUI; five months later there was a second interaction whereby the interfaces were changed: group A interacted with the traditional GUI and group B interacted with the TUI. After both tests the children were asked to draw their experience.

To evaluate the drawings the elements present were grouped into two different groups (table 9): *central elements* which were part of the experience and *other elements*. Each element was scored a point, so the children got a point by each drawn element. The score of elements for both groups was then compared.

Table 9 – Scored elements.

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

The researcher was considered as an element given that it was present in several drawings, especially in the first interaction. After each interaction the 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.

When working with four to five years old children what counts is their *intention* to draw certain elements not the way they represent it [26]. For instance there is no difference if the child represented the computer just by drawing a circle around the tooth or if s/he drew a computer screen, the keyboard and the mouse. In such a situation the computer counts as one represented element in both drawings.

The coding of the drawings was carried by two different coders, following a blind review, so none of them new with which interface the groups had interacted.

Table 10 - Group A: interaction with the TUI (1st interaction).

	central elements		**other elements**			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	56Points	3 Points	34Points	1,88 Points	90Points	5 Points
Coder 2	55 Points	3 Points	38 Points	2 Points	93 Points	5 Points

Table 11 - Group B: interaction with the GUI (1st interaction).

	central elements		other elements			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	62Points	2,69 Points	10Points	0,43 Points	72Points	3 Points
Coder 2	63 Points	2,7 Points	9 Points	0,39 Points	72 Points	3 Points

The results (table 10,11)[2] show that both groups drew the *central elements* to both interfaces: group A scored an average of 3 points/child, group B scored 2, 69 points/child (coder 1) or 2,7 points/child (coder 2). Yet the significant differences between the groups concern the *other elements* with an average total score of 5 drawn elements for group A against 3 drawn elements from group B. 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 were not fully guaranteed [27]. The mean rank of each child in group A was 29, 89 against 14, 04 from group B, differences statistically significant for $p<0.01$.

Analyzing the drawings from the children that interacted with the TUI (fig. 4), we observe 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 action, an indicator of a high level of involvement with the experience [26]. Interesting is also that several children drew not only themselves but also other children. This indicator may suggest that they felt involved in a group experience.

Fig. 4 - Two drawings after the interaction with the TUI. Self portrait holding the brush, the tooth with the germs and the cleaned tooth (left) and two friends holding the brush and cleaning the tooth (right).

[2] These tables replace the tables presented in [7].

The children that interacted with the traditional GUI drew mostly just the tooth with the germs and sometimes the brush (fig. 5). Most drawings represent the elements that the children had seen on the screen.

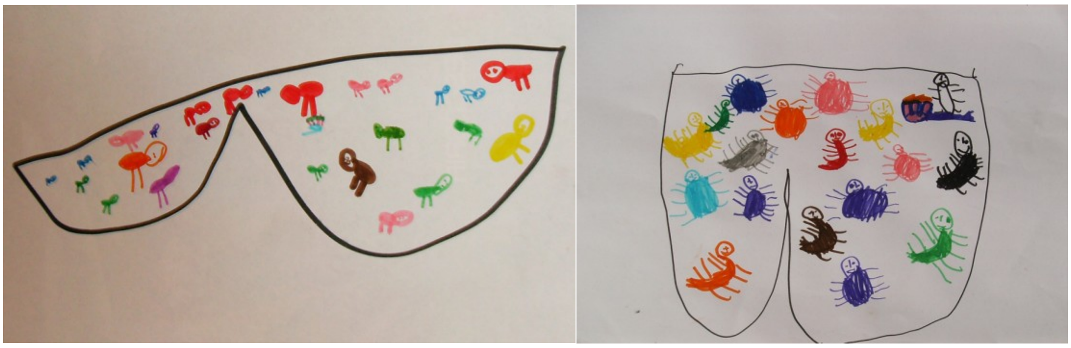

Fig. 5 - Two drawings after the interaction with the GUI. The tooth with the germs (left) and the tooth with the germs and the brush (right).

Five months later - exchanging the interfaces

To control any bias in the groups that could justify the differences between the drawings, five months after the first interaction, the interfaces were swapped. Group A - now composed by 21 children - interacted with the GUI (table 12); group B - 23 children - interacted with the TUI (table 13). The second interaction was conducted under the same conditions as the first. As previously explained, the score shows the number of elements that the children drew after interacting with the interfaces.

Table 12 - Group A: interaction with the GUI (2nd interaction).

	central elements		other elements			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	43Points	2 Points	24Points	1,1 Points	67Points	3,1 Points
Coder 2	45 Points	2 Points	27 Points	1,28 Points	72 Points	3,4 Points

Table 13 - Group B: interaction with the TUI (2nd interaction).

	central elements		other elements			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	69 Points	3 Points	68Points	2,95 Points	137Points	5,95 Points
Coder 2	69 Points	3 Points	57 Points	2,47 Points	126 Points	5,47 Points

Again the results show that the group that interacted with the TUI - now group B - scored on the total an average of 5, 95 points/child (coder 1) or 5,47 points/child coder 2), group B that interacted with the traditional GUI scored on the total 3,1 points/child (coder 1) or 3,4 points/child (coder 2). 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. The mean rank of each child in group A was 12, 38, against 31, 74 from group B, differences statistically significant for $p<0.01$.

Overall comparison of drawings TUI vs. GUI

Looking at the final results and comparing the score achieved by the two groups together interacting respectively with each of the interfaces (table 14,15) they confirm an average advantage of 2 points/child for the TUI, showing a preference independently of any of the groups.

Table 14 - Total score obtained by both groups: Group A+B /interaction with the GUI (44 children).

	central elements		**other elements**			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	105Points	2,3 Points	34Points	0,7 Points	139Points	3,15 Points
Coder 2	108 Points	2,3 Points	36 Points	0,8 Points	144 Points	3,2 Points

Table 15 - Group A+B: interaction with the TUI (41 children).

	central elements		**other elements**			
	score	Average/child	Score	Average/child	Total score	Average/child
Coder 1	125Points	3 Points	102Points	2, 4 Points	227Points	5, 5 Points
Coder 2	124 Points	3 Points	95 Points	2,2 Points	219 Points	5,2 Points

The intercoder reliability for the entire evaluated drawings was 80%, these values were confirmed by Cohen's kappa (k) with a value of 0.739 [28,29,30].

Interviewing the children about their experiences

Some days after the second round of tests the children from group A - who had interacted with the TUI five months before - were interviewed individually about their preferences regarding the interfaces. The children were asked three short questions: if they still remembered both interfaces; which interface they preferred and what did they liked most about the experience. The interviews were carried in the reading corner at a small table using children’s chairs, thus we weren’t in a physically superior position [31]. One child at a time was interviewed to avoid children’s mutual interference, and 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 previous visits to the kindergarten. All children remembered both interfaces; 13 children preferred the TUI, 3 preferred the GUI and 2 liked both interfaces. What children liked most about the experience was the big tooth with the moving germs on its surface and that they had to hold a long brush to clean it.

Discussion

When children make a drawing of a story, they draw the main characters or the scenery that most captured their attention. About 70% of children between four and six years of age draw a *single image*. The concept of the *single image* represents the most important moment of the graphic narrative, the children define the moment or set of elements that they have retained, that most impressed them, transmitting it through their drawings [26].

The group of children that interacted with the traditional GUI concentrated most in drawing the elements represented on the computer screen. The majority of the children that interacted with the TUI drew themselves holding the toothbrush. They drew, besides the tangible objects, their friends or the other children. Indeed, while one child was handling the 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 children became involved in a group experience that encouraged communication and exchange of experiences, important aspects that promote learning [1].

The children were impressed by the physical tooth covered with unexpected moving germs on its surface and the fact that they could interact with it; actually the children even thought that the germs were alive. Most likely the "magic" that tangible interfaces possess of taking the animation out from the screen into the world plays a central role in that notion. Curious as children are, they could not resist touching the germs - though initially with some anxiety - and were very surprised when they found that the germs would not bite. They were also delighted to clean them with an extra large tooth brush, a very sensory task, as children had to move around the tooth and search for hidden germs. To experience knowledge through their own body, with as many senses as possible, seems to highly motivate children to perceive the world around them [23].

Both Froebel and Montessori already knew how important it is that children experience the world through their senses. As a *Froebel-inspired Manipulative* (FiM) the physical tooth enables modeling of a real world object acting simultaneously as a *Montessori-inspired Manipulative* (MiM) making an abstract concept - the importance of tooth brushing - concrete [1].

Limitations of the work

We could not finish without referring some limitations of the study. The conclusions regarding the learning potential promoted 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 TUI has advantages over the GUI regarding its potential to provide more and long lasting engagement, which are key elements to promote learning.

The novelty effect is certainly an important aspect to factor in the analysis. Children as young as four to five years old in the social context where the study was conducted have been previously exposed to computers. The TUI, on the other hand, brought a new experience for the children leaving an impression on them. Nevertheless the authors do not believe that the novelty is necessarily a problem intrinsic to the study but might rather be a characteristic of the TUI itself. The fact that in a TUI the experience occurs in a share space with the child allows more amplitude for novelty to be introduced in the design of the experience where the discovery with the objects and actions plays an important role. A good designed TUI for learning should make use of that effect, which might not be as easily accomplished in a traditional GUI,

The size of the interfaces was not accounted for in the comparison, and children refer to the dimension of the tooth and the brush in their comments. The GUI could eventually benefit from a larger display or projection system.

The evaluation through drawing 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.

Conclusions and future work

Holding a real brush in their hands and moving around the physical tooth to clean it, provides children with a multiple sensory experience. Children are with all their body and senses spatially situated inside of the experience itself, and that immersion in the task is a key to learning [9]. Cleaning the virtual tooth with the mouse, on the other hand, only provides a very limited kinesthetic interaction. Traditional GUIs offer very *limited communication channels*, *falling short of embracing the richness of human senses and skills people have developed through a lifetime of interaction with the physical world* [32].

This ability to engage children is linked to the fact that TUIs meet children's conception of the word, which is still animistic at this age [8,33].

> 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 (Piaget, 1960). 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 [23: 163].

This ability of projecting life into objects and to interact with them is a key component in learning and development, bringing *empathy at the service of intelligence* [33], *offering, like a good toy, the mental room for playful exploration* [33]: raising children's interest, curiosity and willingness to try out and explore new materials, through which they can experience the world in a new way.

Although it is not always clear in every learning situation that TUIs offer more cognitive advantages for learning over traditional GUIs [2,3], the results of the study suggest that the physicality of the TUI has advantages over the traditional GUI since the former seems to have a stronger potential of engaging children in the activity proposed ,sustaining the assumption that *exploratory* activities might be *particularly well supported* by tangible interfaces [2].

Concerning the methodology used, the conjugation of different methods enabled the verification or denial of drawing intervention. The drawings show a clear tendency whether the children had used the TUI or the GUI, which corresponds to the findings of the questionnaires and interviews. The combination of the three methods: drawings, questionnaires and interviews seems to be rather convincing. In future work we will continue to validate the use of drawing as a method for evaluating technology with preschoolers.

Acknowledgements

We would like to thank Colégio Teresiano and Colégio D. Diogo in Braga, the kindergarten teachers Andreia Oliveira e Rosália Henriques, the parents and all the children for their willingness in helping us conducting this study. We thank the anonymous reviewers for their valuable input in helping us improving the original manuscript.

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