Rematerializing the User Interface of a Digitized Toy Through Tokens: A Comparative User Study with Children Aged Five to Six

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Abstract. This research aims to measure and empirically validate the effect of tangible interaction on children's play experience. During this study a Research Through Design approach was followed. A prototype of a programmable toy train with a Tangible User Interface based on tokens, was build. Afterwards a comparative user test with 34 children aged five to six, was carried out to verify the prototype. The prototype was compared to two similar established toys, one with a Physical User Interface and one with a Graphical User Interface. After the user tests, the participants were questioned to gain insight in which type of user interface is preferred and why. Preference was asked with the use of the This-or-That method. Insight into the reasons of preference towards a user interface was gained through a Laddering method.

Keywords: Empirical validation · Research Through Design · Tangible interaction · Children · Laddering · Comparative user test

1 Introduction

Now that microcontrollers have found their way into almost every consumer product, among which also toys, interactive technologies are increasingly pervading children's lives [1]. There is very little dispute that interactive technologies can have great potential for children's play experience. By digitizing play more interactive, engaging and challenging toys can be created [2]. Yet, the use of interactive technologies by children have raised fears about the perils of exposing children to them [3]. After all, by adding digital functionality to a toy, not only the User eXperience (UX) increases, but the interaction with the toy transforms entirely. The physical toy dematerializes and shifts towards a screen based interface with push buttons. These type of interfaces present data and information in a graphical manner, and are referred to as *Graphical User Interfaces* (GUI). While the specific physical shape of traditional toys offered affordances [4] that appealed to the bodily skills of the child, the interaction with GUI's is limited to button-pushing or a set of standardized gestures on a display [5]. As a

W. Chung and C.S. Shin (eds.), *Advances in Affective and Pleasurable Design*,
Advances in Intelligent Systems and Computing 585, DOI 10.1007/978-3-319-60495-4_2

result of dematerialization [6], physical play decreases. Movements become very precise and take place at finger level rather than at hand, arm or body level [7]. Piaget states that the cognitive and psychomotor development of young children roots on physical manipulation and handling of objects [8]. For this reason, toys with a GUI are not appropriate for young children [9, 10]. An alternative for the GUI which doesn't feel computer-like, but instead stimulates physical play, should be used when designing digital toys for children.

Lately, a number of alternative interaction styles among which *tangible interaction* have emerged. These new interaction styles aim at leveraging human skills in interaction with technology [11]. In particular, a *Tangible User Interface* (TUI) can be seen as a promising alternative for the GUI, when designing digitized toys for children. Tangible interaction is an interaction paradigm that integrates the digital world and the physical environment. It strives for interaction with digital information in a non-digital, physical way by giving computational resources and data material form [12]. Tangible interaction strives towards more matter instead of less. In that way, it makes a move towards *rematerialization* [13] and thus physical play. It is argued that tangible interaction can offer several benefits for children's play experience. Not surprisingly many research studies regarding tangibility and children have been carried out in the past. Yet, the results from these studies are often contradictory [14]. These contradictions are partly caused by poor empirical validation on whether it's really the tangibility that is causing the positive effect [15]. An enhanced play experience can also be caused by brand awareness, previous experiences with the product, usability and various other reasons. Furthermore, a thorough description of the research method is often missing [16].

This research aims to measure and empirically validate the effect of tangible interaction on children's play experience. In order to measure the effect, a prototype of a digitized toy with a TUI was build and tested. For this, a *Research Through Design* approach [17], wherein knowledge is gained through the process of designing, building and testing, was followed. First, a prototype of a programmable toy train with a TUI based on tokens [18] was build. Secondly, the prototype was compared to two established counterparts, one with a merely physical interface and one with a GUI. Multiple *comparative user tests* with children aged five to six were carried out. Finally, after the user tests, the participants were questioned to gain insight in which type of user interface is preferred and why. Preference was asked with the use of the *This-or-That* method [19]. Insight into the reasons of preference towards a user interface was gained through a *Laddering* method [20].

2 Methods and Materials

2.1 Construction of the Prototype

A programmable toy train with a TUI based on tokens was developed and prototyped. The prototype consists of three different type of game elements.

The first type of elements are *non-interactive construction elements* or traditional building blocks. Two different train tracks – a turn and a straight track – with which one can build a railway, were developed. These tracks do not contain any computational components and are thus not interactive.

The second type of elements are *tokens* or digitized blocks, that can be identified by an electronic reading system. These tokens can be placed into the train tracks. Each of these tokens embody a different music note or sound sample. The RFID tag with print is located on top of the token and represents the data – note or sound sample – with which the token is associated. These tokens are graspable objects used to access digital data stored inside the memory of the electronic reading system. This way tangible interaction with digital data is allowed.

The third element is an *electronic reading system* that can read, interpret and act in response to the tokens. An electronic toy train that contains a RFID reader which can identify the tokens in the tracks, was build. It responds to a token by playing the note or sound sample it represents. By pushing the train forward, a sequence of tokens will be identified and as a result the train will play the constructed melody. The train contains all the electronic components (power supply, RFID reader, microprocessor, speaker,…) (Fig. 1).

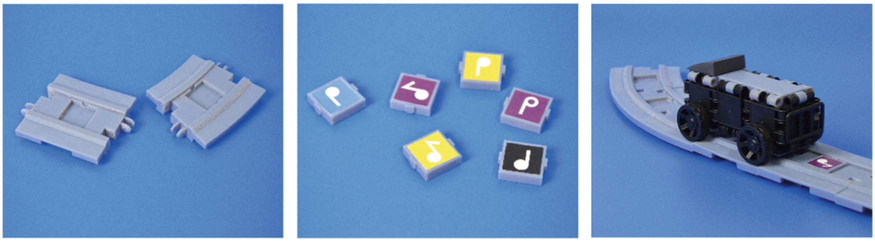

Fig. 1. Prototype of a programmable toy train with a TUI based on tokens. Three different type of game elements. *Left* non-interactive construction elements. *Central* tokens. *Right* electronic reading system.

The prototype can be seen as an exemplary case for digitized toys with a TUI based on tokens. It distinguishes itself from other digital toys by its tangible interaction and its non-digital appearance/form. First of all, the interaction with the digital toy doesn't feel computer-like. The children don't need to navigate through menus or press combinations of buttons, to address to the product's functions. Instead, they can create their own sound compositions by grasping, placing and shifting physical building blocks. Unlike graphical symbols, these building blocks potentially fit our bodies and our repertoire of actions. They are directly graspable and afford to build constructions and therefore stimulate the child to constantly explore new musical possibilities. Furthermore, the prototype is characterized by its traditional, non-digital look. Digital products typically contain a display and/or push buttons. Therefore, the user interface of digital products often look highly similar and need to communicate their functions through icons and text labels, requiring reading and interpretation. The prototype of the programmable train however, communicates its functions and how they should be addressed through its physical form.

2.2 Comparative User Study

To validate the UX of the prototype a comparative user study was carried out. Comparative evaluation studies have the potential to provide more confidence regarding claims for tangibility [15]. Also by providing alternatives, children can compare product attributes and therefore more easily discuss their opinions and experiences [16].

Tested Systems. A comparative user study was carried out with following systems:

– *System 1 - PUI: LEGO duplo train.* Construction toy that allows children to build a railway for a motorized train. Although the train is motorized and can generate sound, the user interface of the toy is merely physical. After all, the game focuses on building a railway with the non-interactive construction elements.
– *System 2 - TUI: prototype of a programmable train.* Prototype of a construction toy, with which children can construct and play their own sound compositions in an intuitive and direct manner. In this study the prototype represents a toy with a TUI.
– *System 3 - GUI: TuneTrain.* An application whereby children can create and play a tune by moving a virtual train over a graphical stave. The touch screen of the smart device allows children to draw a path for the train. The game layout visualizes a musical stave. By pressing on the play symbol, the train follows the path and plays the tune. The interface of the application is graphical (Fig. 2).

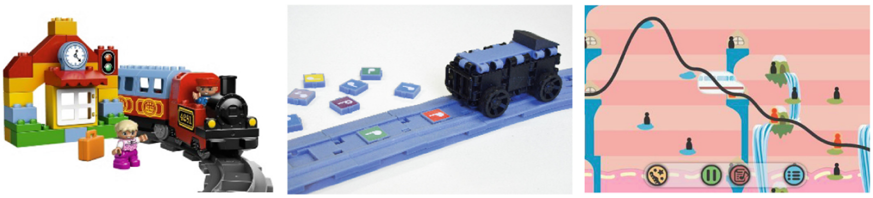

Fig. 2. Tested systems. *Left* LEGO duplo train [21]. *Central* prototype of a programmable toy train. *Right* TuneTrain [22].

Participants. The user tests were conducted at the third grade of kindergarten. Schools provide a well-known environment for the children, as well as adult teachers can help to organize the planned experiment. The testing took place on five days at two different schools located in Antwerp, Belgium. Three different classes participated. In total 34 children (17 boys, 17 girls) aged five to six participated.

Procedure. The participants had to play with each of the three presented systems for a maximum time of 10 min. After playing with each system, the participants were questioned to measure and understand which of the three tested systems got their preference and why. Each child did the test individually. This way the participants could not influence each other’s behavior and responses. One facilitator was present to guide the child and to ask questions at the end of the test. The facilitator obtruded as little as possible and did not give any tasks during play. This way free play was encouraged. The tests and questionnaire at the end of the tests were filmed. Each test had a maximum duration of 35 min. At any instant the participants could indicate if they don't wish to proceed. In that case, they could choose to switch to the next system or to stop the entire test.

Setting. The user tests were conducted in classrooms that were offered by the participating schools. The systems were arranged so that they each had their own place within the room. The camera was placed in the middle of the room so that the camera view could be easily adjusted when one switched to a different system. The interview was conducted in the same classroom where the test took place, in visual contact with all three systems (Fig. 3).

Fig. 3. Setting of the user test.

2.3 Measuring Effect and Validation

After the user tests, the participants were questioned to gain insight in which type of user interface is preferred and why. Preference was asked with the use of the This-or-That method. Insight into the reasons of preference towards a user interface was gained through a Laddering method.

This-or-That Method. The interview starts with asking the participants which system they prefer. To find out which system was preferred most, the This-or-That method was used. The This-or-That method is a comparison scale that is the least cognitively demanding questioning style for children [19]. A series of questions is been asked to the child. *Which game was most fun? Which of the games would you like to receive as a birthday present? Which game would you like to take home? Which would you like to play again?* [23] The child can indicate the preferred system simply by pointing. Afterwards the participants were asked, which of the two remaining systems they found most fun. They again had to answer by pointing. By giving three points for the first choice, two points for the second choice and one point for the last choice, a ranking order could be derived.

Laddering Method. After conducting the This-or-That method, insight into the reasons of preference was asked using Laddering. This method was validated by Vanden Abeele and presented as a promising empirical method to evaluate the effect of tangibility on preschoolers' UX [16]. This method typically consists of a *Laddering* *interviewing technique*, where the user is asked to motivate the reasons why a product was preferred. Subsequently followed by a *Laddering data treatment*, where the Laddering interviews are transcribed and meaningful couplings between product attributes, consequences and values can be derived. These chains of attributes, consequences, and values are also referred to as Ladders. Sometimes the child could not give a motivation or gave a meaningless, random answer. In that case, the Laddering interview was ended quickly.

Statistical Analysis. Anonparametric repeated-measures Friedman test (IBM SPSS Statistics V24) was used to assess the effects of interface type (PUI, TUI, and GUI) on children's play experience (first, second or third choice). Wilcoxon Signed Ranks Test (IBM SPSS Statistics V24) was performed to evaluate within-group pairwise differences. Results are considered statistically significant when $P < 0.050$.

3 Results and Discussion

3.1 Results

Results After This-or-That Method. All of the 34 participants were able to give a first, second and last choice. The mean score is *68*. S1, S2, and S3 respectively scored *56, 67 and 81*. The Friedman test showed that the measured results are significant *(P = 0.010)*. The P-value based on Wilcoxon signed ranks test varies for each pair *(S2–S1, P = 0.218; S3–S2, P = 0.037; S3–S1, P = 0.009)* (Table 1).

Table 1. Results after This-or-That method. Ranking and scores for the three tested systems.

Tested system	S1	S2	S3
User interface	PUI	TUI	GUI
First choice (3)	9	8	17
Second choice (2)	4	17	13
Third choice (1)	21	9	4
Total score	56	67	81
Difference from mean score	−12	−1	+13
Mean rank	1,65	1,97	2,38

Results After Laddering Data Treatment. In this study only system attributes related to the type of interface are taken into account. Other reasons of preference – for example previous experiences with the system – are not valuable within this study. In the table below, all the relevant Ladders are listed by system. In total six relevant Ladders could be put together after conducting the 34 interviews (Table 2).

Discussion on Results. The results of this study show that children aged five to six prefer a GUI over a TUI or PUI. Laddering revealed that the main advantages of a GUI resides in its versatile nature, many possibilities and high level of stimulation. The dynamic nature of a GUI allows to present multiple subgames and musical possibilities

Table 2. Results after Laddering data treatment. Schematic overview of the relevant constructed Ladders.

S	Product attribute	Consequence	Value	Score
S1	Motorized train	Fun to watch the train move on the track	Fun	7/34 = 0.206
S2	Tangible objects	Create something yourself, control, involvement	Fun	3/34 = 0.088
S2	Musical train	Experiencing extraordinary things, surprise effect	Fun	3/34 = 0.088
S3	Touch screen	Immediate feedback, user's actions and system responses are directly linked	Fun	3/34 = 0.088
S3	Large database	Many musical possibilities	Fun	3/34 = 0.088
S3	Versatile application	Many different subgames can be played	Fun	2/34 = 0.059

on one display. Furthermore, the multi touch screen of the GUI makes it possible to give immediate feedback on the user's actions. The user's actions and the system's responses are thus directly linked in time and location. A TUIs qualities, on the other hand, lies in its high level of involvement and surprise effect. The participants had to actually grab the tokens and place them into the tracks, in order to create their own melody. For playing the melody, they had to push the train forward. Their actions take place in the real world. Therefore, the participants got the feeling they were creating something themselves. Another advantage of a TUI can be found in its surprise effect. The participants did not expect any response coming from the non-digital looking train. The moment they heard the notes being played, while pushing the train forward, they were surprised. The difference in preference between a TUI and a PUI is not significant ($P = 0.218$). Mind that, seven of the nine times the PUI was chosen as first choice, was because of its only interactive element, namely the motorized train. It can be presumed that there would be a significant preference for S2 if S1 would not contain any interactive elements.

3.2 Design Recommendations for a Future Prototype

After the Laddering data treatment, multiple design recommendations for a future prototype could be derived. Laddering shows as such its usefulness within an *iterative design methodology* where a cyclic process of prototyping, testing, analyzing, and improving a product or process is performed. Following design recommendations can be formulated:

The train can be divided into a motorized locomotive and a non-motorized railcar which contains the reading system.

More tokens should be developed to enhance the musical and game possibilities of the prototype.

A *Hybrid User Interface* (HUI) [24] can be developed. A HUI is an interface in which users can switch freely between graphical and tangible elements. Elements of both a TUI and a GUI are combined, to take advantage of the best features of each [25].

3.3 Reflection on Method

All participants were able to give a ranking order. This supports that the This-or-That method is a suitable method for measuring children's UX. After the This-or-That method, Laddering was used to gain insights into the reasons of preference. Five of the 34 participants were not able to motivate their preference and thus failed to construct a Ladder that went beyond the choice of preferred system. Eight of the 34 participants' reason of preference was not related to the type of interface. 21 participants constructed a Ladder starting from an interface related attribute. So, in total 21 relevant Ladders were constructed. Like Vanden Abeele previously discovered, these results show that Laddering is possible with children aged five years and older. Furthermore, Laddering proves to be especially useful within an iterative design process.

4 Conclusion

In recent years, it has been argued that tangible interaction can benefit children's play experience. Not surprisingly many research studies regarding tangibility and children have been carried out in the past. Yet, the results from these studies are often contradictory. These contradictions are partly caused by poor empirical validation or deficient research methods. This research aims to measure and empirically validate the effect of tangible interaction on children's play experience. In order to measure the effect, a prototype of a digitized toy with a TUI based on tokens was build. Subsequently the prototype was compared to two similar established toys, one with a PUI and one with a GUI. The results showed that children prefer a GUI over a TUI or PUI. Laddering revealed that the main advantages of a GUI resides in its versatile nature, many possibilities and high level of stimulation. Whereas the main positive aspects of a TUI lies in its high level of involvement and surprise effect. The Laddering technique also allowed to derive multiple recommendations for a future prototype, such as the development of a motorized toy train. Laddering showed as such its usefulness within an iterative design process.

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http://www.springer.com/978-3-319-60494-7

Advances in Affective and Pleasurable Design
Proceedings of the AHFE 2017 International Conference on Affective and Pleasurable Design, July 17–21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA
Chung, W.; Shin, C.S. (Eds.)
2018, XIII, 500 p. 263 illus., Softcover
ISBN: 978-3-319-60494-7