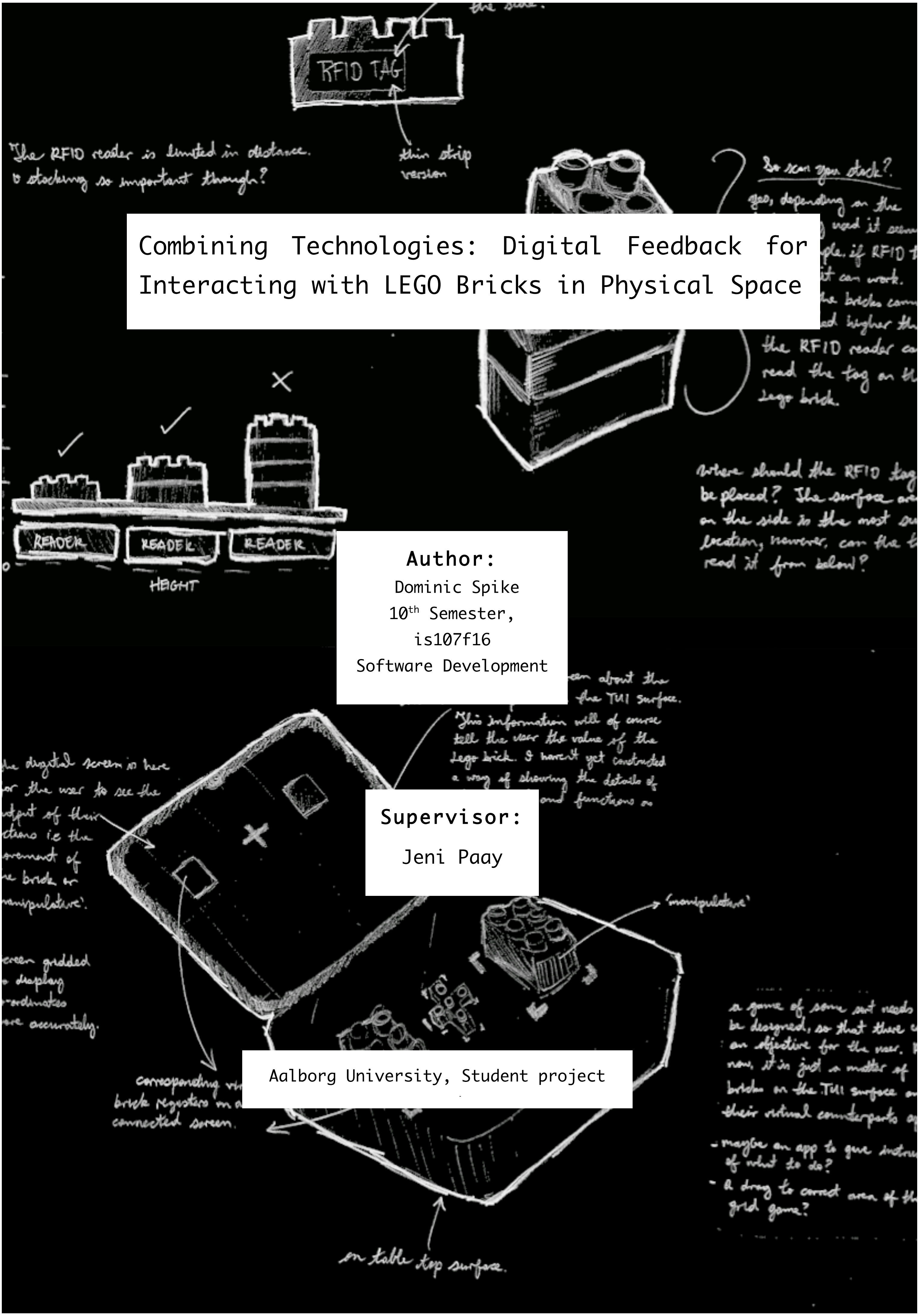

Combining Technologies: Digital Feedback for Interacting with LEGO Bricks in Physical Space

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AALBORG UNIVERSITY
STUDENT REPORT

Computer Science
Aalborg University
http://www.aau.dk

Title:
Combining Technologies: Digital Feedback for Interacting with LEGO Bricks in Physical Space

Theme:
Scientific/Educational Theme

Project Period:
Spring Semester 2016

Project Group:
is107f16

Participant(s):
Dominic Spike

Supervisor(s):
Jeni Paay

Copies: 1

Report Total: 75 pages
Report: 46 pages + 18 appendices
Containing:

- Cover Report
- Research paper: 11 pages

Date of Completion:
June 12, 2016

Abstract:

The paper presented examines how the combination of LEGO bricks and an interactive tablet can be designed using participatory design with children, to create technology that delivers engaging feedback for children ages 5-7 years old, within an educational context. It presents a participatory design workshop that was carried out with a group of eight children between the ages of 11-13 years. The study utilised the research method of participatory design (PD), as it provides researchers with the opportunity to "enhance technology for children by designing with children" (Yip et al., 2013). The overall aim of this study is to create a proof of concept prototype based on the designs gathered from the participatory design workshop with the children. A thematic analysis draws out themes that emerge from the rich, qualitative data. The contribution is an educational system, which involves digital technology used as feedback to undertake LEGO Education's 4Cs constructionist learning using LEGO.

Table of Contents

Preface

This report outlines the semester project conducted for Software Development 10th semester. It builds upon previous research and findings conducted in 9th semester. The report depicted consists of one scientific research paper with accompanying chapters for detailed information on analysis on process and development of the proof-of-concept prototype.

Aalborg University, June 12, 2016

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[INTRODUCTION]

Introduction

Background on Previous Study

Last semester, a study was conducted by Spike (2015) [also see **Appendix A**] about how children interact with LEGO bricks in a digital space compared with using LEGO bricks in a physical space, and how this affected their engagement in learning mathematics by constructionist problem solving.

Findings from Previous Study

Interacting with physical LEGO was found to be more engaging than interacting with the digital tablet within the context of this study. This was observed through using a model of engagement (figure 1) proposed by O' Brien and Toms (2008). The model consisted of 3 stages of engagement - point of engagement, period of engagement and disengagement. The study also revealed a total of 9 identifiable attributes of engagement from the model, as a result of children interacting with both physical LEGO and digital LEGO. Interaction with physical LEGO revealed attributes such as *attention* and *motivation to complete a task* as a link between the first two stages of engagement, whereas the digital LEGO was seen to disengage the children after a short period of interaction. The attributes revealed as a result of this short disengagement with the digital LEGO were *frustration with technology*, *too much of a challenge* and *usability*.

Feedback, an Attribute of Engagement

Despite these findings, the physical LEGO offered children a way to interact with the tasks within the study with more freedom. However, based on the second stage of engagement (period of engagement) from the proposed model of engagement, the physical LEGO does not embrace the attribute feedback in regards to the study. Physical LEGO requires a teacher for feedback. This presents an opportunity for the digital tablet to make a contribution, to build upon the engagement of a future educational system, which offers various ways to represent visual information. For example, there is potential for the digital tablet to be used as live responsive feedback or static, diagrammatic feedback. This is especially useful with harder to grasp concepts such as the food chain, which is essentially about energy transfer (Rogers and Scaife, 1998). Not only can the digital tablet provide visual feedback, but it can also offer audio feedback. For instance, Sanchez et al. (2011) discovered that "sound feedback provoked a wow effect in the children, which encouraged them to continue using the application."

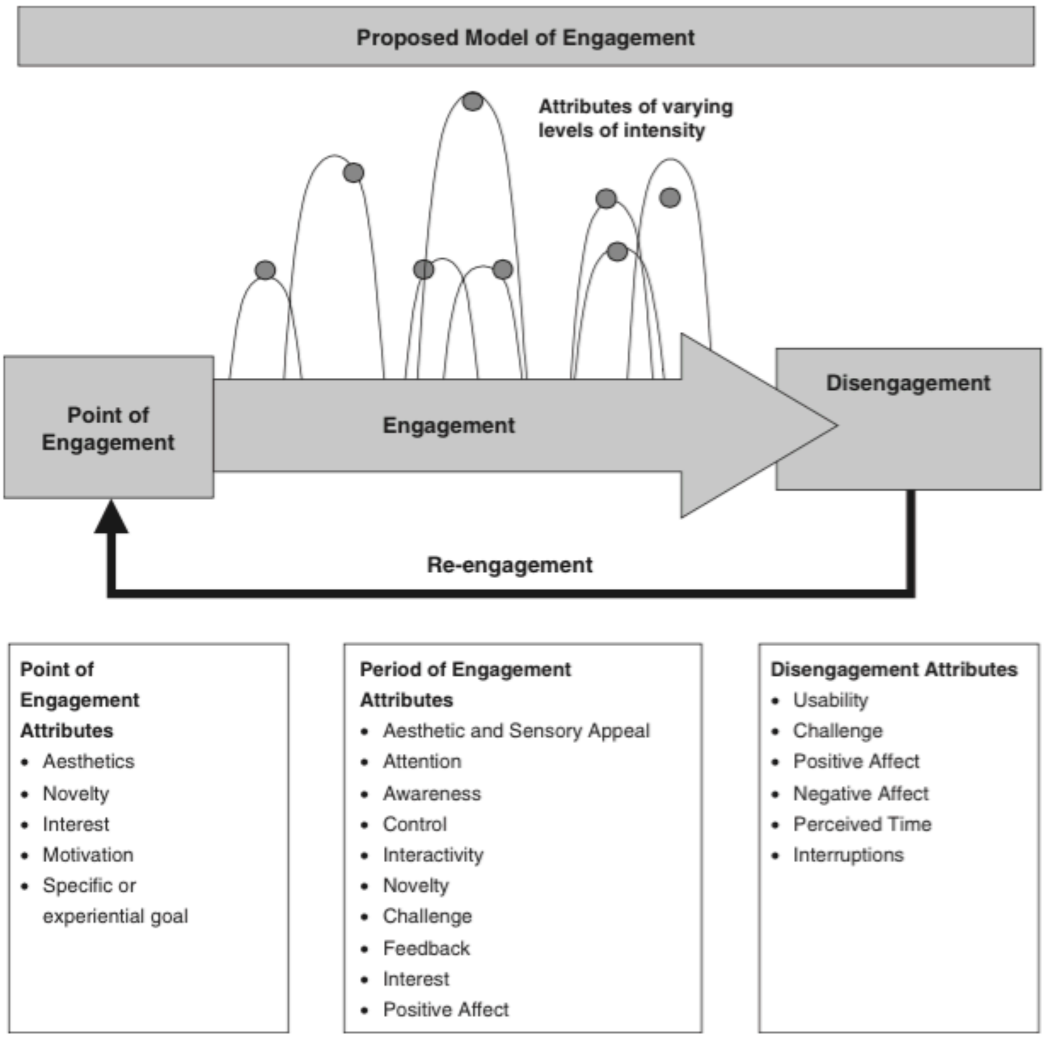

Figure 1. The proposed model of engagement and its attributes (O'Brien & Toms, 2008).

Research Question

With the findings from the previous study conducted in 9th semester and supporting motivation to investigate feedback, the research question as follows:

"How can the combination of LEGO bricks and an interactive tablet be designed using participatory design with children, to create technology that delivers engaging feedback within an educational context?"

Problem Statement

The children in focus for the design of this educational technology are key stage one students/ grade one/ 5-7 years old. Numerous studies support that creating educational technology for children can be difficult. For example, Africano et al. (2004) found one challenge involved in designing information technologies for young children, "in terms of understanding the design requirements of interfaces and interaction modalities to suit their limited reading abilities and motor skills". The study will be conducted within an educational context, as this is where the technology will be used. The time frame to conduct the study and create this technology will happen within a four-month period. As adults, we assume or try to know what children want but there are challenges that emerge with user experience (UX) of children's technology, particularly within an educational context. Through the use of participatory design (PD) methods, it is possible for children to design solutions for an educational system. For example, Guha et al., (2004) use a mix of PD techniques such as drawing, journal entries and observation to elicit design ideas from young children aged between 4-6. PD provides researchers with the opportunity to "enhance technology for children by designing with children" (Yip et al., 2013). In order to get a clear understanding of how children use technology, getting their input during all phases of development i.e. ideation, prototyping and testing is essential (Druin, 1999). By using children as research partners, we can then look at possible solutions into understanding how to develop more engaging systems (Druin, 1999; 2002). Druin (1999) discusses the importance of involving children in the creation of their own technologies. For this study, participatory design techniques will be conducted within the context of an educational environment. The overall aim of this study is to create a proof of concept based on the designs gathered from the participatory design study with the children. For future work, usability testing with children can be conducted to assess the system, to test that it is engaging in delivering aesthetic and responsive feedback within an educational context while learning concepts through constructionist principles.

The background from the previous study and problem statement has informed on the vision of a proof-of-concept prototype combining physical LEGO and the digital feedback from a tablet. Therefore, a brief recap of LEGO Education's 4C approach (figure 2) will provide supporting information for the use of LEGO bricks in teaching children mathematics and the values LEGO Education uphold within their curriculum.

LEGO Education's Four C Approach

LEGO Education's four C approach provides the constructionist framework that is a guiding principle of experiential learning. A brief description on each "C" will give more insight into how it may contribute to a proof of concept prototype.

- The *Connect* phase awakens the curiosity of the learner and encourages them to actively engage (with each other) and question the problem at hand. Discussion and reflection can occur based on the outcome of what they have learned or discovered.
- *Contemplate* focuses on reflection of what a learner has gained from the learning process. This critical assessment of ones learning helps create an awareness, thus allowing the opportunity to explore alternative means of discovering solutions to the task at hand.

- *Construct*, one of the four Cs is essential to this framework, as it is the only part that provides ICT literacy. It states, "When learners construct artefacts in the world, they construct knowledge in their minds. With new knowledge learners build more sophisticated artefacts, yields yet more knowledge" (Lego, 2011). With this in mind, these artefacts also come in the form of ICT. Although not tangible in the same way as LEGO bricks, it is seen as a necessary skill for the 21st century.
- The *Continue* phase extends on ideas by children changing or adding features to models they have built. Children can then move onto more difficult challenges, leading them back to a new connect phase.

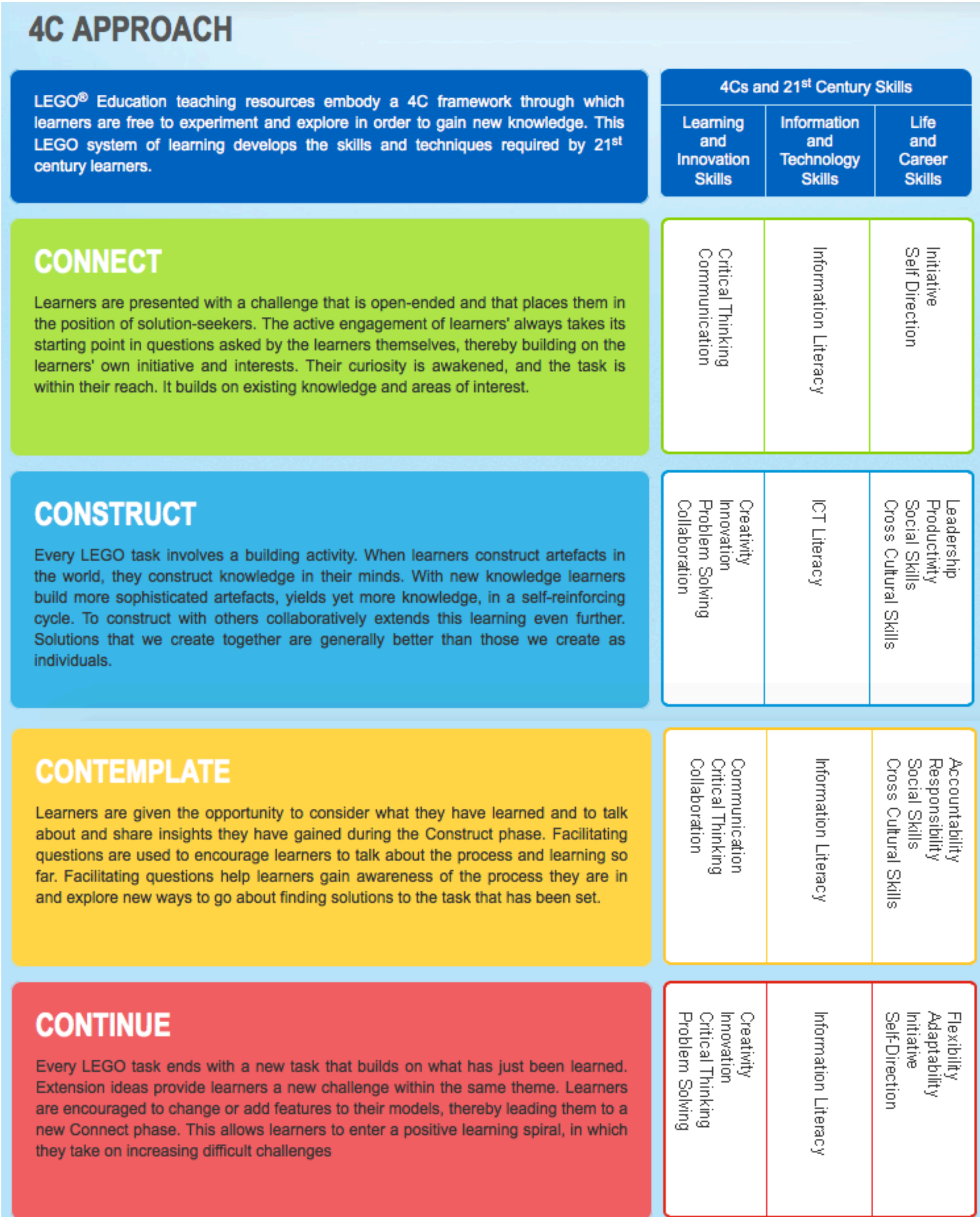

Figure 2. LEGO Education's 4C Approach (LEGO Education 2011).

The Contribution of this Thesis

This study uses participatory design techniques in designing an educational system, to create a unique hybrid system that involves digital technology providing feedback to undertake LEGO Education's 4Cs constructivist learning in combination with physical LEGO bricks. Benefits of such a system:

- Teacher cannot respond to all children at once. The system is there as additional support for when the teacher is not available when needed.
- The system offers various ways to present visual information. This is especially useful with harder to grasp concepts. E.g. Abstract concepts such as energy transfer (Rogers and Scaife, 1998).
- Responsive feedback from the interface. This is useful, as the child will feel in control of their actions.
- The information presented on screen can also reinforce the audio or the information the teacher has said.
- The system can challenge the child's multi-sensory abilities in various ways in which paper exercises with LEGO could not.
- Numerous studies support that children generally have a positive response to technology through the quality of novelty.
- Will provide engaging, fun technology for learning. "Remember, a child's play is work!" (A System for Learning, 2014).

The next chapter will present one scientific paper with the following heading: Flip 'n' Slide: Providing Digital Feedback for Interacting with LEGO Bricks in Physical Space. After the paper will be a brief summary and a short introduction to the project's development in preparation for later chapters.

*The paper will be presented as a separate document within this report and therefore will have its own page numbering.

[THE SCIENTIFIC PAPER]

Combining Technologies: Digital Feedback for Interacting with LEGO Bricks in Physical Space

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ABSTRACT
This paper examines how the combination of LEGO bricks and an interactive tablet can be designed using participatory design with children, to create technology that delivers engaging feedback within an educational context. In a participatory design (PD) workshop carried out with a group of eight children between the ages of 11-13 years, the study utilised the opportunity to "enhance technology for children by designing with children" [50]. The overall aim of this study was to create a proof-of-concept prototype aimed at children ages 5-7 years old, based on the designs gathered from the PD workshop. A thematic analysis draws out themes that emerge from the rich, qualitative data collected. The contribution is a proof-of-concept prototype, using digital technology to increase children's engagement with LEGO Education's 4Cs paper-based constructionist learning package using LEGO bricks.

Author Keywords
Participatory Design; Engagement; Feedback; LEGO Education.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
This paper focuses on interaction design of educational software, specifically the combination of LEGO bricks and an interactive tablet using participatory design with children, to create technology that delivers engaging feedback within an educational context. The appeal of LEGO as a toy and educational tool comes with the ability to express ones creativity through a vast selection of themes and pieces. The LEGO Group has foundations within technology, engineering and education. They have developed a hands-on approach to play and learning supported by constructionist principles of experiential education [25]. Industries such as robotics and engineering have adopted LEGO in teaching, for example, introductory Java through LEGO Mindstorm models [3] and teaching engineering design through LEGO Mindstorms [36]. Seymour Papert is known for his work in child development and the development of LEGO Mindstorms, from which he borrows extensively Piaget's ideas of constructivism and experiential education [4]. He expanded on these ideas with the purpose of teaching children with computers. The research Papert conducted with children convinced him they learned more efficiently if they could see a tangible result for their computing efforts [4].

Children Computer Interaction (CCI) is an area of Human Computer Interaction (HCI) involving children's user experience with technology. CCI gives researchers a lens from which to test, research and evaluate methods with children, in order to attain a clearer understanding of the group in focus. It has been stated that a large number of methods exist, many of which have specific issues when used with children, and all of which have their advantages and disadvantages depending on the purpose of the study [30]. The workshop described in this paper makes use of participatory design (PD) with children, in order to extract potential design ideas that can contribute to the proof-of-concept prototype.

Digital feedback for interacting with LEGO bricks in physical space is under researched within an educational context. Computer games and digital platforms such as LEGO Digital Designer and LEGO Build exist mostly for entertainment. Therefore, the work presented here covers new territory with the hopes of stimulating related research in the future, with LEGO in the educational domain.

Related research by Spike [44] shows that physical LEGO provides more engagement overall than LEGO used on a digital tablet. However, the limitation of manipulating physical objects, particularly in completing a task, is the lack of information about its movement or previous position [27]. The user therefore, cannot assess or reflect on their actions. This study attempts to look at the contribution a digital tablet can provide, building upon the engagement of a potential future educational system, which offers various ways to represent visual information. This is achieved through PD techniques, where the ideas and themes that emerged contributed to the proof-of-concept prototype described in this paper. The prototype itself is a step forward, creating an educational system that delivers engaging feedback for children in an educational context. The current LEGO Education curriculum displays their instructions on paper. However, it must be considered that a static display of instructions cannot provide sufficient feedback to a child engaging with an educational system. Educational software often lacks effective feedback, demonstrating a one-dimensional outcome of either a wrong or right answer [16]. He further states that the user will benefit more from an explanation of their decisions along with the correct answer. It is argued that the design of educational software for children should be grounded in constructivist learning theory and should consider the findings of research on educational technology and educational psychology [33]. In support of children actively engaging in educational technology, Schank [39] insists, "*good educational software is active, not passive. Students ought to be doing something, not watching something*." Therefore, a proof-of-concept design is offered in this study to provide digital feedback for constructivist learning using physical LEGO bricks.

RELATED RESEARCH

A number of studies relating to children engaging with technology [1, 10, 12, 28, 41, 44], provide theoretical support and inspiration for the research conducted in this paper, which highlights feedback as an area for further investigation.

Attributes of Engagement

An observation study conducted by Spike [44] looked at how children interact with LEGO bricks in a digital space compared with using LEGO bricks in a physical space, and how this affected their engagement in learning mathematics by constructionist problem solving. Interacting with physical LEGO was found to be more engaging than interacting with the digital tablet within the context of this study. This was observed using a model of engagement proposed by O'Brien & Toms [32], where they describe engagement as a quality of user experience consisting of three stages of engagement: *point of engagement; period of engagement;* and *disengagement*. The model is characterised by attributes of challenge, positive affect, endurability, aesthetic and sensory appeal, attention, feedback, variety/novelty, interactivity, and perceived user control falling into any of these categories. This definition of the model of engagement is based on past works on engagement within HCI.

The results revealed a total of nine identifiable attributes of engagement from the model, as a result of observing children interacting with both physical LEGO and digital LEGO. Interaction with physical LEGO revealed attributes such as *attention* and *motivation to complete a task* as a link between the first two stages of engagement, whereas the digital LEGO was seen to disengage the children after a short period of interaction. The attributes revealed as a result of this disengagement with the digital LEGO were *frustration with technology*, *too much of a challenge* and *usability*. Despite these findings, physical LEGO offered children a way to interact with more freedom [44].

Feedback as Engagement

Feedback is the information communicated to users about actions that have occurred and results that have been achieved. Feedback may be visual, auditory, or tactile [46]. Feedback according to the proposed model of engagement is part of a much wider context of engagement, which itself is a part of user experience. However, based on the second stage of engagement, *period of engagement*, the physical LEGO did not offer the attribute *feedback* in regards to the study. Physical LEGO requires a teacher for feedback. This opens up an opportunity for a digital device to make a contribution, to build upon the engagement of a future educational system, by facilitating various forms of feedback. For example, there is potential for the digital tablet to be used as live responsive feedback or static, diagrammatic feedback. This is especially useful with difficult to grasp concepts that are abstract such as the food chain, which is essentially about energy transfer [37]. One limitation of manipulating physical objects in completing a task is the lack of information about their movement or previous position [27]. The user therefore, cannot assess or reflect on their actions. Digital feedback therefore, can make a contribution to this by displaying the position of one's movement. In its application to the real world, this would be useful in completing a grouping exercise in LEGO Education's curriculum exercises. The state change of adding or subtracting LEGO bricks can be traced, thereby providing necessary feedback for the user to complete the task. Such features are important to context specific software, as it helps maintain engagement over a sustained period of time. In addition to optimising certain features, studies have indicated that minimising the amount of off-task behaviour can help to maintain a child's engagement with educational technology [1, 22, 42]. For example, the teacher in the current system would have to monitor each individual child/group (depending on the scenario), whereas a digital tablet can be used as a temporary support, whilst the teacher is helping others.

Not only can the digital tablet provide visual feedback, but it can also offer audio feedback. In the study of Sánchez et al. [38], they discovered that "*sound feedback provoked a wow effect in the children, which encouraged them to continue using the application*." Visual and audio feedback from a tablet provides multiple ways of presenting feedback to the user, and can be used independently or combined. However, this must be done with caution, as Alty [2] suggests audio feedback presents positive responses for the imagination, while text feedback is most useful when outlining details and images for demonstrating ideas. There are suggested guidelines that state unnecessary imagery can hinder the learner, where a basic display of text would suffice [7]. The design phase of the educational software must consider these feedback mechanisms in order to deliver positive learning outcomes.

Tactile feedback is another form of feedback that can be used to notify the user of their actions through vibrations. One of the key drawbacks of interacting with LEGO on the digital tablet was the engagement attribute of *perceived user control* [44]. This is the desire to feel one is in control of the interaction [40]. According to the model of engagement [32], perceived user control helps users engage with technology. Therefore, combining positive attributes of the tablet (feedback) and the physical LEGO bricks (perceived user control) can provide an engaging experience for children's educational technology.

Children and Technology

The complex transformation of cognitive capabilities from infancy to adulthood is captured in Piaget's stages of development [20], outlining children's understanding and experiences of the world as fundamentally different to adults. Children have different needs to adults when considering the design of technologies [11]. It has been observed that children's technologies have been designed based on adults' products, which is not suitable for children as they have different skills and requirements [21]. It should also be noted that children are more exploratory in the use of their technology, whereas adults use technology in a more task-directed manner [9].

LEGO EDUCATION'S FOUR C APPROACH

The constructionist influence on LEGO Education's vision takes form in the shape of a framework called the four C approach. It outlines how a child can experience learning with LEGO bricks through the following phases: *connect*, *contemplate*, *construct* and *continue*. This framework developed by LEGO Education has strong foundations in Constructionism, "which is rooted in the belief that children learn best when they experience things firsthand and within a meaningful context" [25]. Theorists such as Broström [5] note that the influence of Constructivism has helped to shape play within preschools. This relationship between constructivism and play is reflected in the 21st Century skills, outlined in LEGO Education's four C approach.

Physical and Digital

It is claimed that Tangible User Interfaces (TUIs) are more natural and intuitive to children because they share affordances familiar to their day-to-day experiences [15]. There are a number of studies that compare physical manipulation and digital manipulation [15, 13, 48]. For example, Fitzmaurice, Ishii and Buxton's pioneering work [15] proposes Graspable User Interfaces that allow direct control of electronic or virtual objects through physical artefacts. They move outside the confines of Graphical User Interfaces (GUI) in exploring possibilities of Graspable User Interfaces. Fails et al. [13] conducted a comparative study with the use of desktop and physical interactive environments by preschool-aged children. They found that by having children acting out the story, instead of just responding to verbal questions, the test results can lead to a better understanding of the advantages and disadvantages of desktop versus physical interactive environments for young children. Their qualitative analysis showed the physical environment had several advantages over the desktop environment as suggested by a decrease in "*I don't know*" responses and facilitator prompts, and an increased depth of response. Finally, their findings also suggest that embedding technology in the physical world, rather than simply presenting traditional desktop apps, may be beneficial to young children. An experiment conducted by Tuddenham, Kirk & Izadi [48] compares multi-touch and TUIs for basic interface actions. They found that interface control objects in the tangible condition were easiest to acquire and, once acquired, were easier/more accurate to manipulate. Their qualitative analysis suggested that tangibles offer greater adaptability of control and specifically highlighted a problem of exit error that can undermine fine-grained control in multi-touch interactions. Research has suggested that interaction with tangibles encourages engagement [34] and collaboration [1]. The point of emphasis for Manches & O'Malley [27], assert that physical manipulatives (also called tangibles) may support learning through cognitive offloading and conceptual metaphors. However, Marshall [29] writes that there is limited empirical information to support that tangible interfaces benefit learning. Conversely, Manches & Price [28] assert that manipulatives can aid learning through physical actions and Resnick et al. [35] argue that constructionist ideas have inspired digital manipulatives, allowing children to explore computational, material, and structural concepts with supporting tools.

PARTICIPATORY DESIGN

When working with children, it is important to select appropriate research techniques [12], as the challenges are different for each age group [14]. Participatory Design is proven to be an effective method for creating technologies with children [10, 12, 18]. According to Crosier, Cobb & Wilson [8], involving informants early in the concept development phase of virtual environments, prove to be beneficial as information from various contributors inform specific requirements of technology design. However, Stanton et al. [45] state that end-users have little impact on design decisions of educational software even though they may have contributed to the idea generation phase.

Designing for Younger Children

In recent times, including children either as *informants* or *design partners* has proven to be beneficial in eliciting qualitative user information, gathering design ideas and understanding users [11]. In this study, the children at whom the educational technology is aimed are key stage one students (5-7 years old). Numerous studies support that creating educational technology for children can be difficult. For example, Africano et al. [1] found that "*understanding the design requirements of interfaces and interaction modalities to suit their limited reading abilities and motor skills*" was a challenge. This paper's PD study will be using older children as design informants outside of the target group. Piaget's stages of development guided selection of children for this workshop. The *formal operational* stage begins at around age 11 and is the last stage of development in Piaget's theory [20]. At this age, children can use abstract reasoning, perform more complex calculations, think creatively, group and categorise objects in a more complex manner and demonstrate a capacity for higher-order reasoning [31]. This is advantageous for the workshop as it allows clearer verbal and written communication between the children informants and adult researchers.

THE WORKSHOP

A participatory design workshop was conducted with children aged 11-13 years, to elicit ideas for a LEGO based educational system for younger students aged 5-7. This took place in a Danish school in Northern Jutland. Eight children *informants* and three adult researchers participated in the workshop, which took place over a period of one day. Although the target age group for the design is 5-7 years old, the older age children were intentionally selected for the following reasons. One of the challenges faced with using young children in participatory design studies is that they find it difficult to work in groups [12]. It was also reported that adult researchers found it difficult to get children to listen to each other's ideas. The study also revealed that children had difficulty in expressing written ideas as well as generating them. In light of these limitations, an older age group is more appropriate, as the workshop requires idea generation and collaboration to create a detailed proof-of-concept prototype. The children were selected by the teacher based on their English-speaking capabilities as well as an interest in taking part in the workshop. The four main activities included: a questionnaire, an independent drawing activity, a collaborative drawing session, and a prototyping activity. Each activity was followed by a discussion. Two research assistants took part in all activities. The point of using participatory design in this workshop was to involve the children as *informants*. Two of the researchers participated completely in the activities whilst the third took notes of comments made by the children. After an introduction to the day, the children were briefed on the activities that were to take place. They were told they would be research partners in helping researchers design ideas for an educational technology to be used in teaching mathematics to children aged 5-7 years old. The emphasis was on how LEGO could be combined with a digital tablet to deliver engaging feedback.

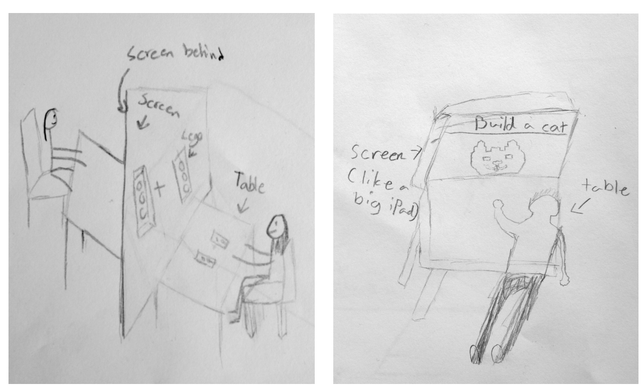
Methods

Four techniques were used to generate ideas and drawings in the workshop. The first activity was a questionnaire for the children, used as a starting point for a group discussion on their initial ideas. The second technique was a solo drawing session to sketch the ideas they had discussed. The third and fourth techniques required the children to be split into two groups of four, with an adult researcher in one of each. For clarity, the groups will be referred to as Group A and Group B. These drawing sessions used *Big Idea* and *Bags of Stuff*, which are techniques used in participatory design studies with children [18, 19, 50]. Yip et al. [50] suggest that co-design techniques that are more familiar work best with children with little design experience. *Big Idea* encourages children to combine their individual drawings and expand on what they originally discussed. *Bags of Stuff* is a low-tech prototyping technique used with children to add depth to 2-dimensional drawings and potentially open up design alternatives. The combination of these third and fourth techniques delivers a qualitatively rich, iterative design process and they are designed specifically for use with children.

Questionnaire

The questionnaire consisted of six questions and was filled in on the day of the study by all children. The aim was to get an idea of these children's thoughts on LEGO as a tool for learning mathematics. The general consensus was that using LEGO to teach mathematics would be fun for young children. Their responses indicated that the educational element is still important and possible using LEGO bricks. As one child said, *"Yes it is more fun using LEGO because it is more like playing a game than doing math. For example, if you compute 1 + 2 you can just add a LEGO and count how many LEGOs are there. You can also do it with minus"*. The questionnaire challenged them with the idea of learning with LEGO in physical form, digital form and combined. The questions also focused on how could this combination deliver engaging feedback to a child learning math. One of the written responses described, "*When it is wrong, it vibrates and the colour is red and it makes the sound erhhhh…and when it is right, it's green and the sound is ding…*" Already, a visual picture is being painted with sound effects of what the feedback should do when a particular action is taken. There were also suggestions of icon feedback with thumbs up and thumbs down gestures, plus tactile feedback. The questionnaire also brought up some initial suggestions of knowing if a child has got a question right. One child suggested addition of "*A video that explains how to solve the mathematics problem with LEGO, and if they forget it, they can see the video again.*"

Individual Drawings



(a) **(b)**

Figure 1. Two drawings by children from the individual drawing session.

The individual drawing activity followed the discussion of the questionnaire, helping children to visualize their ideas. Throughout this activity, a variety of ideas were generated. For instance, drawings showed communication through collaboration, e.g., someone describing the LEGO bricks on screen, whilst another builds it, and a battleship type setup where both children alternate in guessing coordinates of LEGO bricks on an interactive table. Figure 1 shows two examples from the individual drawing session. Figure 1(a) depicts an image of a large screen, which can be used to display a live image of what a child is doing with the LEGO bricks on the table. The children labelled the drawings to indicate what the elements were. Figure 1(b) demonstrates a big digital tablet, which allows the child to use the tabletop space to perform the tasks with LEGO bricks. These initial ideas are missing practical features. For example, both drawings in figure 1 do not specify how the LEGO bricks are being displayed on the screen. Which is fine in a sketching exercise. We can then imagine solutions such as a camera device recognising the LEGO bricks placed on the table, or the table itself imbedded with sensor technology, which in turn is connected to the screen.

Big Idea

The *Big Idea* method is described by Guha et al. [19] as mixing all the ideas together to formulate a collective idea. This is done by cutting out individual drawings and assembling them together guided by the children. A final idea is then drawn on one large paper. A discussion took place on how individual drawings could be combined. After the discussion, the children were put into facilitated groups, A and B. *Big Idea* then allowed the individual ideas to evolve into one idea, based on discussion on individual drawings.

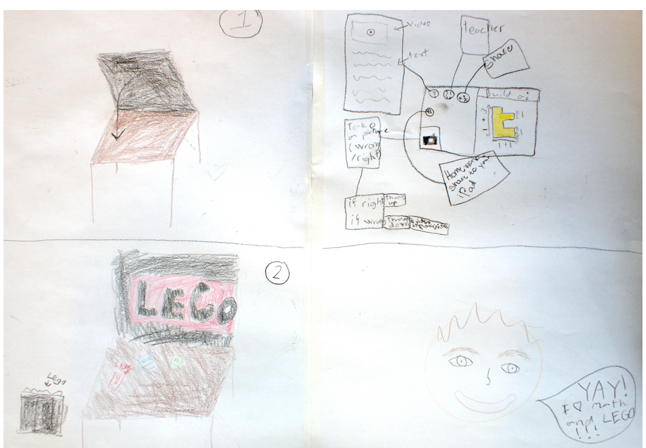


Figure 2. *Big Idea* created by Group A, combining LEGO bricks on a tabletop with a virtual feedback system.

Big Idea expands on the "drawing" method with more details and elaboration of the design idea. Group A designed a tabletop (figure 2) where children can perform their tasks with LEGO bricks, expanding the idea of the big digital tablet from figure 1(b). It details a way for children to perform an array of functions. For example, the top right of the figure (2) shows help, video and share icons. It also outlines an icon to share homework externally to a digital tablet and take a picture of the physical LEGO brick to display the task on screen. In relation to the individual drawings, it is apparent that the level of detail is higher as the discussions began to question certain design decisions. The questions posed by the researcher to the children informants *Big Ideas* were: *How do we access these icons without the need to touch the screen? Can a child understand these symbols? Where are the LEGO bricks shown in relation to the camera?*

However, in contrast to Group A's design of working collaboratively, Group B's *Big Idea* situated around independent activity. Their sketch represented a traditional classroom layout, where children have their own worktable. These tables have screens that separate the students, and provide the necessary feedback for them. To further the idea of feedback, Group B designed a flow schematic of what the educational software does when an answer is wrong or right. For example, one of the ideas depicted the physical LEGO brick being recognised by the camera, then leading to two possible outcomes. The first scenario is if the answer is correct. The tablet indicates green and the child then moves onto the next question. The second scenario is if the answer is incorrect, then the tablet screen turns red and the correct answer is displayed along with a video explaining how to do the activity correctly. At the end of the activity, ideas were discussed with both Group A and B together and noted down by the researcher assistant.

Bags of Stuff

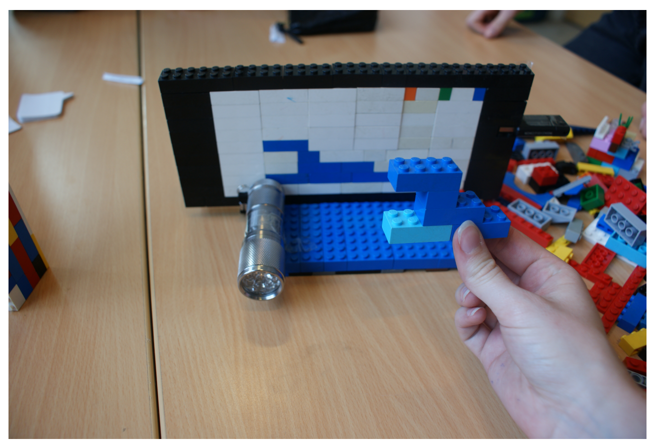


Figure 3. A prototype created by Group B, demonstrating a digital tablet with an object recognition camera to detect LEGO bricks.

Bags of Stuff is a low-tech prototyping technique [10] that is used to transform the drawings into something tangible. The goal of *Bags of Stuff* is to generate ideas for how the child user can interact with the combination of LEGO bricks and a tablet. To promote a little more divergent thinking in this task, random items were placed with the LEGO bricks for each of the two groups, A and B. In response, one of the groups used a flashlight (figure 3) to indicate whether an answer is correct or not by the colour displayed: red if wrong and green if correct. This idea originated in the questionnaire stage and developed through the *Big Idea* technique. Another concept was the ability to share solutions with other children and the teacher. Group A elaborated on this feature. In the *Big Idea* activity they showed sharing capabilities limited to digital format. With further discussion, the *Bags of Stuff* prototype demonstrates an additional sharing capability with other external digital tablet devices in the form of a USB (figure 3).

Another prototype consisted of a small screen that was described as an RFID scanner of LEGO brick objects. For example, if the scanned objects were correct in an exercise on symmetry, it would beep "*DING!*" and display a green light at the top of the device. An incorrect scan would create an "*ERHHH! Try again*" sound with a red light.

Data Collection

Each design activity resulted in different outcomes, which included drawings, photographs of artefacts, low-fidelity prototypes and researcher's notes. Although not a design activity as such, the questionnaire provided data for the research team to analyse and later compare to the design outcomes. Memos were written during breaks to uncover any early emerging themes and then compared with the notes of one other researcher after the workshop.

Analysis of Data

In order to assess this diversity of qualitative data types, exploratory thematic analysis was chosen. Thematic analysis allows the researcher to carefully read the data, meticulously scanning for key words, trends, themes, or ideas in the data that will help outline the analysis, before any analysis takes place [17]. The data sets collected, consisting of low-tech prototypes, notes, questionnaires, memos and drawings where thematically analysed to produce design ideas and themes. The data sets were important in understanding the co-design partnership with children through these ideas and themes. Open coding was done on all data and gradually themed accordingly after two more coding sessions. Codes developed through similarity in design requirements, types of feedback, and ways of interacting with the system, in addition to social elements such as video, texting, sharing and aesthetic consideration. This information was condensed into related themes by triangulating all the data sets to check that data supported each other. The aim of grouping the data was to reduce the number of categories by collapsing those that are similar into broader categories [6]. To achieve inter-researcher reliability and reduce researcher bias, the adult researchers performed independent analysis of the data. Codes and themes were then checked against each other and minor variations were resolved as a team.

FINDINGS

Below are six main themes that emerged from the thematic analysis conducted after the workshop.

1. Combination of tablet and LEGO
2. Video explaining solution
3. Icons to show/confirm actions
4. More fun for children
5. Tablet is a distraction
6. Vibration, audio and visual feedback

The following sections will outline the themes and assess how they relate to the model of engagement [32], and how they provide engagement for interacting with physical LEGO bricks in a physical space.

Combination of Tablet and LEGO

The questionnaire codes revealed that the fun element of LEGO and a digital tablet could be realised together, in a way children could learn mathematics. The children throughout the workshop use the words tablet and iPad synonymously. When asked about the combination of LEGO bricks and an ipad making learning maths fun, they responded, "*Yes because then you get to draw something on the ipad and then build it in your hand.*" and *"Maybe, yes because kids love LEGO and also ipads, and my little brother loves to play LEGO games on his ipad, and he also likes real LEGO, so I think it could be really fun together."*

The discussion after the questionnaire revealed that the novelty of the combining a digital tablet and physical LEGO bricks would motivate young children to do maths. The informants believed it would hold children's attention because it involves more senses in a fun and challenging way. The attributes of *novelty* and *motivation* appear in the model of engagement as positive aspects of technology.

Video Explaining Solution

Most of the drawings had a video of the teacher explaining the answer. This concern was further coded as a necessity if a child is stuck. It reveals that the educational software has to "fill in" if the teacher is unable to be there to explain or give the correct answer. The discussion with the children revealed that being stuck or not, receiving help is important to be addressed in the design of educational software. In the case of being stuck, according to the model of engagement, this can lead to a number of *negative effects* such as being *too much of a challenge* and result in *frustration with technology*, which are attributes of the model of engagement. If a child cannot receive the appropriate feedback from the system, then it could result in *boredom* and *disengagement* from the system. Therefore, it is of great importance that feedback is displayed when necessary when using educational software.

Icons to Show/Confirm Actions

The notion of icons emerged enough times to be coded as important. The discussion elaborated on how the children would utilize familiar icons within an ideal system. Ideas suggested including icons that they could identify with such as thumbs up and smiley faces. The model of engagement shows that graphics can keep *attention* and *evoke realism* and that customised views of information are ideal for an engaging system. Objects used in day-to-day experiences of a child were suggested to be used as part of these engaging interfaces in the workshop.

More Engaging for Children

The children informants felt using physical LEGO bricks would be more fun than using digital LEGO. The comments revealed the "hands on" interaction was a more effective means for young children to understand shapes, for instance. There was also a sense that younger children would become more involved in the subject matter, rather than "*just tapping a screen*". The model of engagement indicates that an engaging system should be *fun*, *enjoyable* and increase *physiological arousal*. The children believe that designing the educational software like a game, combining the positive aspect of the tangibility of LEGO bricks with a stimulating interface for feedback, would make it more appealing for younger children to learn mathematics.

Problems with Digital LEGO

All child informants commented in the questionnaire that the digital LEGO on a tablet could be a potential distraction for young children when learning. Some reported "*maybe the child will go on another game if there is not a teacher*". During the discussion, further elements of concern became apparent such as "*getting lost*" within the software or being "*stuck*". An interesting finding was that all the children agreed on the questionnaire and in the post discussion that LEGO in a digital form on a tablet and moved around like real LEGO would not be fun for children learning maths. Nevertheless, one of the prototypes was a digital only design, with focus on audio and visual feedback based on direct contact with the screen. Within the model of engagement, *interruptions* and *distractions* were described as external factors that disengage users. The distractions can also be related to the usability of the technology. If distracting features such as pop-ups or overlapping elements on screen disrupt the flow of concentration, then the design needs to be re-evaluated.

Vibration, Audio and Visual Feedback

Based on the illustrations and comments made by the children, visual feedback was the most common form of feedback, followed by audio then tactile (vibration). This theme helped to prioritise the most important sensory elements in the final proof-of-concept prototype. In it, visual feedback appeared more highly favourable than audio and tactile feedback. However, audio feedback was shown to be necessary in each example as supporting feedback to the visual elements. The least mentioned, hence the least prioritised was tactile feedback, as it only served as an additional feature accompanying audio to notify users of the software. The model of engagement mentions *aesthetic and sensory appeal* as engaging elements with *rich interfaces and graphics* that keep *attention*. The interface design must be a true representation of the tactile interaction with LEGO bricks. The design decisions still require further negotiation of when feedback is necessary and what type, if at all. For example, would tactile feedback be necessary if the input of placing the LEGO bricks is already tactile?

What do these themes mean?

Based on the thematic analysis conducted, the themes that emerged reflect desired attributes for engaging educational technology. For example, the discussions in the workshop with the child informants placed emphasis on educational technology being fun. In terms of the model of engagement, the system should keep the child engaged (*positive effect*), be designed with levels of difficulty (*challenging*), and not distracting (*disengaging and interruptions*). It was also discussed that the feedback the child receives must encourage (*motivate*) and be easy to use (*usability*). The threads of experiences within the model of engagement emerged as important considerations whilst designing these concepts. It deals with the sensual, emotional and spatiotemporal aspects of engagement. Sensual threads focus on *aesthetic appeal* and *novelty* of an engaging education system. The children discussed that the feedback must have an appealing presentation to maintain interest. For example, there were suggestions for the use of primary colours and large display text to read. Emotional threads are described as having an interest or being *motivated to complete a task*. This came through in some of the designs where game challenges and levels were introduced to demonstrate progression. For instance, in one of LEGO Education's LearnToLearn mathematics exercises called *Mirror, mirror*, the objective is to create symmetry with LEGO bricks. There were multiple suggestions on displaying an image and allowing the child to copy it. To challenge students further, it was suggested that a partial image could be shown and the exact bricks and colours would have to be used to finish the image. Spatiotemporal refers to *becoming situated in the story*. There were a few comments from child informants regarding this, including "*I think kids will build with real LEGO because they can create their own fantasy*". Their reflection on using real LEGO is indicative that a digital system should try to achieve a similar effect.

DESIGN OF PROTOTYPE

There are multiple ideas stemming from a previous study [48] and the participatory design workshop with children presented in this paper. This collection of rich information was used as inspiration in creating a working prototype for young children that combines physical LEGO bricks and a digital tablet. The prototype in figure 4 is a reflection of a collaborative effort of working with children to create fun, educational software that can be used within the classroom.

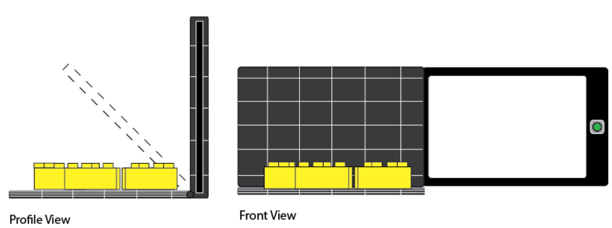


Figure 4. ***flip'n'slide:*** **An object sensor inspired design.**

This prototype is called the *flip'n'slide*. The name derives from the functionality of a standard digital tablet being encased within a shell and built to slide out. The case itself can be closed like a laptop, onto the work mat surface where the child performs all the physical LEGO activities. The base of the work mat has weight sensors capable of identifying LEGO bricks anywhere on it (figure 4). Both the encasing area and base mat have grids that are divided into x, y and z-axis, which calculate the dimensions of the LEGO bricks. The idea of a work mat and digital tablet independent of each other works with limitations of current sensor and camera technologies. One of the key design problems that emerged within the workshop was the inflexibility of the camera to recognise the LEGO bricks. Therefore, as a design solution, the physical work area relies on the tablet to show the information and the tablet coordinates with physical interactions on the work mat. The tablet is connected to the sensors via a fixed cable inside the shell. The instructions for the *flip'n'slide* are a step-by-step written display with the choice of audio for reinforcing information. The ability to have repeated access to instructions and solutions were concerns highlighted in the workshop by the children informants. The important element in focus is feedback and how the system will affect children's interaction. The screen is split into two parts. On one side, instructions from the LearnToLearn LEGO exercises are displayed and on the other is the work area, which the child will receive visual feedback on their creations. On the screen is a 3-dimensional rendering of the physical construction (figure 5). The arrow keys around the button can manipulate this 3D display on an x, y and z-axis, so that there is minimal obstruction of onscreen viewing whilst building. *Flip'n'slide* offers audio feedback when a brick is placed and removed, indicating to the child that their actions are being registered by the system. The sound creates a bridge between the physical actions and the digital interface. The interactive surface is designed with a grid, which does not influence the result of user actions and is provided as a guide when building objects. If other objects are placed on the grid, they are not registered, due to the system's unique LEGO brick identification algorithm.

Contribution of Prototype System

The introduction of such a software system in an educational context proposes multiple benefits. Firstly, the teacher cannot respond to all children at once during an activity. For instance, an exercise on symmetry would require the child to have confirmation of the placement of bricks. The software can provide the necessary feedback ensuring that if the arrangement does not represent symmetry, then the interface will provide details on how to achieve such. This can come, as suggested in the PD workshop, as a video or even text bubbles with hints or examples. The digital tablet has an interface that is flexible and can represent images in 2D and 3D formats. The advantage of this is the ability to display LEGO bricks as a true representation in real-time. Responsive feedback from the interface allows a more engaging feedback according the model of engagement [32]. The engagement allows the child to feel in control of their actions. The model of engagement describes this as *perceived user control*, a positive attribute of engagement.

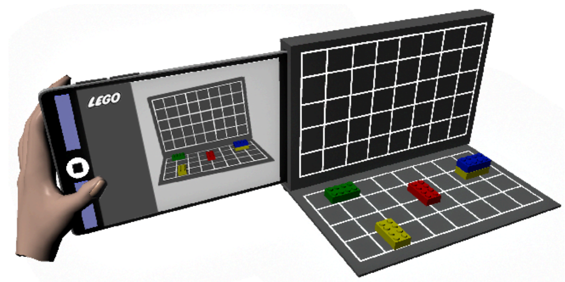


Figure 5. A 3D rendered version of *flip'n'slide*.

The software system presented can challenge the child's multi-sensory abilities in various ways, in which the current paper exercises with LEGO cannot. For example, the paper-based instruction requires the teacher to dictate to the class. There are a few uncertainties that come with this approach. Firstly, children may misunderstand what they are being told to do, especially if the instructions are dictated only once. The case could be, that missed information would have to be repeated when the teacher has finished dictating, resulting in waiting and uncertainty. The scenario could be to ask questions during the dictation. Unfortunately, this would mean disrupting the flow of information to other children. Secondly, children between five and seven years old may not have acquired advanced reading and understanding capabilities, if they have to read the paper instructions. Again, the waiting time for help with words they don't understand relies on the teacher's attention. Even if they attempt to do the exercise, how do they know that they are following the objectives of the tasks correctly? Thirdly, paper cannot provide audio-based instructions. With the proposed system, the possibility for the child to hear the instructions repeatedly makes it easier for them to engage with the task. This then allows the teacher to focus on other learning outcomes in the lesson. The software system proposed is not designed to replace the teacher, but to be a reliable stand-in for delivering engaging feedback for the children. In a study by Klein, Nir-Gal & Darom [24], they reported that preschool children better developed their cognitive skills using computers when the educators took a mediating role as opposed to when educators had a passive role.

Lastly, the system is there as additional support for when the teacher is unavailable at a point in time when a student requires help. This support can be seen as a way to become independent of the need for a teacher at all times, tying in with the 21st Century skills outlined in LEGO Education's four C approach. The opportunity to present visual information in various ways adds to the system's versatility. This is especially useful with more abstract concepts. Moreover, responsive feedback from the interface is useful, as the child will feel in control of their actions. The information presented on screen can furthermore reinforce the audio or the information previously dictated by the teacher. It is also argued, that digital representations of instructions allow children to view models from different perspectives [47]. However, Tseng & Resnick [47] found that when children followed paper-based instructions, it was difficult because of the inability to view the model from multiple perspectives. With the educational benefit of such systems, Lepper & Cordova [26] believe that there are "significant educational benefits" to be gained from computer-based instructional activities, however, with careful planning so that they can support learning. The designs gathered from the workshop and previous work [44] indicate that an interactive tablet can be combined with LEGO bricks in such a way as to deliver immediate and relevant feedback to children using LEGO Educations 4C's constructionist learning, potentially increasing children's engagement in learning.

Limitations

Despite the positive features described by the proof-of-concept prototype, how can we be sure that it will provide the necessary feedback described in this paper? Would measuring feedback be an indication of an improved system? How should this feedback be measured? The model of engagement has limitations in regards to being proposed in the context of user engagement. The model itself was designed around an adult target group. Can this definition be applied to the user engagement of children with educational technology, and importantly, does this mean that the themes found in the workshop are not useful? If the model were to be used, then appropriate methods and evaluations would also have to be used.

The discussion primarily took place around the digital tablet providing feedback, however, with little to no emphasis on how the feedback should be presented, with regards to LEGO Education's four C framework. This requires further investigation into the display of LEGO instructions in a digital format. The children may have also lacked the knowledge of other emerging technologies. For example, there was no mention of augmented reality, radio frequency identification or virtual reality solutions. As a result, potential ideas were limited.

The results are also under scrutiny, as thematic analysis is highly interpretive. It requires interpretation from the researcher in defining and applying codes to a related text. In combination with a participatory design workshop, the lens from which the research is based increases the bias. Despite these limitations, it is the most commonly used method of analysis in qualitative research [17]. Using a triangulated analysis method helped to strengthen the core themes of the designs. Some of the drawings, discussions and comments revealed the difficulty of designing for younger children. For example, the 11-year old child informants could not grasp certain limitations of younger children's use of technology. As a result, many of the concepts revolved around how they used technology.

CONCLUSION

Information gathered from the workshop brings to light a selection of methods, techniques and a theoretical lens for HCI researchers who are interested in developing tangible educational software for children. The model of engagement provides a useful framework in establishing ideas on desirable characteristics of an interface. The empirical outcomes are themes derived from a participatory design workshop with children and then used to conceptualise a proof-of-concept prototype, *flip'n'slide*. The contribution of this study is a proof-of-concept prototype, in the form of a digital tablet connected with a work mat and embedded sensors, to explore the ways in which the combination of digital feedback and physical LEGO bricks could increase children's engagement in learning maths using LEGO Education's 4Cs principles.

FUTURE RESEARCH

An investigation into other technologies could bring to light more effective means of engagement and feedback for educational systems for young children. Possibly future educational technologies that are tablet-based can be integrated with everyday objects, to be ubiquitous within the surroundings of the classroom. Researchers such as Xu et al. [49] have already begun these investigations. The possibility of applying this research outside the context of the classroom could benefit home-schooled children. There are a number of studies that support the use of educational technology outside the context of the classroom [23, 43] but seamlessly integrated into our everyday surroundings.

ACKNOWLEDGMENTS

Thank you to Jeni Paay, my supervisor who was an invaluable sounding board through each step of the process. The coordination and involvement of my research partners help bring together elements needed for the workshop. The children of Sofiendalskolen also have my gratitude for their participation and contribution of creative ideas.

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Summary

The scientific paper endeavours to cover a number of themes. Firstly, it looks at working with children by conducting participatory design (PD) studies and the necessity of working with children in such a manner to gain optimal results. Thematic analysis is also touched upon in the handling of such qualitative data. Secondly, the paper focuses on feedback, a specific attribute of engagement, which in turn is a part of a broader body of user experience. This came as a result of findings from a previous study conducted by the same author of this paper. Thirdly, the model of engagement (O’Brien and Toms, 2008) helps to define feedback in relation to technology and user experience, by providing a suggestion of other supporting attributes for creating engaging technology. Lastly, it aims to use these structures to create a proof of concept prototype that delivers engaging feedback within an educational context.

The following chapters will give more insight into the processes of how this proof of concept prototype came to be, starting with details of the analysis of data gathered from the workshop. The *Details of the Analysis Process* chapter will detail the steps the author took in gathering, analysing and categorising the data from the workshop with photographic evidence and researcher’s memos.

[DETAILS OF THE ANALYSIS PROCESS]

Details of the Analysis Process

From the inception of the idea of creating a suitable technology for children to learn mathematics in an educational context emerged, the process was documented for academic purposes, but also for my own records. This section outlines the tools and techniques used to create the proof-of-concept prototype, giving some insight into how I approached thematic analysis. The workshop plan can be found in **Appendix D**.

Data Gathering and Analysis

(a) (b) (c)

Figure 3. A triptych displaying the thematic analysis process of creating notes, narrowing them down into themes, then finally categorising them accordingly.

Pictured in figure 3 is my room where I conducted the thematic analysis with the data from the workshop. It was necessary to spread out all the drawings, photographs, comments etc, in order to get a broad understanding of the data. The colour coordination played a huge role in organising various patterns that emerged regularly. Yellow = iteration 1, blue = iteration 2 and red = iteration 3. The data was assessed more than once to add rigour to the findings, narrowing down the categories into consistent reoccurring themes. This wall served as inspiration for the design of the proof-of-concept prototype called flip 'n' slide (figure 3. a, b and c).

Outlining Design Ideas

This phase briefly focuses on the method of identifying ideas that were extracted in the workshop, by describing them and the child's intention when designing it. This is done through categorising the themes (described above). In order to create a theme, patterns in the data were compared along with other reoccurring words or concept.

1. Converting raw data into codes
2. Initial coding (iteration 1)
3. Focused coding (iteration 2)
4. Theoretical coding (iteration 3)
5. Memo notes from study
6. Creation of themes
7. Categorising themes

The discovery of similar terms and ideas were not the only reliance for the creation and categorisation of themes. The model of engagement (O'Brien and Toms, 2008) has provided the theoretical lens for the attribute in focus, and helps to provide a definition for these designs. By using the model of engagement's definition with the themes of the workshop, it allowed me to critically reflect upon the limitations of the model.

Memos

Memos were written about the initial and focused codes to help record my thinking process about how and when relevant (and not so relevant) themes occurred, how they changed, and what their consequences were. In these memos, I made comparisons between data, cases and codes in order to find similarities and differences, and raised questions to be answered in the design activities. Parts of the data that are relevant to the research question and the model of engagement were coded accordingly. Below are examples of memos written during the phase of the study.

Thinking process of how analysis of design ideas occurred

The small extracts below are taken from the memos I had written during and after the study, to constantly question my own work and observations being made, and to note my current state of mind whilst making these observations. Even when scrutinising my own data and decisions, the observations of course can still be labelled as biased. However, the research assistant also read and made notes of her own to confirm or highlight any unclear observations I had mentioned.

"The idea was to have the children complete the questionnaire before I came to the school to do the presentation and introduce my ideas and perspective on using LEGO and technology to teach mathematics to school children. However, this was not the case and the questionnaire was completed in a slot just before the introduction. I felt this initial exposure before attending the workshop would get them thinking before being bombarded with ideas and activities. The discussion should have been used to kick-start the ideas they would have come in to the work shop with. Maybe a couple days head start would have help to prepare the children with some ideas to start with. However, the improvised questionnaire session did not change the outline of the day. A discussion section still took place.

Question 6 – The codes indicate a lot of collaboration, as the ideas were similar. This could be because of the set up of the tables or the students' interpretation of the situation to "share ideas". The ideas that were generated by the students had interesting uses of colour, sound to indicate if something was right or wrong. The students seem to understand the concept of physical and digital interaction. They used the camera as a way to access the digital world."

Thinking process of when analysis of design ideas occurred

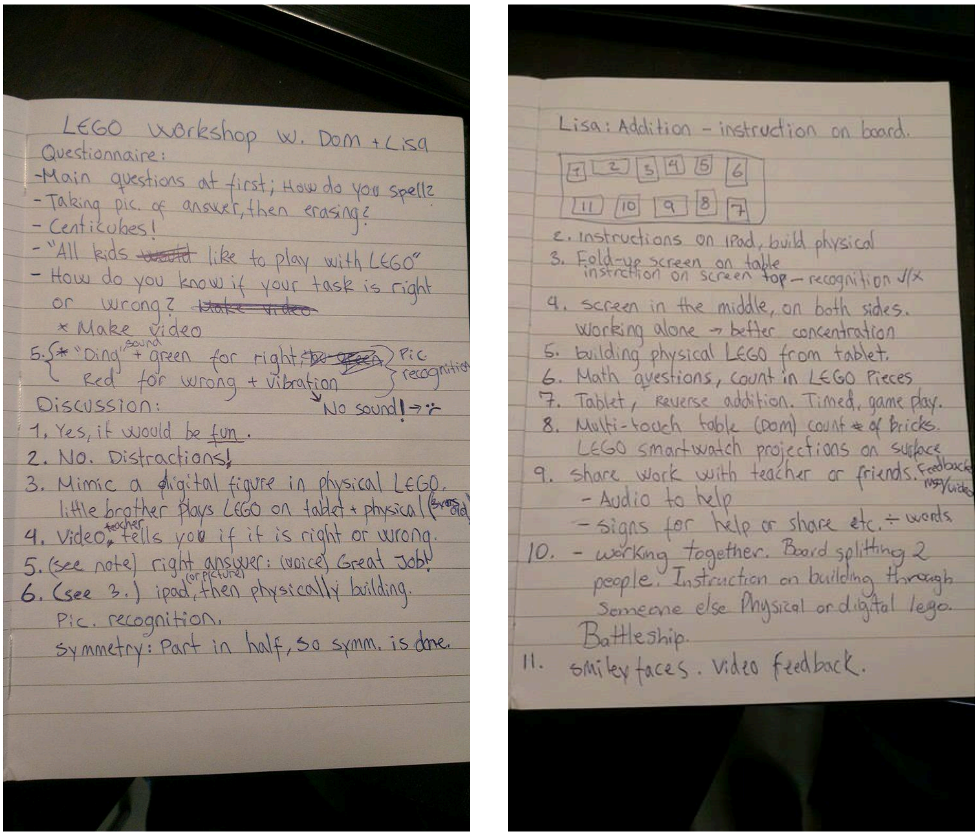
"Maria also helped to take notes during the workshop. It will be integrated into my own notes. Whilst I was taking the discussion with the students, they were able to elaborate more on their ideas that they had expressed in the questionnaire. Lisa, a research assistant, also took part in these discussions and activities. An important point to note was that a sub-path of cooperative inquiry was practiced throughout the

workshop. All the adults took part in the activities, so that the children felt like research partners."

How thinking process changed

"For question number 2, everyone answered that digital technology would not be useful in helping children to learn mathematics. For example, distraction of other digital elements, or physical LEGO seen as better for "fantasy play". However, the discussion suggested was in which technology would be useful. We established that the ideas amongst everyone for question number 6 were similar. The discussion helped to expand these ideas into other possibilities. For example, using a table with a folding screen or collaboration through getting students to build together were other suggestions."

Research Assistant Notes



(a) (b)

Figure 4. Two example pages of notes taken by the research assistant.

The notes depict a general sense of attitude towards LEGO being used as a teaching tool and digital feedback and also individual comments. These notes contributed to the analysis of the designs as they captured the opinions in the moment of the workshop. They helped to align my ideas without me imposing on their thoughts. Questions from the questionnaire can be found in **Appendix C**.

With 3 iterations of data analysis and 6 themes, the data had enough rigour to begin the next phase. The following chapter introduces additional background into the proof-of-concept prototype with a focus on possible technology alternatives, techniques of their design and programming examples of the flip ‘n’ slide presented in the scientific paper.

[DEVELOPMENT]

Development

The previous chapter discussed the method of how I analysed the data from the workshop. This chapter provides a little more background into the development of design ideas inspired from the workshop, technologies and my own programming capabilities (also found in **Appendix B**).

There are a number of ideas that could not be presented in the scientific paper for reasons concerning size and relevance to the themes aforementioned in the previous section. However, I feel it necessary to demonstrate some of the core ideas, which help contribute to the proof-of-concept prototype presented in the paper. Three versions are shown with some of the techniques behind their development, example code and programs.

Solution One

The first solution is called the LEGO Maths Cam (figure 5 and 6). As the name suggests, it uses a web camera to capture live footage of interaction with LEGO. This software recognises the LEGO bricks and inputs the data onto a computer, which in turn displays the appropriate information about the brick. This first solution has some positive qualities, in that it gives responsive feedback to the intended users. The examples below (figure 5) show LEGO bricks captured with a blue outline. Further development would have seen additional information such as the colour of the LEGO (even if apparent), the size of the piece (2 by 4 brick) and shape.

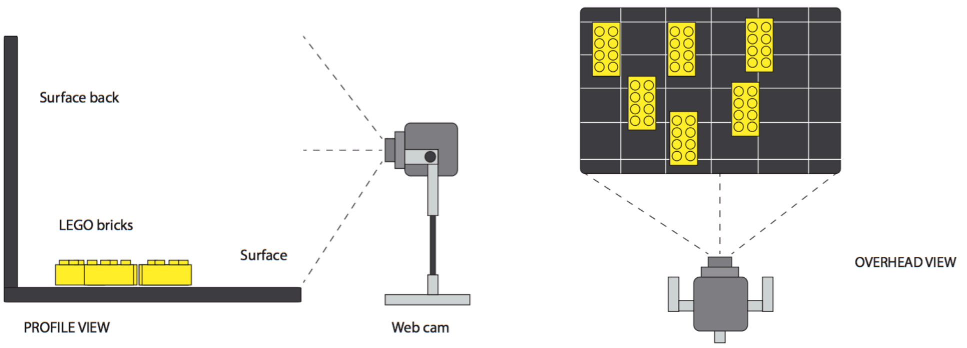


Figure 5. The LEGO Maths Cam prototype design - depicting the setup of the webcam and LEGO bricks on a gridded surface (without tablet).

The 2D sketch of the LEGO Maths Cam (figure 5) gives a much clearer idea of the look and some aspects of functionality. By this stage in the development phase, I could see that there could be potential limitations of the camera in various positions. However, the focus at this point was providing effective digital feedback and I made the decision to go ahead with creating a proof of concept prototype.

Object Detection Software

In developing the LEGO Maths Cam, open source code was used as a starting point. I used code from Luigi De Russis, as he has kindly developed the template for projects in Java, a programming language I am familiar with.

My use for the software identifies and tracks the LEGO bricks via webcam video stream by using the colour range of the LEGO bricks through the erosion and dilation and findContours method. The quantity of Hue, Saturation and Value (HSV) is used to control the image threshold. In Luigi De Russis' tutorial, he explains that the webcam then captures and processes the image by removing noise in order to facilitate object recognition. The techniques of erosion and dilation are used to identify the objects using the contours obtained after the image processing.

Building Solution One

The sketch version differs to this version but the principle is the same. Notice the threshold screens are picking up the shape and colour of the LEGO bricks. It is quite accurate as the values were adjusted in order to favour the yellow bricks. This is an important feature of the LEGO Maths Cam as it can display the different shapes and colours to the user on screen.

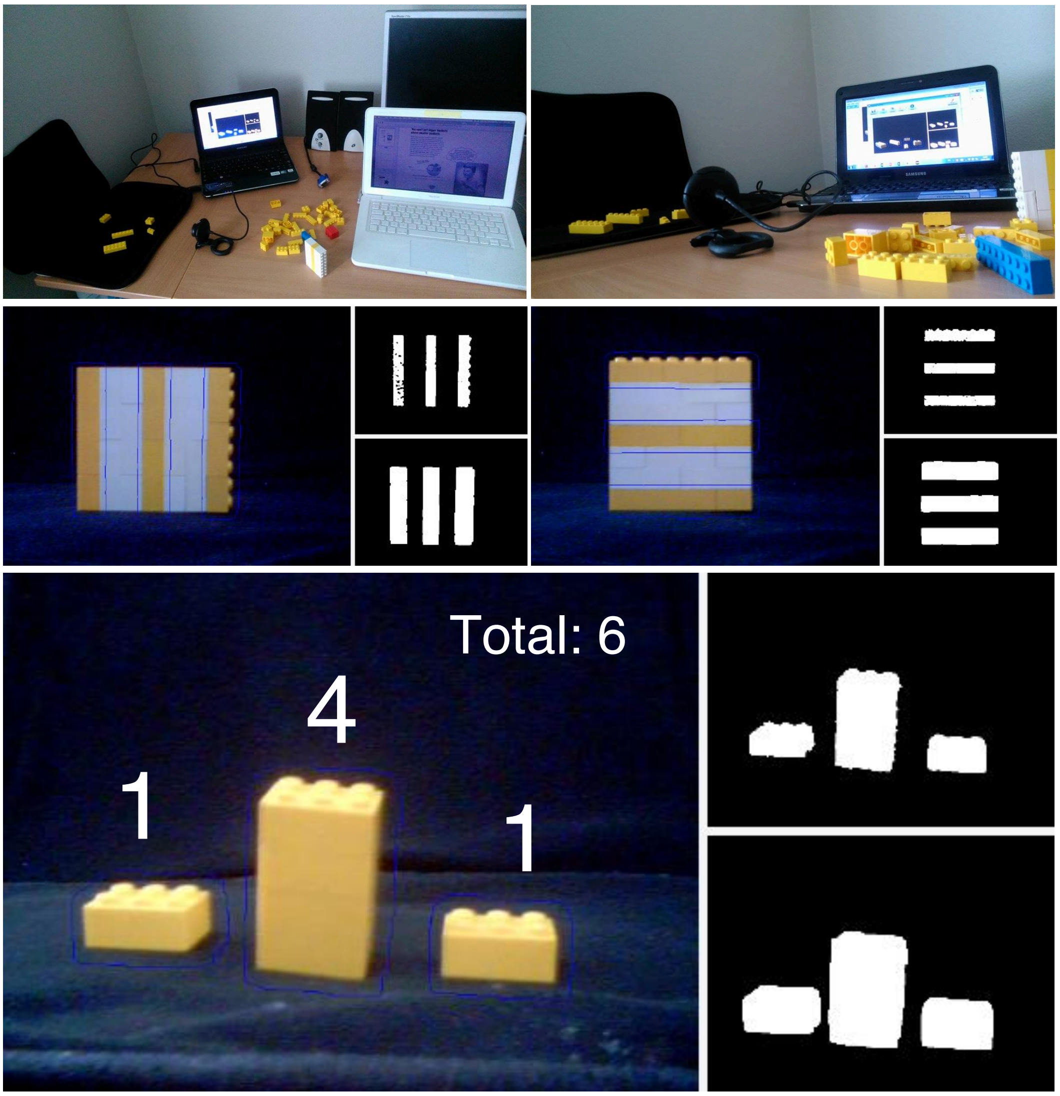


Figure 6. The setup of the LEGO Maths Cam showing the webcam using object recognition to display LEGO bricks on a laptop screen.

Reflection on Solution One

One of the front running ideas from the workshop included using a camera to capture the physical into the digital world. This was apparent through the designs by the children and researchers in the workshop. However, upon development, the camera presented a number of issues. An embedded camera on a tablet lacks mobility. A webcam, however, solves this problem. Nonetheless, it is cumbersome in a way that does not allow a clean interaction by the user. For example, user interaction with LEGO bricks are jeopardised by multiple camera positions and possible obstruction. The sturdiness of the screen and camera has to be considered to endure usage by small children. An additional component such as an external camera presents further complexity to the system with the tablet and software. Nonetheless, the LEGO Maths Cam presents a strong case for delivering effective digital feedback.

Solution Two

LEGO Maths Cam technology certainly has the capabilities in presenting continuous feedback in a digital space, though not without its drawbacks (as highlighted above). Other technology had to be considered in trying to achieve the same or similar results. For example, Radio Frequency Identification technology (RFID) was considered but lacked in a few areas, which would ultimately affect the goal of feedback. In this case, the LEGO brick would need to contain an embedded tag so that the digital reader will be able to recognise the brick. These specialised bricks do not integrate with the existing LEGO curriculum pieces, which would in effect exclude a large potential user base of schools, which currently work with ordinary LEGO bricks. Another flaw would be the element of stacking the bricks. Firstly, the RFID is limited in its ability to read waves from a limited distance. How would the software know that a LEGO brick has been placed on top of another brick? An alternate solution comes in the form of a different type of sensor; one that *partially* addresses the issue of brick stacking and the use of regular bricks, and any standard tablet with a 2.0/3.0 USB port.

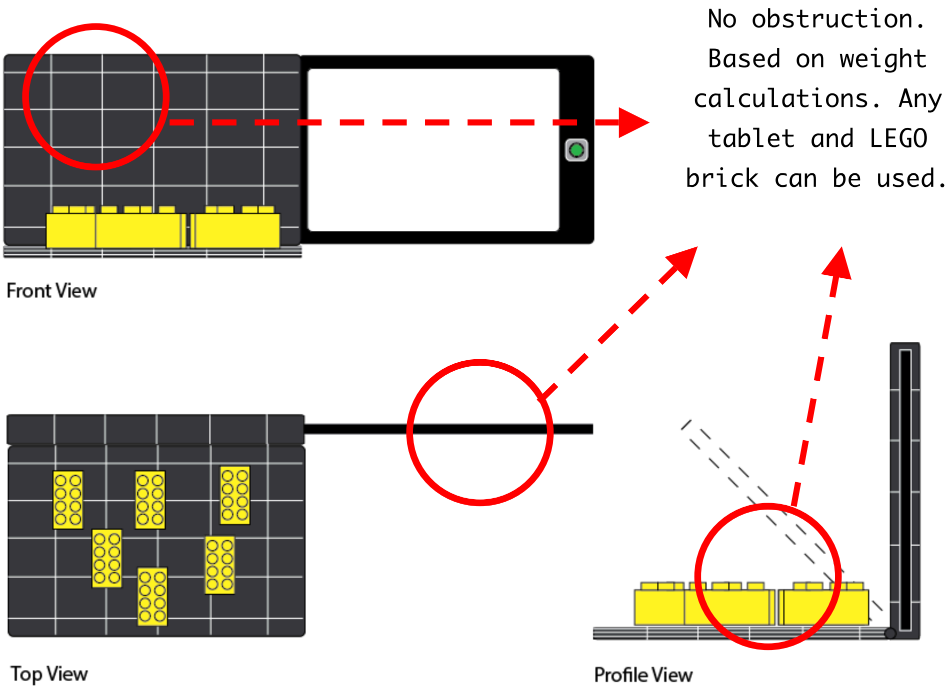


Figure 7. A 2D layout of the flip ‘n’ slide LEGO technology, addressing the flaws of the LEGO Maths Cam system.

The flip ‘n’ slide addresses a number of issues that the LEGO Maths Cam has. For example, figure 7 points out that there is no camera to obstruct a user’s actions when using the device. The scientific paper touches a little on the technology used to create this, though not in depth. The Force Sensitive Resistor (FSR) is embedded in the base of the device where it can detect LEGO bricks and deliver feedback to the digital tablet.

The same steps were followed in creating a 3D mock up the flip ‘n’ slide in order to get a clearer understanding of its functionality and usability. The tablet can be slid in and out of the case holding and connected by a USB cable to the mat, where the FSR sensors are embedded. The idea of using pressure sensor technology allows the system to know that an additional LEGO brick has been placed on top of an existing on.

Building Solution Two

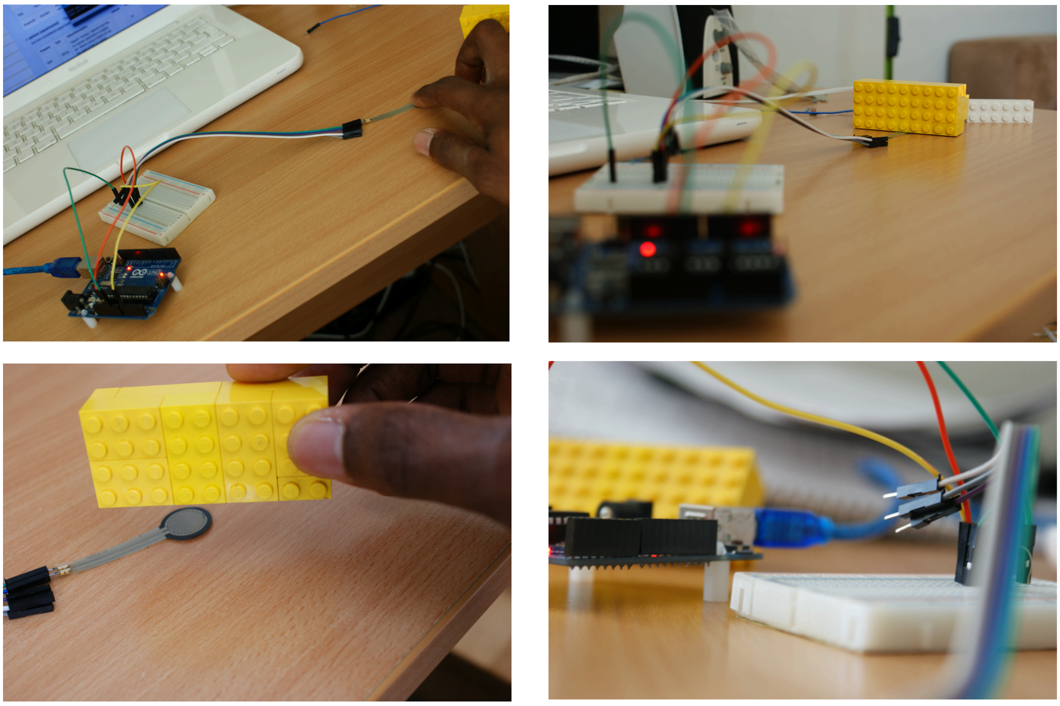


Figure 8. Programming Arduino to work with an FSR sensor.

The images in figure 8 show the making of the flip 'n' slide with two software programs. The primary software for making a connection with the FSR sensor is called Arduino. An Arduino board, a breadboard, jumper cables, a resistor, a USB connection and an FSR sensor are required for setup. After coding, the information needs to be uploaded to the Arduino board where it can be displayed on a serial monitor. My programming capabilities stretched a lot further into creating an interface to display this information. This is where a program called Processing comes in to read the serial data from Arduino. Processing comes with custom-made API libraries that can allow one to use a variety of media such as sound, images and scalable vector graphics (SVG).

Example Code

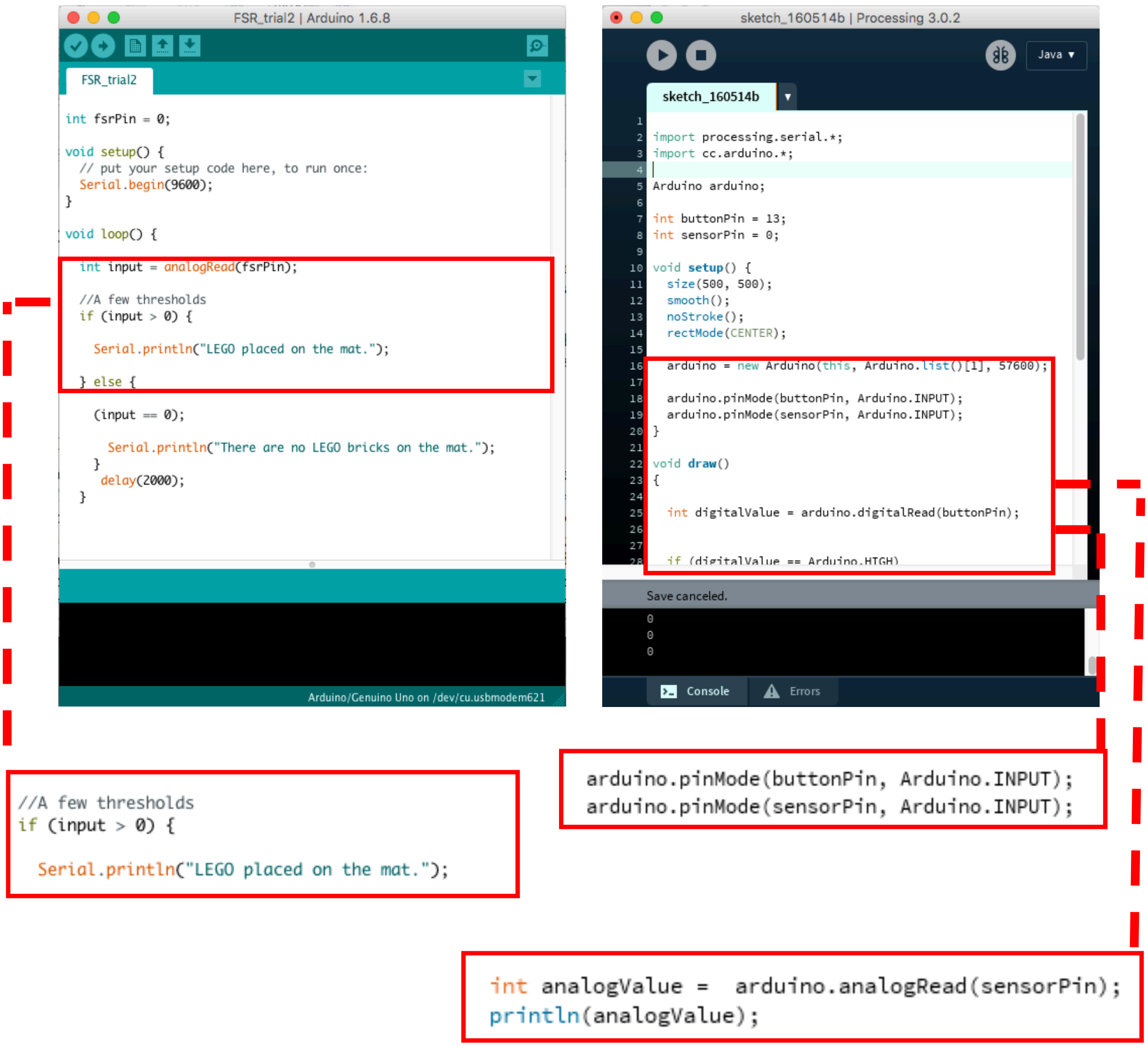


Figure 9. Code snippets of Arduino (left) and Processing (right) used to create the flip 'n' slide software.

The Arduino example code simply takes an analogue input reading from the sensor. I can then set threshold values based on the amount of pressure applied to the force sensitive resistor sensor. When there is pressure applied i.e. a LEGO brick, then the system is notified and an output value is displayed. Processing can retrieve values from Arduino in a number of ways. The technique used in the example prioritises an Ardunio class directly into Processing. This way, I can get the data directly through the serial port selected through the Arduino.list() method. An interface can now be developed to represent these values visually. However, this prototype will display a 2 dimensional representation of the LEGO brick, although it has been stated that if a final working version were to be created, the feedback would be displayed in a 3 dimensional digital environment.

Reflection on Solution Two

This version of the flip 'n' slide has limitations in the technology, which needs further development. This prototype works well when a visual interface is not developed. In spite of the possibility of an interface, the FSR technology itself is limited in providing information about the LEGO brick(s). When pressure is applied to the Force Sensitive Resistor (FSR), the serial monitor (the screen that displays text data) can know that pressure has been applied. The values are adjusted according to the object's weight. The problem lies in interpreting this information to an interface. How do we know the shape and colour of the LEGO brick by only its weight? With this limitation, the engaging feedback that is required for the prototype cannot be met. Therefore, further technology investigation is required.

Solution Three

The idea with this third solution builds upon the idea of using a combination of sensors to create hybrid software. Solution two requires sensors that will detect the object i.e. the LEGO brick and the dimensions of the LEGO brick in combination with the FSR sensors. This enhances the possibility of creating a much more complete system that can provide engaging feedback.

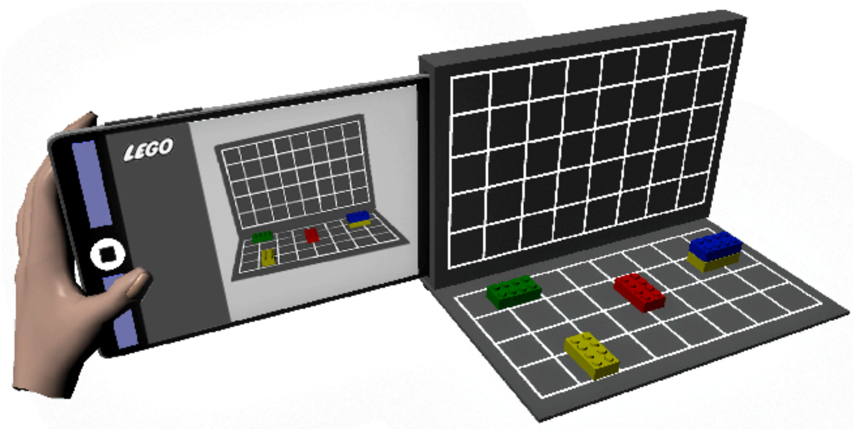


Figure 10. A 3D rendered version of the flip 'n' slide LEGO technology detailing a 3D digital environment, reflecting the physical world.

Solution three does not have a physical prototype but instead, a 3D rendered drawing of a suggested technology. It can be described as a hybrid system, consisting of a combination of technologies. The 3D rendered drawing (figure 10) displays LEGO bricks on the mat surface in the physical world, which is then translated into the digital world. This enhanced version of the flip 'n' slide is selected as a possible solution presented in the paper, as it attempts to cover the concerns outlined by the previous proof-of-concept prototypes and importantly, to address the research question.

Summary

There were a number of other unmentioned designs created in the workshop of feedback a child can gain from a tablet learning mathematics. For instance, the idea of playing mathematics battleship with physical and digital LEGO against a classmate or a more individual experience with wearable devices that can scan and project LEGO bricks onto a surface. The flip 'n' slide presented in the scientific paper was developed as a result of inspired design ideas from the workshop with children, technological reasoning and guidance from the model of engagement.

[DISCUSSION & CONCLUSION]

Discussion

The discussion section will be used to elaborate on a couple of points mentioned within the paper that needed additional clarification.

An Affordable Product

The paper overlooks an interesting aspect that could potentially see the flip 'n' slide prototype as very marketable educational software. A complete version of flip' n' slide can offer a cheaper alternative to tangible user interfaces (TUI), as it does not require a large investment on specialised equipment. Sensor technology is very affordable at a consumer level (the images of my own purchases within this report) and the materials used to create the grid are also cheap to produce. The software can be downloaded onto any tablet containing a USB port and plugged into the work mat for children child to use. Other future factors to consider are: who is the exact target group to market this product to? Are the schools purchasing it or the parents? Are the parents then "forced" to buy it?

Was the Workshop Necessary?

One of the understated points within the paper passively mentions the role of the children during the design phase of the project. It is important to bare in mind how much of a role and impact children have within such studies. The four roles children usually play in the development of technology can be categorized as users, testers, informants and design partners (Druin, 2002). The project's paper adopts the children of the workshop in the informant role, as the children are only involved at certain stages of the process i.e. prototyping and informing on design. User and tester roles require less involvement, where the participant has minimal input in the early stages of the inception of the idea. The informant and design partner role require more active participation, with the latter being the most involving of them all. The informant role takes into consideration the ideas from child informants, however, the adult researcher ultimately makes the informed design decision. Just to reiterate from the paper, Stanton et al., (2001) remark that end-users have little impact on design decisions of educational software even though they may have contributed to the idea generation phase. The children's involvement within the workshop did impact the final design. Their level of participation was apparent during the exercises and discussion. The expectations of what they would like to see in a system, demonstrated an interest a useful educational tool. They were able to relate some of their experiences as young children and through younger siblings, in response to the need for help by suggesting stronger interface design with clear text, colours and icons. The physical appearance of the flip 'n' slide was also taken from the workshop, though the researcher further developed the rearrangement of the elements such as the housing of a tablet in a shell. The breadth of the ideas allowed many possible ideas to be developed, which is in part due to the immense cooperation of the children and contribution of ideas.

Conclusion

The purpose of the conclusion within the report differs slightly to that of the conclusion presented in the paper. It attempts to address the project on a broader level, giving an overview on the research question, model of engagement and LEGO Education's four C approach and the next steps to pursue the project.

Research Question

"How can the combination of LEGO bricks and an interactive tablet be designed using participatory design with children, to create technology that delivers engaging feedback within an educational context?"

The project aimed to address the research question through supporting research from last semester and also from other existing material. Investigations into participatory design and technologies for a proof-of-concept prototype help to establish a base from which to conduct the workshop. The findings from the workshop revealed a number of themes, which arguably help to inspire the ideas for the suggested technology presented in the paper. The study has created an opportunity for a proof-of-concept to be tested within an educational context. The workshop sample was small but generated qualitative data to inspire a design.

The Model of Engagement

The model of engagement in this project is used to define engagement and the attribute in focus, feedback. The model defines feedback as one of the essential attributes to software being engaging. In the case of this project, the feedback is from a digital tablet, which has to support the system when a physical interaction takes place. The model of engagement's applicability comes into question, as it has been taken out of its original context and applied to a different domain. For instance, the study that proposed this model used semi-structured interviews on adults with how they use technology e.g. online-shopping and gaming. Despite the contrast to what this project has adopted the model for, the model of engagement is also supported by a number of definitions of engagement by various authors in other fields such as Chapman, 1997; Csikszentmihalyi, 1990; Kappelman, 1995. Therefore, the scope of the definition is not just limited to one particular area.

The Proof-of-Concept Prototype and the 4C Approach

Based on the flip 'n' slide proof-of-concept prototype presented in this report, LEGO Education's 4C approach can be an indication of whether this system meets the curriculum requirements. The following is important to have in mind when considering the use of the system by the target group.

- *Connect* - Will the child's curiosity be awakened by the flip 'n' slide prototype?
- *Contemplate* – Feedback supports reflection and therefore, the flip 'n' slide would be interesting to study in use.

- *Construct* – It is suggested in previous chapters and the research paper, that feedback from a digital tablet can offer various ways to represent visual and audio information. In turn, the flip 'n' slide can be useful in helping a child to construct knowledge about the subject matter in a multidimensional way.
- *Continue* – By knowing the answer is right, is it possible to extend ideas and continue to a higher-level problem? The LEGO Education curriculum is designed in such a way that it describes the building process as "iterative". This means that the flip 'n' slide should have the capability of allowing the children to build on what they have previously learnt/created, thus returning to the connect phase to expand on that knowledge.

The problem in addressing LEGO Education's 4C approach is that they are educational concepts, which are covered by the written exercises. In order not to change or alter these already carefully, structured educational instructions through the digital tablet representation, further investigation would be needed into appropriate and effective presentation and feedback of the instructions on a digital tablet.

Next Steps...

The flip 'n' slide is currently not in a prototype state in which it can be tested with the target group. The main aspects of visual, sound and tactile feedback have been achieved, albeit, at a very basic level. In spite of this, these features are not integrated into a complete system with instructional feedback from the LEGO LearnToLearn curriculum with a need for more technical fortitude and hardware resources.

Following this version of the flip 'n' slide, a more complete version would have the following:

- An integrated system with the LEGO LearnToLearn curriculum. Since LearnToLearn is aimed at 5-7 year old children, the system will present these tasks. Future versions can host MoreToMaths, which is aimed at children 6 years plus.

- A 3 dimensional representation of the workspace in the digital environment. The current working version is only 2 dimensional.
- A more aesthetic and safer design i.e. rounded edges and no circuitry dangling from the device, softer interior as to not damage the screen of the tablet and a more robust material.

These future developments can see a step into conducting tests with the flip 'n' slide. The target group naturally will be children between 5-7 years old. Further research on usability testing and heuristic guidelines with children will be investigated in order to take into considerations the limitations of children within these settings. The results of the test(s) will also reflect the usefulness of the model of engagement and demonstrate to some degree, whether this suggested technology does deliver engaging feedback within an educational context.

[REFLECTION]

Reflection

Improving the study

Upon reflection, the research and analysis methods used for this project can be improved. For instance, implementing audio and video recordings for retrospective analysis could have provided even richer data for the thematic analysis. The video data could also open up interesting analysis into the children's ideation and thought processes in design.

It is possible that there were some language and communication barriers between student researchers and adult researchers. Two out of three researchers were non-native Danish speakers. However, the third researcher, who was also the note taker, was able to clarify any misunderstandings with instructions or discussions and catch verbal comments during design activities. Therefore, this research may benefit from being repeated in and English-speaking context. Eight students participated in this workshop and according to Janne Jul Jensen (2013), "anywhere between six to twelve is a good workshop size." However, the study could have benefitted from additional workshops of a similar group size, given an extended time period, for a variety of broader and richer data.

An Argument Against Technology in Education

The ongoing debate on how technology affects learning questions the proof of concept prototype presented in this paper. The flip 'n' slide proof-of-concept prototype presented, fundamentally aims to follow the guidelines and principles of constructivist learning through LEGO Education's four C approach. Healey (1998) points out that children's selective attention are put at risk by "electronic stimulation" i.e. whether or not we become aware of sensory information and can focus on a task without becoming distracted (Benyon, 2013). However, McKenzie (2000) presents a more balanced outlook and believes "that in order to utilise technology appropriately to engage children in learning, more emphasis needs to be placed away from the packaging and special effects."

Self Limitations

The previous study by (Spike, 2015), mentioned the potential opportunities to heighten the engagement of children using technology within an educational context. This project actively explored the possibilities of current technologies and how they could provide feedback within the educational domain. The research was extended as far as possible, taking into consideration my own programming capabilities in the given time frame.

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[APPENDICES]

Appendices

Appendix A: Digital Lego: Building on Learning

Spike, Dominic Matthew. 2015. Digital Lego: Building on Learning.

Access to this report is available through this link QR code:

projekter.aau.dk/projekter/da/studentthesis/digital-lego-buildling-on-learning(f49c3a3d-310c-489d-bf49-2ee0296e

Figure 11. Screenshot of report page.

Appendix B: Workshop Drawings, Photographs & Notes

Workshop Drawings

Below are a selection of drawings (figure 12), prototypes and exploratory designs to give an idea of the thought process in the development of the proof-of-concept prototype described in the paper. Image (a) was drawn by a child informant. It depicts a transitional diagram of how the response of the LEGO software system would respond to a right a wrong answer. Image (b) shows a collection of drawings by both adult and child researchers. We all stood around the table and presented each idea.

Figure 12. Drawings from the individual drawing session conducted in the participatory design workshop.

Image (c) describes two images. The top half shows collaboration between two students. One is holding a tablet and the other the LEGO bricks. The person holding the tablet is describing the LEGO image they see on the tablet whilst the other individual with the bricks is building. The purpose of this idea creates an environment where there is constant communication through verbal feedback and visual feedback. Image (d) shows a classroom setting of a teacher with a LEGO task on the board where the children must copy the example. Image (e) is based on a laptop design where the bricks are placed on a grid system. This was one of the stronger ideas taken forward as it addressed the nature of visual, audio and tactile feedback, however with the drawback of building LEGO obstructing the screen. Finally, image (f) is of a girl standing by a table using LEGO bricks beside a tablet. Once she has finished building, the tablet can be used to scan the physical LEGO. The idea of keeping the physical building to the digital manipulation, help to inspire the digital mat used in the flip ‘n’ slide proof of concept prototype.

Researcher’s Post Workshop Designs

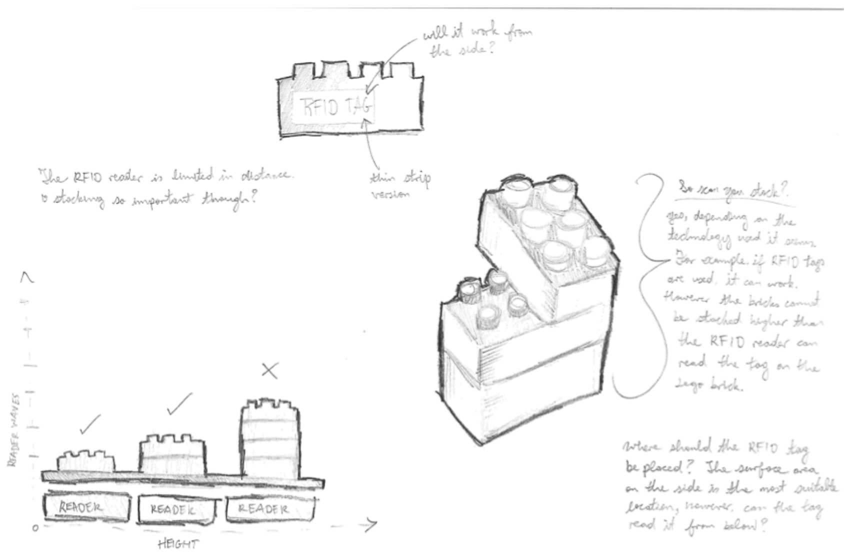


Figure 13. Sketch of Radio Frequency Identification concept with annotations.

Figure 13 describes the RFID technology being embedded in LEGO bricks. There were multiple considerations of how to stack the bricks with the reader being able to register them. There were questions that also came to mind and exposed the limitations of RFID technology in designing this technology to teach children mathematics. For instance, how does the reader “unregister” the brick if it is removed from the surface? Or how would the system know that the LEGO brick has been placed on top of another LEGO brick and not just “registered” on the mat?

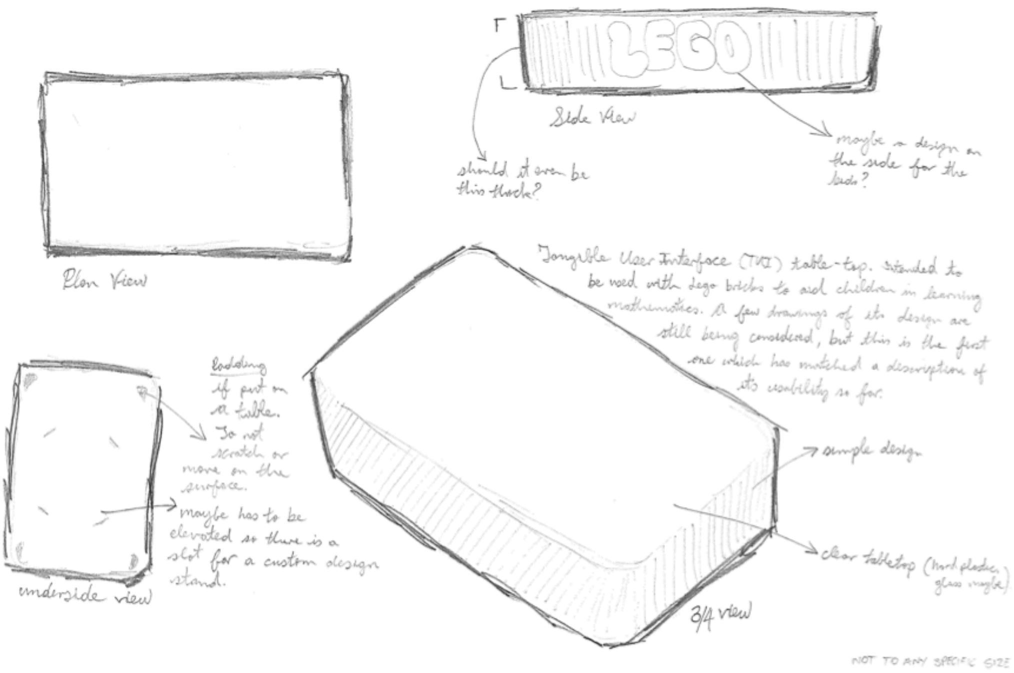


Figure 14. Sketch of multi-touch surface concept with annotations.

This idea was inspired in part by some of the tabletop examples inspired by the workshop, for example image (c) and (f) and other existing technologies. The idea behind these sketches was to create the feedback on the table surface itself, based on the brick interactions. It is an idea with many possibilities that could potentially be developed for the future with further research on multi-touch technology for children.

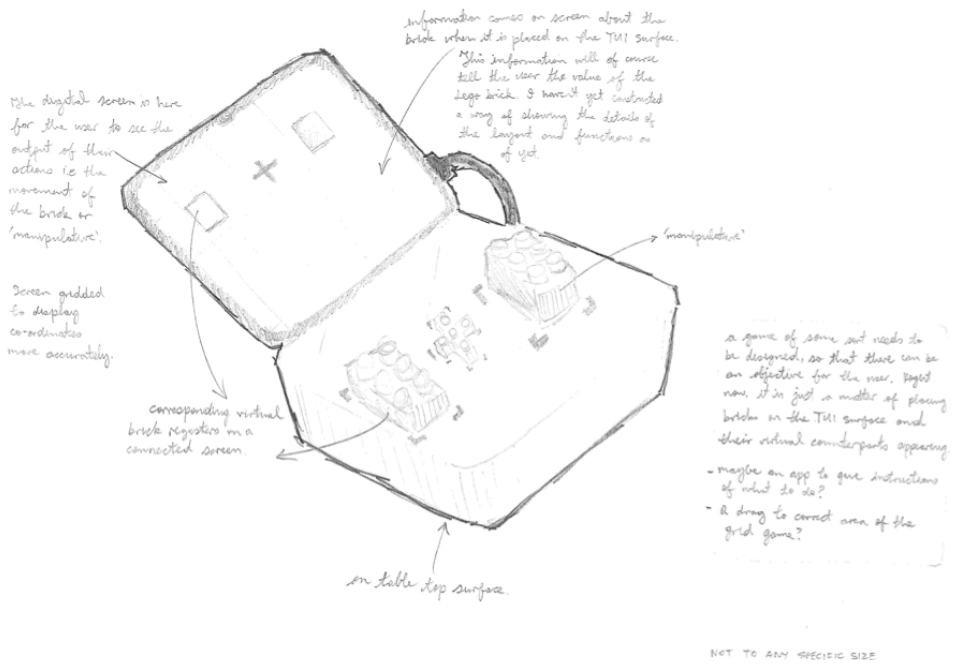


Figure 15. Sketch of multi-touch surface with a connected tablet interface, accompanied by detailed annotations.

Figure 15 is an elaboration of the laptop idea on image (e). More details are shown about the LEGO bricks being displayed, descriptions of how the screen will retrieve the information and the mobility of the hardware.

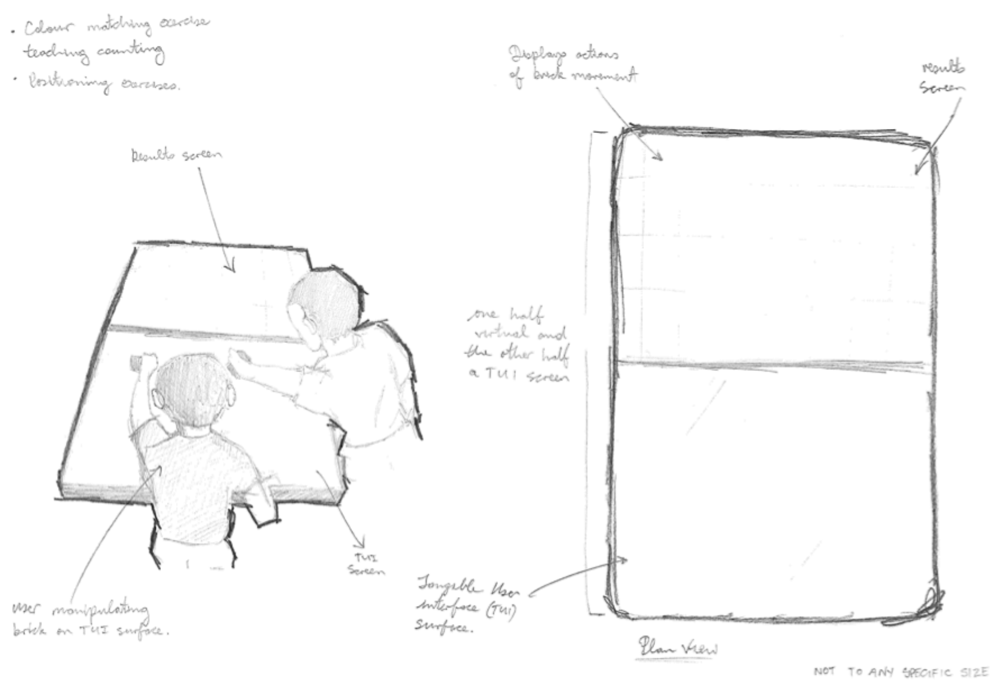
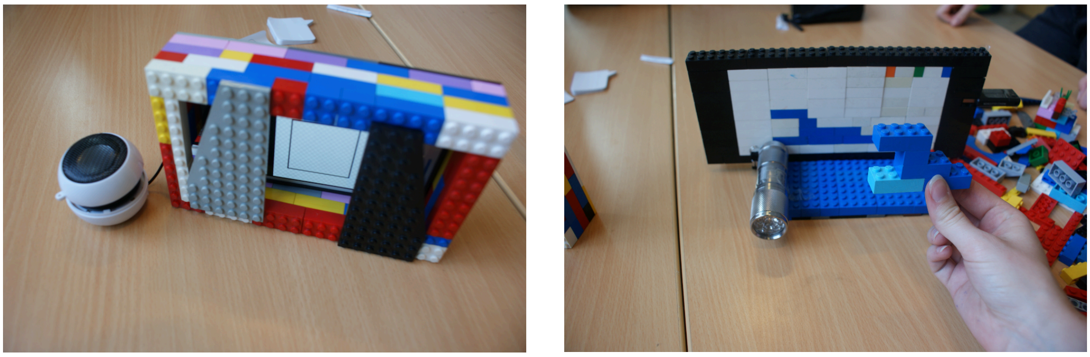


Figure 16. Sketch of children using multi-touch surface with annotations.

Figure 16 demonstrates a larger version of the tabletop display to promote collaborative learning. The image tries to create a context where the children can learn standing around the multi touch table. The table is split into 2 sides with one being digital for the interactions to take place and the other for the feedback. This particular design layout is limited in more than one way. For instance, standing at the other side of the table will inhibit the view on the feedback screen. However, this can be improved upon and be applied to the context of the classroom.

Workshop Photographs



(a) (b)

Figure 17. Two prototypes designed by children from the workshop.

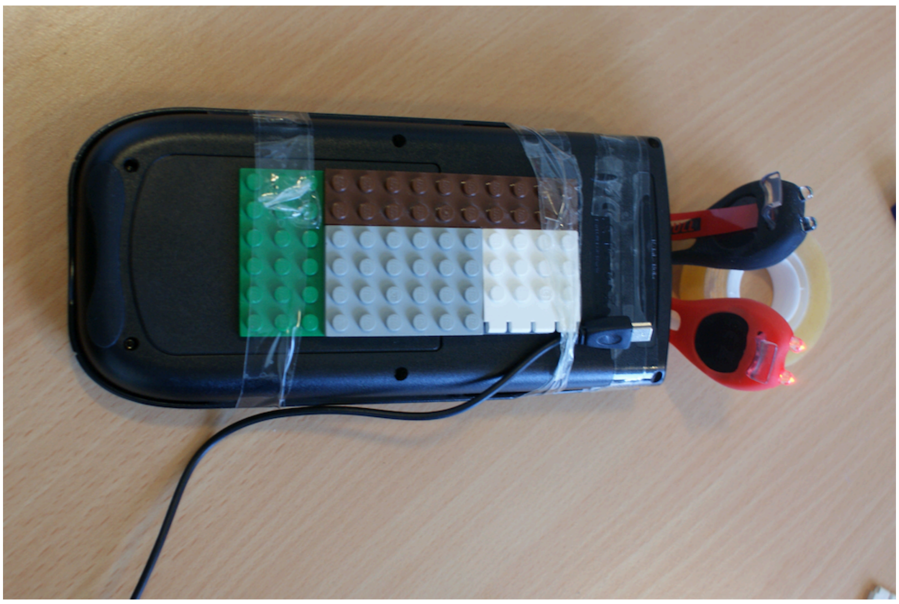


Figure 18. A prototype designed by the adult researchers in the workshop depicting a LEGO scanning device that gives visual and audio feedback.

Figures 17 and 18 are prototypes created on the day of the workshop. After the workshop, the researcher, based on the information gathered, designed a number of prototypes. This prototype created by the researchers is based on the idea of a mobile scanner. The LEGO pieces represent a small screen that displays information about the brick when the device is passed over the outcome. The lights blink accordingly, depending on whether the answer is wrong. The screen will inform the child, whether the outcome they scanned in was right or wrong. The USB cable is used to plug into a larger screen in order to display the information in larger groups. We also thought about sharing LEGO outcomes through these means.

Appendix C: Questionnaire

Have you ever tried to make something for other kids to learn with?

I mean kids much younger than yourself? I can say it is very difficult!

That's why I need your help in helping me make a *really* fun learning kit

using a computer tablet for children ages 5 - 7.

You guessed it. We are using LEGO to do this!

Below are just a few questions to think about before we meet to talk about our ideas together. There are no wrong answers and it is NOT a test!

And don't worry, you don't have to fill up these boxes with your answer.

1. Do you think LEGO can help make learning Mathematics fun for children?
   If you answered yes, what would make it fun?
   If you answered no, why would it not be fun?

2. Do you think LEGO drawn on an iPad that could be moved around the screen like real LEGO would make it more fun learning mathematics?
   If yes, what would be fun about it? If no, why would it not be fun?

3. Do you think using real LEGO bricks and an iPad together would make it more fun for children to learn Mathematics?
   If yes, what would make it more fun? If no, why would it not be more fun?

4. What is the best way to know if you get a Mathematics problem right?

5. What different ways could an iPad be used to show children they have the answers right when they are working with LEGO?
   Think about using the touch screen, sound or vibration to show them…

6. Write down or draw your idea of how LEGO can be used together with an iPad - for children learning Mathematics.

7. **Now let's all get together and share our ideas - and think up some more!**

Lego® Participatory Design Study

Workshop Outline

ABSTRACT

Documentation outlining the participatory design study that will take place within Sofiendalskolen.

This participatory design (PD) study seeks to involve children aged 11-13 in creating prototypes towards an educational system for children aged 5-7. The purpose is to involve children in the design of educational systems for other children. PD provides researchers with the opportunity to "enhance technology for children by designing with children" (Yip et al., 2013). I aim to use the children's ideas in addition to the findings from a study conducted last semester within an educational context, to create this hybrid educational system that will be used as a tool to learn concepts through constructionist principles.

LEGO is a fun and internationally recognised tool, focused on play and creativity. It is also used within institutions as an experiential educational tool to develop children's understanding of the world around them using real life problems. LearnToLearn is one of these tools, designed for key stage one students where they can engage the subject matter through direct interaction. How can the combination of LEGO bricks and an interactive tablet be designed using participatory design with children, to create technology that delivers engaging feedback within an educational context?

School: Sofiendalskolen

Key stage one teacher: Jakob Andersen

Students: 8

Research Question: How can the combination of LEGO bricks and an interactive tablet be designed using participatory design with children, to create technology that delivers engaging feedback within an educational context?

Experiment: LEGO Participatory Design Study

Project name: Combining Technologies: Digital Feedback for Interacting with LEGO Bricks in Physical Space.

Date: March 14, 2016

Duration: Experiment time 80mins/120mins

Time: 10:00am

Briefing for teacher: The children will see new faces and be curious as to what we are doing here. Participation will be entirely voluntary where students will be able to leave an activity at any time they wish. The times below are approximate and maybe more or less than specified.

Introduction - 10 mins

Discussion – 10 mins

Task 1 – 10 mins + 5 mins discussion

Task 2 – 15 mins + 5 mins discussion

Task 3 – 20 mins + 5 mins discussion

Post session Discussion – 5 mins

Wrap up of Session – 5 mins

------------------------------- The Study ------------------------------

Aim: To use a variety of Participatory Design techniques such as drawing, paper prototyping and observation to elicit design ideas from children aged between 11-13.

Apparatus: LEGO Bricks, learn-to-learn curriculum exercise examples, translator (though not necessary) and an extra pair of hands for crowd control (hopefully a teacher or Lisa Störtenbecker).

Method: This section includes the main experiment. The main experiment has the following tasks:

1. Timed: 10 minutes. Introduce myself with a PowerPoint presentation which will include:
    a. Lego and Education – my project, why I am here.
    b. The findings from the experiment conducted last semester.
    c. The tasks of what the children will be doing and whom they will be doing it for.

   * Since this is a small focus group, it will be very informal and involving.

2. Timed: 10 - 15 minutes. Start with a large group discussion with all students before splitting into smaller groups. The smaller group numbers will be specified based on the task. This discussion will be used to aim questions at the children about using LEGO and digital LEGO in an educational context.

   I will use the questionnaire as a starting point. The children will be asked about the ideas they came up with. Question 6 where they were asked to draw or write down how LEGO can be combined with an iPad would be good to get the ball rolling.

   Then after, the first activity will start from the question "Let's think up some more ideas!"

Participatory Design Techniques:

Bags of Stuff and Big Idea – Prototype

Sticky notes – Critique

White board discussions – Reflect

3. Timed: 10 minutes. The first PD activity is an individual drawing session. The students, teacher and researcher will be given approximately 10 minutes to generate some ideas. (EMPHASIS TO LABEL DRAWINGS – makes it easier for post analysis). After, we will put the individual drawings up on a board and reflect on the system ideas. Since we are a small group, this part can be done in a SCRUM format where we are standing around the board with the ideas.

Another researcher is taking notes or possibly using sticky notes to place on the drawings. This will also help with explaining unclear labels or elaborate on ideas. Timing around 10 minutes.

4. Timed: 15 minutes. The second participatory design (PD) activity. The children will remain as one group where the big idea technique; a paper prototyping technique will be used. A large paper is set in the middle of the floor. Each child contributes drawings to this sheet of paper. Collaboration is encouraged. I am also drawing along with the teacher and research assistant. I am talking through the key attribute that I am investigating i.e. feedback. E.g. how would a child know if what they had done with the Lego brick is correct? Are colours important to indicate meaning? Etc.

   After this activity, we will hang this on the wall and explain what the ideas mean and how they would contribute to an education system that delivers engaging feedback. Even look at combining all the ideas together. A research assistant will take notes on a large paper beside the ideas. This section should take around 10 minutes or so.

5. Timed: Roughly 20 minutes. After, I will introduce the technique called bags of stuff. This is where children collaborate to build a single idea. I will split the group into 2, therefore, 2 groups of 3 children each. This technique requires low-tech prototyping. The materials will be arts and craft supplies. Importantly, there will be Lego bricks for the children to help visualise how they can be used with the system they are prototyping.

I will stop the activity and get each group to present their idea in front of the other group. Again, a research assistant will record the ideas on large white paper. Another 5 – 10 minutes will be used to write down on sticky notes the likes, dislikes and design ideas, which are organised accordingly. This is happening quite dynamically, so the students can go up any time.

Post session discussion: After the activities have been completed, there will be a short focus group discussion with the children. One of the research assistants will be taking notes on final thoughts.

Wrap up Session: This will be a brief discussion session with the teacher(s) and research assistants of how the session went and what will happen with the results. Thank the school and teachers for their time and will be in touch when the "results" have been processed. I will arrange a thank you gift for both students and teachers ahead of time e.g. coupons, Lego bricks, stickers or sweets.

----------------------------- End of Study -----------------------------

Extra Information:

"Bonded Design is similar to Cooperative Inquiry, except that design partners work with researchers for shorter periods of time and the design projects are done in schools instead of a lab environment. This is done because the amount of time and resources required for a full-year of design partnering are often outside the means of design researchers. One philosophical difference of Bonded Design from Cooperative Inquiry is that all participants are also thought of as learners in addition to being designers." – (Walsh, 2013).