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.

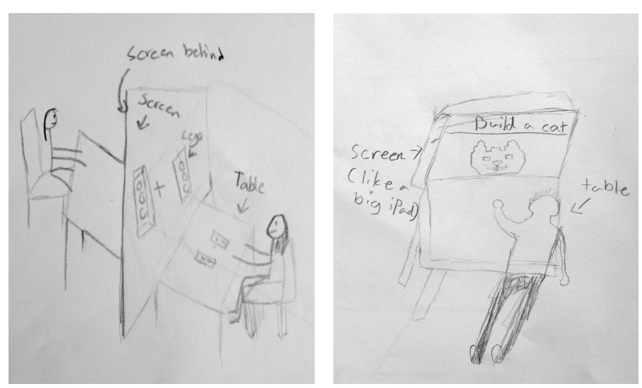
Methods

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.

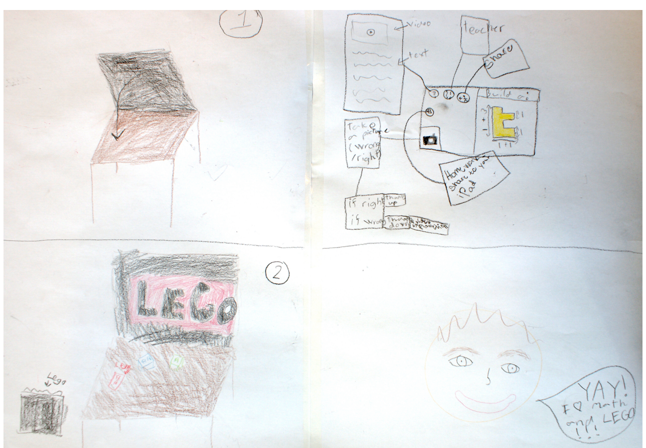


Figure 2. *Big Idea* created by Group A, combining LEGO bricks on a tabletop with a virtual feedback system.

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

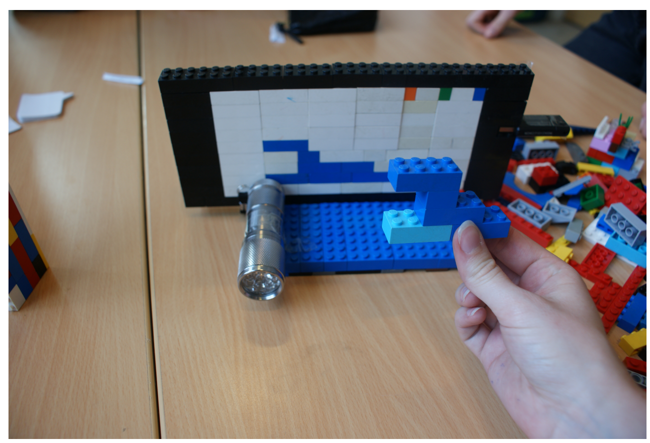


Figure 3. A prototype created by Group B, demonstrating a digital tablet with an object recognition camera to detect LEGO bricks.

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.

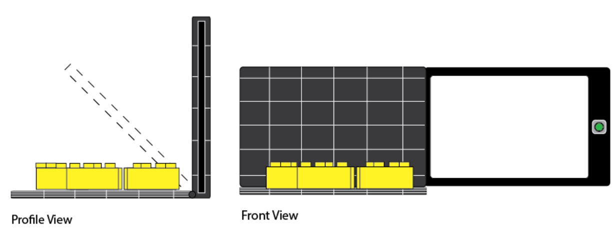


Figure 4. ***flip'n'slide:*** **An object sensor inspired design.**

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.

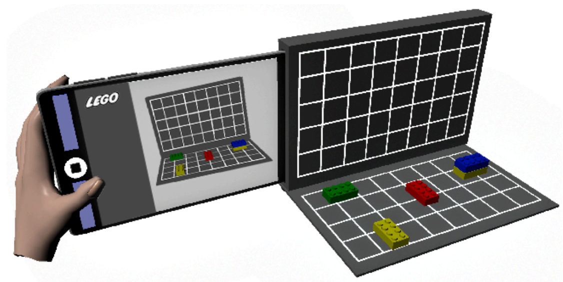


Figure 5. A 3D rendered version of *flip'n'slide*.

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.

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