Won’t somebody please think of the parents? Designing activities for engagement with STEM learning.

Jennifer Sheahan

Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>2</td>
</tr>
<tr>
<td>2 Literature Review</td>
<td>3</td>
</tr>
<tr>
<td>2.1 The Importance of STEM Learning</td>
<td>3</td>
</tr>
<tr>
<td>2.2 The Benefits of Parental Engagement in Learning</td>
<td>3</td>
</tr>
<tr>
<td>2.3 STEM Learning</td>
<td>4</td>
</tr>
<tr>
<td>2.4 Designing for Engagement and Collaboration</td>
<td>5</td>
</tr>
<tr>
<td>2.5 The Benefits of Tangible Interactions</td>
<td>5</td>
</tr>
<tr>
<td>2.6 Existing STEM Toolkits</td>
<td>6</td>
</tr>
<tr>
<td>3 Design and Evaluation Methodology</td>
<td>6</td>
</tr>
<tr>
<td>3.1 Design Goals</td>
<td>6</td>
</tr>
<tr>
<td>3.2 Design and Prototype Process</td>
<td>6</td>
</tr>
<tr>
<td>3.3 Evaluation Methods</td>
<td>7</td>
</tr>
<tr>
<td>3.4 Possible Alternative Evaluation Methods</td>
<td>8</td>
</tr>
<tr>
<td>4 Design and Prototype</td>
<td>8</td>
</tr>
<tr>
<td>4.1 Phase 1 – Concept Generation</td>
<td>8</td>
</tr>
<tr>
<td>4.2 Phase 2 – Paper Prototyping</td>
<td>10</td>
</tr>
<tr>
<td>4.3 Phase 3 – First Functional prototype</td>
<td>11</td>
</tr>
<tr>
<td>4.4 Phase 4 – Final Prototype</td>
<td>13</td>
</tr>
<tr>
<td>5 Evaluations</td>
<td>14</td>
</tr>
<tr>
<td>5.1 Usability Testing</td>
<td>14</td>
</tr>
<tr>
<td>5.2 User Evaluations</td>
<td>15</td>
</tr>
<tr>
<td>5.3 Expert Evaluation</td>
<td>18</td>
</tr>
<tr>
<td>6 Discussion</td>
<td>19</td>
</tr>
<tr>
<td>6.1 Facilitating Parent / Child Interaction</td>
<td>20</td>
</tr>
<tr>
<td>6.2 Encouraging future STEM Exploration</td>
<td>20</td>
</tr>
<tr>
<td>6.3 Advancing Cognition through STEM Learning</td>
<td>20</td>
</tr>
<tr>
<td>6.4 Recommendations for Future Work</td>
<td>21</td>
</tr>
<tr>
<td>6.5 Limitations</td>
<td>21</td>
</tr>
<tr>
<td>7 Conclusion</td>
<td>21</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>21</td>
</tr>
<tr>
<td>References</td>
<td>22</td>
</tr>
</tbody>
</table>

Word Count: 14,172
Won’t Somebody Please Think of the Parents? Designing Activities for Engagement with STEM Learning.

Jennifer Sheahan  
HCI-E MSc Final Project Report 2016  
UCL Interaction Centre, University College London  
Supervisors: Nicolai Marquardt and Zuzanna Lechelt

ABSTRACT  
STEM (Science, Technology, Engineering, and Maths) subjects are instrumental facets of learning, due to the thinking framework they impart and the increasing market demand for such skills. Parental engagement with their child’s STEM learning is a key determinant of the child’s academic success in this area, yet this can prove difficult for those parents who do not have a STEM background. There is a gap in current research for child-parent learning activities which cater for these parents. This project provides a unique contribution by designing and evaluating a series of activities to address this gap. An extensive literature review was conducted to determine design goals which encompass the needs of both parent and child. A series of iterative design phases implemented these goals into a functional prototype; an interactive book containing activities based on a framework of computational thinking. Finally, a novel combination of evaluation methods was applied to assess whether the prototype effectively engaged parents with their child’s STEM learning, and to determine its value as a STEM learning tool. The findings show that relating new concepts to a familiar activity structure facilitates parental engagement in their child’s learning, without requiring explicit subject knowledge. This paper concludes by suggesting design and evaluation recommendations for future work in this area.

Author Keywords  
Education; Toys; Tangible Interfaces; Children

ACM Classification Keywords  
K.3.1 Computer Uses in Education: Collaborative learning  
H.5.2 User Interfaces: Prototyping

MSc Contribution Types  
Design/Artefact

MSC HCI-E FINAL PROJECT REPORT  
Project report submitted in part fulfilment of the requirements for the degree of Master of Science (Human-Computer Interaction with Ergonomics) in the Faculty of Brain Sciences, University College London, 2016.

NOTE BY THE UNIVERSITY  
This project report is submitted as an examination paper. No responsibility can be held by London University for the accuracy or completeness of the material therein.

1 INTRODUCTION  
STEM (Science, Technology, Engineering, and Maths) subjects are increasingly under focus as technology proliferates and demand for STEM skills rises [55]. STEM subjects provide a thinking framework that is beneficial to other areas of learning [34]. As schools endeavour to implement a STEM curriculum that will adequately prepare children for this modern world [59], it is increasingly important to provide educational materials that support this learning in a way that is effective and enjoyable.

Parental engagement provides multiple benefits to children’s learning [26] and often influences later career choices [50]. However, an increasingly complex academic environment can prove daunting for parents who may not be confident in their child’s subject matter. This is particularly the case in STEM subjects; opinion reports suggest they can be negatively perceived by those who do not have a background in STEM [1][53]. This can lead to an increased risk of hindering a child’s learning. Educational technologies that support learning at home by engaging parents are therefore instrumental in minimizing this risk.

There are many excellent resources for amateurs (children and adults) to get started in STEM exploration; for example, Arduino [60], Little Bits [6], Scratch [44], and a variety of toys and kits, e.g. chemistry sets [61]. However, these tend to either be marketed to children, or to experienced makers and tinkerers. There is a lack of resources specifically aimed at adult amateurs who will be learning at home, alongside their children. There are also plenty of resources aimed at
amateur adult learning, but these are mostly for specific technologies (usually programming or software training) and are generally for the purposes of increasing marketable employment skills rather than overall enjoyment and learning.

Where they don’t have a background in STEM, there is a gap for parents who may want to be involved with their children’s STEM learning, but are daunted by the prospect and don’t know where to begin; and parents for whom STEM isn’t really on their radar – they are removed from the field and aren’t aware that their engagement would be beneficial to their child’s learning. Therefore, this project aims to address the following design challenge:

*Can we design a series of activities to engage parents who do not have a STEM background in exploring STEM learning with their children?*

The goal in this instance is not to measure improvements in academic performance, rather it is to benefit both children and parents by fostering an interest in general STEM exploration, and to facilitate a collaborative learning environment that addresses the needs and abilities of both parent and child. There is a gap in current research for parent-child user groups, particularly for the purpose of collaborative learning; thus this project provides a unique contribution by suggesting design recommendations for this group and providing initial evaluation results. It is hoped that future work in this area will build upon the promising findings of this project.

In order to meet this design challenge, an extensive literature review was conducted with the purpose of identifying design goals. Based on these goals, a series of iterative design phases was completed, resulting in a functional prototype; an interactive book with a series of activities structured around computational thinking, which are designed to be relatable to both children and adults. Finally, a combination of evaluation methods was conducted using the prototype, with the goals of addressing usability issues, assessing whether the prototype met the design goals, and eliciting input for future iterations of the design. The concluding contribution of this project will be to propose design and evaluation recommendations which we hope will inform future research and design of collaborative parent and child STEM education technologies.

## 2 LITERATURE REVIEW

This section discusses the relevant related work demonstrating the importance of STEM learning, the benefits of parental involvement, learning and engagement approaches for both adults and children, and the argument for interactive physical artefacts in favour of computer-based learning. This section also briefly reviews relevant existing STEM-based educational tools, and highlights gaps that we will seek to address in the design section of this dissertation.

### 2.1 The Importance of STEM Learning

STEM learning is increasingly imperative for two significant reasons. Firstly, technology and scientific advancements are proliferating exponentially. The job market in these areas will only continue to grow, and it is increasingly important to understand technology in order to appreciate the world around us [36]. Secondly, and arguably more importantly, STEM learning teaches a particularly useful skillset and thinking framework that is applicable to almost every other discipline, originally defined in 1980 by Seymour Papert as “Computational Thinking”; a computer-science based approach to problem solving [34][35]. This concept has been further explored and refined by Jeanette Wing, who defines Computational Thinking as “solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science”, and focuses particularly on abstraction and decomposition as its fundamental approaches [57]. Wing further states that Computational Thinking transfers to a wide range of disciplines, for example applications of algorithms to represent protein structures in biology. Shayer and Adey proved this transfer effect in 1993 with their CASE (Cognitive Acceleration through Science Education) intervention, where implementation of a two-year Science-based lesson framework resulted in not only in improved grades for GCSE Science, but equally for GCSE English [48].

More recently, an association between the International Society for Technology in Education (ISTE), the UK Computing at School working group (CAS), and the Computer Science Teachers Association (CSTA) has published an Operational Definition of Computational Thinking for K-12 education [54]. This has been further refined in collaboration with Google, who have proposed the following simplified process to describe Computational Thinking [62]:

- **Decomposition** – breaking down large problems into small parts
- **Pattern Matching** – recognising patterns or trends
- **Abstraction** – identifying common characteristics of those patterns or trends
- **Algorithms** – developing instructions to solve problems

This framework for solving problems and creating solutions is beneficial for general learning, and is valuable for both children and adults.

### 2.2 The Benefits of Parental Engagement in Learning

Parental involvement is crucial in supporting children’s informal science learning, and to influence a positive attitude towards learning in school [26]. Of particular interest is Lee and Nie’s proposal of three types of support that parents can provide children:

1. **Behavioural support** involves parents acting as role-models for their children. This includes learning together and engaging in exploratory activities together.
2. Psychological support requires parents to create a nurturing learning environment.

3. Intellectual–cognitive support involves providing psychological or cognitive stimulation for children. Lee and Nie note the importance of providing learning opportunities in daily life.

While no prior STEM knowledge is required to provide psychological support, providing behavioural and intellectual–cognitive support could be difficult for parents with non-STEM backgrounds. Engaging in STEM activities with their child will require initial motivation, and some knowledge of what to learn and how to support resources. Intellectual–cognitive support certainly requires at least some prior familiarity with STEM subjects in order to identify learning opportunities in daily life. This is not easy for those parents who may not have experience with STEM.

Additionally, parents are best placed to provide experiences for young children which foster an early interest in STEM; for example, visits to Science Museums or exploring simple chemistry experiments in the home. These experiences influence engagement with learning, and one study found that learning from a parent about the reality of STEM careers was often a significant factor in that child choosing a STEM career later in life [50]. Crucially, this study also finds that the parents do not have to work in the STEM field to be influential in this manner – it is enough that they display an interest in the area and act as a role-model for their children to also learn about STEM. This is a very important finding for our purposes, as it means we can help to increase parental interest and engagement with STEM subjects for all parents, regardless of their background.

A recent NESTA report on digital education showed that most parents very much want to support this learning [39]. From the report:

“89% think it is a worthwhile activity for their children. 73% encourage their children to make things with technology... 53% have purchased hardware or software to support their child in digital making... 84% agree that the skills associated with digital making are important for jobs or careers for their children.”

However, it is also clear from the NESTA report that many parents lack (or do not avail of) the resources to actively engage with their children’s learning:

“Only 12% of parents felt informed enough of face-to-face digital making activities to signpost their children to them. A similar number said the same was true of online resources. Less than a third were aware of the existence of online resources, kits or face-to-face activities.”

This propensity towards parental support is crucial – clearly the motivation to engage with STEM learning already exists. However, there is a clear gap between motivation and action, which seems to be at least partially due to lack of information and access to resources.

2.3 STEM Learning

Adults and children are at different cognitive stages of development, and as such different approaches are required to engage them in learning activities. This section will explore the social and cognitive needs of both parent and child in the context of collaborative STEM activities.

2.3.1 STEM Learning for Adults

The primary purpose of this project is not to teach specific STEM concepts to adults, but rather to engage them in supporting their child’s learning. Therefore, some of the traditional principles of adult learning will not apply here. Instead, we discuss those that are pertinent to supporting collaborative learning with a child.

Lee and Nie state that parents need not be subject-matter experts in order to facilitate their child’s learning [26]; they can provide beneficial guidance without imparting topic-specific knowledge. Malcolm Knowles’ seminal work on adult learning proposes that there should be “increasing emphasis on experiential techniques which tap the experience of the learners” [25]. This is a key principle that can be used to guide parents; relating new STEM concepts to familiar experiences would allow the parent to utilise their existing knowledge, giving them confidence to support their child through learning.

However, should the parent be so inclined, there are many success stories of STEM learning later in life; one recent study has shown that older adults (60-80) have no problem mastering new technology designed for learning; i.e. the MaKey MaKey toolkit [46]. A pertinent finding of this study was that adults proactively collaborated when engaging in this learning activity, a behaviour that is key to the success of parental engagement with their child’s STEM learning. While the target age-group of this study is likely older than ours will be, it is reasonable to assume that this characteristic will generalise positively to younger adult age-groups. Another key finding in this study is the increasing levels of confidence as adults “played” with the toolkit. STEM learning can be characterised as a series of failures; breaking things is the key to making things. This could be a difficult concept for those not used to this style of learning; electronics in particular can be intimidating, as there is a worry of getting hurt or damaging something valuable. It is encouraging that these barriers appeared to be overcome during the course of experimenting with the MaKey MaKey toolkit.

2.3.2 STEM Learning for Children

Children learn best in a social context which allows them to communicate and collaborate, according to Vygotsky’s theory of social constructivism [56]. One relevant aspect of this theory is the “Zone of Proximal Development”. This postulates that collaborative learning can be particularly beneficial to children when working with adults, who can “boost” the capabilities of the child. This has been shown to be applicable to technology learning, where collaboration
between people with different skills and backgrounds is ultimately more beneficial [16].

Arguably, the most influential theories regarding child education stem from Jean Piaget’s seminal 1970 work where he proposes the concept of constructivism [37]. Put simply, constructivism is the theory that learning is a result of comparing new information gained through experience with existing ideas or “schemata”. These schemata become increasingly complex when challenged with novel experiences. Piaget posits that children must be active participants of the learning experience, and must be afforded the opportunity to reflect on this experience.

A decade later, Seymour Papert built on this theory and postulated his own, which further addresses the experiential aspects of this learning process. Papert’s theory of constructionism notably states that children assimilate new ideas through the use of “objects to think with” [34] – physical tools that are used to construct and communicate ideas.

Combined, these theories lead to the conclusion that the most advantageous learning tool for children will include physical objects to allow external sense-making and communication of ideas, and will facilitate collaboration with an adult to allow the exploration of more advanced concepts through guided learning.

2.4 Designing for Engagement and Collaboration
In order to maximise learning and encourage future STEM exploration in the home, the activities designed must be collaborative and engaging. This can be difficult when there are two distinct targets user groups, each at different social and developmental stages. Therefore, it is important to understand the attributes of each group, in order to meet both of their needs.

In our children’s target group of 5-9 year olds, we are likely to encounter both the “pre-operational” (2-7yrs) and “operational” (7-11yrs) phases of development, as classified by Piaget [37]. Bruckman et al [10] describe the design challenges for these age-groups in contrast with adults. Children generally have a shorter attention span; this could prove frustrating for adults, yet children may become bored if forced to spend too long on one activity. Additionally, children’s capacity for short-term memory is lower than adult’s – very young children may only hold be able to hold one item in their memory at a time; adults can hold an average of seven [30]. Children particularly struggle with abstract thought – a key factor in Computational Thinking. This is important when designing activities that might require semantic categorisation or complex levels of understanding of a concept. Young children also have lower levels of literacy than adults, and so designs for the younger age group must consider other methods of conveying and interpreting dialogue.

Children in particular are highly creative and usually require a narrative to accompany the activity, or a way to link it to other more artistic disciplines – either prescribed or, ideally, left to themselves to invent [7]. Children also do well when they have a sense of control over the direction of the game, and thus it is important to allow openness in the activity, such that inflexible rules do not stifle the child’s creativity [43].

Fundamental to creating an engaging activity for all ages is ensuring that activity is challenging [14] – specifically that it is increasingly challenging at the right level, i.e. neither frustratingly difficult nor boringly easy. This is potentially a difficult design aspect as different things will be challenging to children and adults; for example, a child may find memory strategies challenging, whereas an adult may find creating a narrative more challenging. Another key aspect to engagement is time – parents will often be busy.

There are, however, strategies for engagement that will generalise to all age-groups. Of pertinence to our design is: social interaction – either collaboration towards a shared goal, or competition to win a shared game; appropriate feedback and rewards; and novel tasks which include variety and choice [15]. Both children and adults learn best through experience and exploration [5].

2.4.1 Barriers to Engagement for Parents
Lee and Nie describe three main influences on parental engagement with their child’s STEM learning: time and commitment, self-efficacy, and resources [26]. Time and commitment is self-evident – parents are busy, and extra-curricular learning can often include costly trips to clubs or time-heavy lessons in the home.

Self-efficacy is perhaps more important; this encompasses the parent’s belief in their own ability to contribute positively to their child’s education [21]. As the child’s curriculum advances in areas beyond their own knowledge, parents may lose confidence in their intellectual–cognitive support capabilities.

Thirdly, parents who do not have a STEM background may lack the resources to identify or create STEM activities in the home, and may mistakenly believe they must invest in expensive equipment to do so. There are some key elements to being comfortable exploring STEM projects – things are going to break, or not work at all, and while resources are available online, one needs to know where to look and how to assimilate the information.

2.5 The Benefits of Tangible Interactions
The use of physical and tangible computing to design learning activities has a number of benefits over screen-based activities. Physical objects support collaboration, exploration, feedback, affordances, multi-sensory inputs, and can help make concepts less abstract [22]. Exploration through tangible objects can also help children construct more complex mental models as they assimilate new information [28].

The concept of enhancing education through physical objects dates back to Froebel’s work in the late 19th century [17].
This was soon followed by the still-popular Montessori method, which builds on Papert’s constructionist theory to teach concepts through working with physical materials, rather than didactic lessons [31]. More recently, tangible interfaces have been shown to facilitate experiential and collaborative learning by allowing one to see what others are doing [4]. Another recent study demonstrated that construction with physical objects facilitates collaboration between those of mixed skill levels [23].

2.6 Existing STEM Toolkits

There now exist a number of excellent toolkits aimed at encouraging STEM education which encompass many of the benefits of tangible interactions; the most relevant of these are briefly discussed here in the context of our goal of engaging non-STEM parents.

2.6.1 Circuit-board kits

Boards like the Arduino [60], Raspberry Pi [63], .NET Gadgeteer, [64], and the Makey Makey [49] cater to varying levels of ability and provide the opportunity for low-cost entry to exploring computer science and microcontroller interactions. Many of these have large support communities; adults tend do well with such a structure, particularly access to text-based resources and social support (e.g. forums) [5]. However, all of them require some level of proficiency to set up, creating a barrier for some parents. Additionally, while tangible items can be used with them, they are not tangible in and of themselves.

2.6.2 Electronic kits

Products such as littleBits [6], LEGO Mindstorms [42], SAM Labs [65], CodeMe [66], and Google Bloks [8] allow exploration of computational concepts through the use of interactive physical blocks or cubes. However, many of these require computer access and literacy in order to programme them, and all are aimed specifically at children (not adults).

3 DESIGN AND EVALUATION METHODOLOGY

This section describes the design goals identified as a result of the previous literature review, and outlines and justifies the design and evaluation methodologies that were followed throughout the project in order to achieve these design goals.

3.1 Design Goals

Three overall design goals emerged from the literature review; design features were identified to address each.

<table>
<thead>
<tr>
<th>Design Goal</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilitate interaction between parent and child.</td>
<td>Enable non-STEM parents to provide learning support for their child: Relate the activities to familiar concepts to assist non-STEM parents by drawing on their existing knowledge. Facilitate social interaction for children.</td>
</tr>
<tr>
<td></td>
<td><strong>Make the activities tangible:</strong> Create physically interactive activities to maximise collaboration, feedback, affordances, and to reduce abstraction.</td>
</tr>
<tr>
<td></td>
<td><strong>Design for flexibility:</strong> Parents will often be busy. Create portable and flexible activities where children can continue without constant adult involvement.</td>
</tr>
<tr>
<td></td>
<td><strong>Use cheap or free open source hardware / software</strong>: Ensure resources can be easily accessed with minimal cost.</td>
</tr>
</tbody>
</table>

Table 1: Design Goals

3.2 Design and Prototype Process

The design process was based on a User-Centred Approach, following the three principles defined by Gould and Lewis [18]:

- **Early focus on users and tasks**

For this project, initial information about users and tasks was derived from the literature review, and distilled into a list of design goals.

- **Empirical measurement**

A core aspect of user-centred design is eliciting feedback from target users through structured evaluation. In this case, as there was no existing artefact, early testing with target users was not possible. In lieu, feedback sessions were conducted at each phase of the design process with what will be referred to herein as the “Feedback Group”. This was a
group consisting of at least one (sometimes both) of the supervisors of this project, another HCI academic working in child STEM education research, and a classmate of the author whose MSc dissertation research also focused on educational technologies. Once a working prototype had been developed, studies were conducted with target users.

- **Iterative design**

There were four phases to the iterative design process. Each phase concluded with a feedback session, which was incorporated into the next iteration of the design. The fourth phase resulted in the final prototype which was used for user testing and expert evaluations.

![Figure 2: Overview of Design and Evaluation Process](image)

The first phase was concept generation. For this process, the “10 plus 10” sketching method was employed [19]. Ten diverse design concepts were sketched. The best of these were evaluated by the Feedback Group. The most fitting concept was chosen, and more detailed variations were explored through further sketching. The best of these were again presented to the Feedback Group, and moved into phase 2 of the design process. This sketch is considered the first iteration of the prototype.

Phase two involved creating paper prototypes of the chosen design concept to explore feasibility. A number of prototypes were explored and evaluated with the Feedback Group before choosing the final design. This resulted in the second iteration of the prototype.

In phase three, a working prototype was built to incorporate the intended functionality. The resulting prototype – the third iteration – underwent a formal usability testing session.

Feedback from this session was incorporated into the fourth and final iteration of the prototype, which was fully functional. This final iteration was used for the User Evaluations and Expert Evaluation (described in the following section 3.3).

### 3.3 Evaluation Methods

The primary goal of the evaluations was to assess how well the design answered the research question; i.e. to what extent the intended result of engaging parents with their child’s STEM learning activities was achieved. The secondary goal was to evaluate the prototype for its effectiveness as a tool for children’s STEM learning. The third and final goal was to elicit feedback to improve future iterations of the design. The prototype was also evaluated to reduce any potential usability issues prior to evaluations with target users.

To meet these goals, a combination of evaluation techniques was employed. Due to the largely qualitative nature of the data, the time constraints of the project, a single investigator, and the small number of participants (16 total), there was a higher probability of subjective bias. Therefore, a combination of methods was chosen to maximise the validity of the evaluation via triangulation of data and methodological triangulation [24].

<table>
<thead>
<tr>
<th>Evaluation goals</th>
<th>Usability issues</th>
<th>Level of engagement</th>
<th>STEM learning</th>
<th>Future iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability Testing</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>User Evaluations</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Expert Evaluation</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
</tbody>
</table>

**Table 2: Evaluation methods and goals**

#### 3.3.1 Usability Testing

The first evaluation phase was a usability test to uncover potential issues that may hinder user evaluations. The Cognitive Walkthrough method was used, following guidelines originally set out by Polson, Lewis, Riemann and Wharton [38]. This method is a widely accepted industry standard for evaluating new interfaces, and was thus chosen for its applicability to novel, task-based systems. In this method, usability experts are given details about the target users, and proceed to conduct the actions of the interface in the intended sequence, verbalising their thoughts as they do so. The investigator observes their journey and records any issues that arise.

The alternative Heuristic Evaluation method [32] would have been less effective here as the prototype was a new design for which no rules-of-thumb yet exist. Cognitive walkthroughs do have some limitations; in this case the testers were not the end users, and particularly as the end users include children, it should not be assumed that they will approach the task in the same way.

#### 3.3.2 User Evaluations

Target users were recruited to test the prototype. The goal was to measure whether the prototype facilitated collaboration between parent and child and whether the prototype activities were engaging. A combination of questionnaires, observation, and interviews was employed.

Pre-study and post-study questionnaires were used to measure whether the activity had an effect on parents’ attitude and behaviour towards STEM subjects, and to gather demographic data about the participants. Questionnaires are easy to distribute, and they allowed time for parents to answer in private and at their own pace [11].

Observations and interviews took place during evaluation of the prototype. Post-evaluation interviews were chosen instead of contextual inquiries in order to avoid influencing the participants’ experience of the prototype activities. The
interviews were semi-structured to allow potentially unanticipated information to emerge [11]. The evaluation footage and the following interview data was analysed using thematic analysis [9]. Thematic analysis was chosen as the goal was to identify themes that would inform us about the nature of the participants’ collaboration and engagement with the activities. However, it should be noted that such an evaluation is only as good as its analysis. In this case, the investigator was also the designer of the prototype, and as such any bias towards a favourable outcome cannot be discounted. In addition, the investigator in this case was inexperienced with conducting evaluations with children.

The Smileyometer from the Fun Toolkit [40] was employed to enable feedback from children about whether they enjoyed the activities. Children in the pre-operational and operational developmental stages find it difficult to interpret questions and formulate responses [41]; the Smileyometer was chosen to encourage expression of opinions using visual aids. This method has some limitations; young children (up to age 9) have been shown to have a tendency to rate everything highly on the Smileyometer, reducing its validity; although this effect is slightly lowered where the evaluation calls for comparison of activities [41].

3.3.3 Expert Evaluation
An expert review of the prototype was conducted with a Science education academic to evaluate the effectiveness of the prototype as a learning tool, and to elicit feedback to improve future iterations of the design. There were two stages; a think-aloud assessment of the prototype, and a design challenge.

The Think-Aloud method [27] was chosen to evaluate the prototype as a STEM learning tool. This method can sometimes be impeded by investigator prompting, however care was taken to keep any prompts as neutral as possible.

Next, a design challenge was chosen as a creative way to elicit ideas for future iterations of the design within a short space of time [20]. This method also facilitated identification of issues that had not previously been considered. The structure was based on the “Inventomania” challenge, designed by Inna Alesina and Ellen Lupton [67]. This method involves posing a design challenge (the research question of this project), and working to address it through brainstorming and prototyping.

Although this method is usually done with teams of participants, in this case the expert qualifications of the participant were rare and as such only one person was available. As the participant in this case was well acquainted with the researcher, it should be considered that the participant’s feedback may have been positively skewed [45].

3.4 Possible Alternative Evaluation Methods
The following evaluation methods were also considered for this study:

Diary Study
In order to effectively measure the success of the prototype as a tool for engaging parents and promoting STEM learning, a longitudinal study could be undertaken. Prototypes could be deployed to households for a number of weeks, and participants could keep a diary recording their experiences [45]. This was not possible due to the time constraints of this study; additionally, the current prototype would need to be expanded to include more activities.

Pre- and Post-Evaluation Tests
In order to measure the degree of learning, participants could complete a STEM-related task prior to and following the evaluation activities [12]. However, a pre-test may be viewed as intimidating by participants who don’t have a STEM background, and results would not be significant for the small sample size and short nature of this project. Such an activity might better be used during longer evaluation periods with a greater number of participants.

4 DESIGN AND PROTOTYPE
There were four iterative design phases. This section describes these in detail, including the feedback that informed each iteration and justifications for design decisions.

4.1 Phase 1 – Concept Generation
The first phase involved the generation of as many ideas as possible, which incorporated the design goals listed in Section 3. In order to ensure the right design was chosen, the “10 plus 10” sketching method was followed [19]. To begin, the following design challenge was set:

How can we design activities to encourage parents with no STEM background to engage in their child’s STEM learning?

The identified design goals from the literature review were used as a structure for the design challenge. Ten concepts were generated through sketching; the best of these were
chosen and presented to the Feedback Group (see section 3). Below are the top 3 chosen concepts that were discussed:

1) Play house – a 3d structure of a house where each room would represent a specific activity.
2) eBoard – a large board where objects could be placed and drawings could be made to complete activities.
3) Interactive Book – a paper-based book containing electronics with interactive activities on each page.

This idea was ultimately rejected as being unfamiliar to users, difficult to implement, and limiting in the number of activities that could ultimately be created.

2) Structure the book as a story about an every-day task, e.g. making dinner. Base the activities on the four stages of computational thinking.

This idea was chosen for its familiar structure and for the opportunity to explore a number of concepts for each activity. The story of “planning a birthday party” was chosen as the narrative structure. This was considered a neutral activity that was familiar to a wide range of users, and which afforded a number of options for creating activity concepts.

The final stage in this phase was to create activities for each page of the book. To further promote STEM learning and interaction, the activities were designed to each include one key element of the STEM curriculum. The final ideas for each activity are discussed below:

4.1.1 Activity #1: Decomposition
1) Planning the party: breaking down all tasks that needed to be done in order to have the party.
2) Inviting friends: writing and posting invitations, and receiving replies.

The latter was chosen as the preferred option, as these steps are very familiar to most, whereas planning a party leaves room for erroneous design assumptions. Gears were chosen to represent the concept of a task being carried out. Each gear would be an appropriate size to the task – large gears represent bigger tasks, and smaller gears represent subtasks. Gears can easily be designed such that they must be placed in the correct order to work, therefore making it easy to meet the goal of designing for feedback and constraints. Gears are also tangible, and they visibly work together to carry out a common goal. Gears are studied as part of the UK year 5 curriculum [68], thus slightly advanced for the target ages of 5-9, but likely achievable within the Zone of Proximal Development [56].

4.1.2 Activity #2: Pattern matching and abstraction
In order to recognise a pattern, a young child must hold a representation of the repeating pattern in their mind and match it to similar items. This is difficult for young ages (5-7) where working memory is still limited [10]. The concept of abstracting this pattern to create a model for further use is more difficult still. In an effort to reduce abstraction, the decision was made to combine these two stages of computational thinking. The ideas considered included:

1) Music: Simple music could be played using an MP3 shield, and the user could identify and play the repeating phrase on paper “piano”, made using conductive foil and a Makey-Makey board.
2) Choosing the entertainment: A game where three entertainers are shown wearing tangible accessories. All three entertainers are the same person (pattern matching). The second phase of the activity is to

Figure 4: Ideation sketches
The “Play House” was discarded as design and construction would likely be outside the scope of this project, and its design may be limiting for future work. The “eBoard” was considered but ultimately rejected as it would likely be difficult to transport and costly to create. The “Interactive Book” was chosen as it had the potential to meet all the design goals – books are familiar to users and are an existing part of many household routines; they facilitate a creative narrative for children; they are portable and flexible; and they can be easily expanded to incorporate more complex future work – taking advantage of the “low-floor and wide-walls” design approach recommended by Resnik and Silverman [43]. New products such as conductive ink make it easy to create low cost interactive components, which meet the design goal of being tangible to the user.

The next stage in this phase involved generating 10 more detailed sketches to explore the book concept. Two key ideas were evaluated:

1) Allow the order of pages to be changed to create different activity structures. The order would dictate the final result of the “activity” which would be displayed on the back page.
abstract the person’s outline “try on” the accessories of each entertainer.

The former idea was explored through prototyping, but ultimately rejected for three reasons. The first was that incorporating the Makey Makey would call for “black box” design [43]. Secondly, holding an abstract representation (e.g. a music phrase) in their memory is difficult for children. This concept would be suitable for more advanced stages of learning, and so may be reconsidered in future iterations.

The latter concept was chosen for the reasons outlined above – it included tangible items-to-think-with [34], and could be explored in a way that was visible to users. Stage 2 of the activity was ultimately constructed as a circuit – the outline of the entertainer was made with conductive paint, and his accessories include basic circuit components. Building basic circuits is part of the UK STEM curriculum for Year 4 [68].

4.1.3 Activity #3: Algorithms
Algorithms are often subconsciously used in daily life, e.g. in following instructions or giving directions. The key was to demonstrate to parents that they held this existing knowledge. The ideas considered included:

1) Baking a cake: Writing a recipe that would result in baking a birthday cake.
2) Shopping for party supplies: This idea for this activity came from classic Hamiltonian Path problem; in this scenario, the user must visit a set of pre-defined destinations only once, e.g. [13].

The former activity was rejected as it did not leave sufficient scope for increasing complexity; the latter was thus chosen for this reason. The final design displayed three shopping destinations on the page. The goal was to write directions to each destination using provided programming tiles. Programming, particularly algorithms, is part of the “Key Stage 1” UK curriculum for computer science in schools [69].

4.2 Phase 2 – Paper Prototyping
The goal of this phase was to build paper prototypes of each activity, in order to test its feasibility, explore suitable materials, and determine the optimum layout. The layout of each activity was also explored in this phase. Each activity included the story narrative; information about what the activity taught; examples of where these skills are used; and where to find further relevant STEM learning resources.

4.2.1 Activity #1: Decomposition – “Inviting Your Friends!”
The goal of this activity was to introduce the concept of decomposition by providing a set of tasks and subtasks that made up the overall action of inviting friends to the party. These were split into three task groups; each gear was labelled with its associated task.

<table>
<thead>
<tr>
<th>Task</th>
<th>Subtasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing the invitation</td>
<td>• Adding the time.</td>
</tr>
<tr>
<td></td>
<td>• Adding the location.</td>
</tr>
<tr>
<td>Posting the invitation</td>
<td>• Put the invitation in an envelope.</td>
</tr>
<tr>
<td></td>
<td>• Put a stamp on the envelope.</td>
</tr>
<tr>
<td>Receiving an RSVP</td>
<td>(n/a)</td>
</tr>
</tbody>
</table>

Table 3: Tasks and subtasks
A set of plastic toy gears was used to test this concept. It was quickly discovered that gears require a flat, stable surface – paper posed some issues in this regard. Paper is not rigid and is prone to bending, which often results in the teeth of the gears not meeting. To combat this, the design of the gears was changed to make the teeth longer. This would increase the overlap area, and thus reduce the impact of a slightly uneven surface. Based on a feedback session, the book pages were also changed from paper to 5mm foam-board; this was also suitable for securing the gear shafts and housing electronics such as motors and batteries. Future iterations could explore other materials such as pressed cardboard.

Next, various feedback mechanisms were explored to let the user know they had correctly completed the activity. First, the gears were made with slight variations in size. This meant that incorrect placements caused the gears to either overlap or not meet. Second, when the gears were correctly in place, they connected to a pulley system. Cartoon images of children at a party were placed on a belt, and a pop-up “party house” was located on the page beside the pulley system. When the system was complete, the belt rotated, resulting in an animation of children entering the party house.
4.2.2 Activity #2: Pattern matching and abstraction – “Choosing Entertainment!”

In this activity, tangible representations of three “entertainers” in the form of paper cut-outs were placed on the page. These comprised three images of the same person, each wearing a different accessory – a clown head, a guitar, and a magic wand. The accessories could be removed, so that it became clear that it was the same person underneath, thus identifying the pattern. The goal was to place things that were the same (the person) in one column, and things that were different (the accessories) in another column. This prepared the child for the next stage of the activity, which was abstracting the pattern (the outline of the person) into a reusable object.

Figure 7: Paper prototype of activity #2 (stage 1)

The next stage displayed the abstracted outline of the person. The goal was to add the accessories to the outline, to demonstrate how the abstracted pattern could be reused to create many entertainers, thus demonstrating that an abstracted pattern can be used to form a model upon which to build more complex solutions. In this phase, the accessories were added to the outline by folding over parts of the page – see image below.

Figure 8: Paper prototype of activity #2 (stage 2)

4.2.3 Activity #3: Algorithms – “Shopping for Supplies!”

The chosen destinations for this activity were a balloon shop, a cake shop, and a party hat shop. In order to easily construct directions to these destinations, it was decided that a grid layout was optimal. This would allow the user to easily count the number of steps in each direction to reach the desired destination. Next, ways of describing the directions were explored – for example, “three steps left then one step down”. Based on a feedback session, the chosen solution was to lay out two sentences of “code” on the page, each containing a gap where the variables of number of steps and direction could be placed. The code was designed to provide the simplest directions possible [43].

Figure 9: Paper prototype of activity #3

4.3 Phase 3 – First Functional prototype

In this phase, the designs from the paper prototype were built upon to incorporate interactive functionality.

4.3.1 Activity #1: Decomposition – “Inviting Your Friends!”

The gears were designed using online software [70]. The gear designs were exported to Adobe Illustrator and cut from 3mm plywood using a laser cutter. Next, the pulley system which drove the animation was designed. Initially, the belt was designed using Sugru [71]. However, this material was ultimately too heavy, and did not hold well when thinner versions were made. Next, rubber bands were explored, however the rubber did not catch well on the teeth of the gears, and any attempt to make notches resulted in breakage. Additionally, the rubber gave a lot of resistance when the pulleys were turned. Finally, paper was explored as an option. This worked well as paper offers little resistance, and customisable holes could be made to fit the teeth of the pulley. Pulleys were designed using 3mm white acrylic, in order to differentiate them from the interactive gears.

Figure 10: Gears, pulleys, and belt

The gear and pulley system was motorised using a 9v DC rotary motor, which was attached to one fixed gear on the page. A momentary push button was wired to the motor for control. The button was placed at the bottom right of the page, away from the gears, so that little fingers wouldn’t get caught in the moving parts.
4.3.2 Activity #2: Pattern matching and abstraction – “Choosing Entertainment!”

The three entertainers and their accessories were made out of thin card, with magnets attached to the back, which allowed them to be placed in the “same” and “different” columns. The polarity of the magnets was such that items would not stick in the wrong column, providing some feedback and constraints to users.

In stage two of the activity, a circuit was chosen with the outline of the person as the base of the circuit, and accessories as the circuit components. A number of options were explored for the circuit; first, conductive copper tape was tested. This was quickly rejected; copper tape is excellent when flat, but the edges can be quite sharp when it is bent to form curved outlines, which is unsafe especially for children. Next, the ink from the Circuit Scribe pen was trialled [72]. This was also rejected as the silver colour was not very visible in all lighting conditions, and the ink lost a lot of conductivity over large surfaces (the outline took up most of an A4 page). Finally, Bare Conductive paint was chosen as it addressed all the previous issues [73]. However, it is not without its drawbacks – it can pose high resistances which drains batteries, and it is messy to paint with. Templates are recommended for neat outlines.

![Figure 11: Exploring circuit materials](image)

Finally, basic circuit components were chosen for each accessory – a red LED for the clown nose; a musical buzzer for the musician; and a vibro-motor to cause the stars on the magician’s wand to shake. The circuit was connected to a 3v coin battery.

It was discovered early on that folding flaps to reveal the accessories (as was the design in the phase 2) would not work in this instance as the current would flow through the existing circuit without anything to force it though the components. For this reason, the design was changed to display the accessories as pull tabs. Three tabs were added which, when pulled, would move the existing piece of the outline and replace it with an accessory.

4.3.3 Activity #3: Algorithms – “Shopping for Supplies!”

The representation of the three shops was first explored using an 8×8 LED matrix. This was quickly replaced, because it was too small and only displayed one colour (red), which made differentiation difficult. It was replaced with a 5×8 Neopixel shield, which displayed different colours and was a larger size.

In order to make the activity tangible, it was decided to use RFID (Radio-Frequency Identification) tags attached to physical objects that would represent the variables of the directions. RFID was chosen for its ability to detect a number of different tags; an NFC (Near-Field Communication) reader could have equally been used, however RFID was favoured in this instance purely due to availability and cost. The RFID reader was placed underneath the two written lines of code, connected to an Arduino and the Neopixel shield.

The “variables” were made using laser cut tiles of while 3mm acrylic. Each tile contained one RFID tag, and was labelled with one of two types of variables; direction (up, down, left, right); and number of steps (one, two, three). The two groups were each a different shape – the directions were rectangles and the numbers were squares – to constrain where they could be placed within the code.

Finally, the Arduino was programmed to control the RFID reader and power the Neopixel shield. Three different coloured lights represented each shop, and one white light represented the user. The code was written so that the RFID reader would store the most recently presented variable from each group (direction and number of steps), and upon a button press would move the user light to the appropriate location. When the user landed on a shop light, that light was turned off for the remainder of the activity. The code was developed using the Adafruit Neopixel and the MFRC522 RFID libraries, and examples from these libraries were used to write the code [2][29].

The intended route to visit each “shop” was structured to incorporate increasing complexity. The first was easy – take three steps right. The next required the user to take three steps right, then take two steps down. The final visit required the user to take two steps down, then take five steps left. The final five steps involved some calculation – only the numbers one, two, and three were available. Therefore, the user had to deduce that two moves were required.

Finally, two control buttons were added – “start” to execute the directions, and “reset” in case the user wanted to start over. These were momentary push buttons, and were connected to the Arduino. They were covered with laser-cut tiles to make them easier to press.

While the activity contained some black-box design, this was considered acceptable as the goal in this case was to teach the construction of algorithms through physical objects. Such
objects – defined by Zuckerman as “Digital Montessori-Inspired Manipulatives” – help young children to model abstract concepts [58].

4.4  Phase 4 – Final Prototype

The third iteration of the prototype was used for usability testing. The resulting recommendations were incorporated into the fourth and final iteration of the prototype, and are described below. In addition to the specific activity feedback points, it was noted that it was difficult to observe whether users spent any time reading the information about the activities – i.e. what they teach and where to learn more. Therefore, the decision was taken to include a flap over this section in order to aid observation.

4.4.1  Activity #1: Decomposition – “Inviting Your Friends!”

Four usability issues were identified:

**Issues 1 & 2:** There should be visual cues for the target location of the gears, and the gear labels should be worded more clearly.

To address this point, the layout of the page was changed to include visual cues about the size of the gears. The three task groups were colour-coded to match the labels on the gears, and icons were added to the page with corresponding icons on the gears.

**Issue 3:** There should be feedback to indicate when the user has placed all the gears correctly.

This point was addressed by adding a green LED beside the “start” button. Copper tape was placed at the underside of each gear and was used to create a circuit with gaps on the page. This was powered by a 3v coin battery. When all gears were in place, the circuit was completed and the green LED lit up.

**Issue 4:** The motor speed is either too fast or too slow.

This was a major difficulty during usage. The resistance posed by the gears on the paper and the belt on the pulleys caused the motor batteries to wear out quickly. Initial attempts to rectify this included increasing the power to the motor, and reducing the tension on the belt. However, both of these caused the motor to spin too fast, which was dangerous for little fingers. Resistors were trialled to reach the desired power and speed. This worked for a short time, but once the batteries drained a little there was not enough power to move the gears. At this point, there was no time to try further solutions, and the decision was made to add a fixed gear with a handle to allow the user to turn the system manually. Future versions could address this problem by minimising resistance and altering the gear ratio.

4.4.2  Activity #2: Pattern matching and abstraction – “Choosing Entertainment!”

One usability issue was identified in this activity:

**Issue 1:** Provide feedback when the items are all placed correctly (stage 1).

Green LEDs were added to each column and copper tape was added to the magnets at the back of the items. Conductive ink was used to draw a circuit with gaps that were connected when the items were placed in the correct columns.

4.4.3  Activity #3: Algorithms – “Shopping for Supplies!”

Three usability issues were found with this activity:

**Issue 1:** The “user” light should be more distinguishable.
To make the difference more obvious, the user light was updated to blink slowly while the other three remained lit.

**Issue 2:** The location of the control buttons should be grouped closer to their intended effects.

The location of controls was moved to make it more obvious which each button related to - “go” under the code and “reset” under the grid.

**Issue 3:** The lights should be set at a high brightness to accommodate all environments and visibilities.

The Neopixel lights were slightly dim in a brightly lit room; the brightness was set higher to ensure they were visible in all environments.

To make the difference more obvious, the user light was updated to blink slowly while the other three remained lit.

**Issue 2:** The location of the control buttons should be grouped closer to their intended effects.

The location of controls was moved to make it more obvious which each button related to - “go” under the code and “reset” under the grid.

**Issue 3:** The lights should be set at a high brightness to accommodate all environments and visibilities.

The Neopixel lights were slightly dim in a brightly lit room; the brightness was set higher to ensure they were visible in all environments.

**Figure 14:** Final iteration of activity #3

The final code for this activity can be found in appendix (iii).

5 EVALUATIONS

The below sections detail the process that was followed for each evaluation. An analysis of the results is presented for each evaluation phase.

5.1 Usability Testing

The goal of usability testing was to uncover any potential issues that may hinder the user evaluations. Although the participants did not represent the target user, they were all experienced HCI practitioners and as such were well placed to evaluate usability issues of an interactive system.

**5.1.1 Participants**

There were five participants (2 female, 3 male), all of whom were master’s students at University College London (UCL), studying Human-Computer Interaction (HCI). Five is an optimal number of evaluators, as demonstrated by Nielsen and Mack [33]. None of the participants had previously seen the prototype.

**5.1.2 Design**

The evaluation was conducted as a cognitive walkthrough [38]. All five participants used the prototype as a group, and verbalised their thoughts as they progressed through the activities. Identified issues were discussed following the evaluation.

5.1.3 Materials

The third iteration of the prototype was used during the evaluation. The evaluation was audio recorded, and notes were taken throughout the evaluation and subsequent discussion.

5.1.4 Procedure

The participants were informed of the intended purpose of the prototype, and were given details about the target users through personas. Participants were provided with the prototype and asked to complete the activities and verbalise their thoughts during the process, keeping the target users in mind. Guidance was not provided during the activities so as not to interrupt the intended, although participants were instructed to ask questions if they got stuck. A complete list of optimal actions for completing each activity was compiled by the author, and any observed deviations from this optimal path were noted as a potential issue. Following the guidelines originally set out by Lewis and Rieman [38], participants were observed to see whether they 1) tried to produce the intended effect of the activity, 2) quickly located the controls, 3) understood the functionality of the controls, and 4) understood feedback about their actions. A discussion was held following the evaluation prioritise the identified issues.

**Figure 15:** Persona to convey target user information

5.1.5 Results

All participants were able to complete the activities without observer intervention. The study uncovered eight addressable usability issues. These issues were prioritised as Priority 1: to be corrected immediately, or Priority 2: to be considered for future iterations. The issues related mostly to feedback and affordances. This was valuable input as these factors are of utmost importance when encountering a novel interface. The prototype was refined to correct the priority 1 issues before the user evaluations – see Section 4 for a detailed explanation of identified issues and the steps taken to address them.

Priority 2 suggestions for future iterations of the design are listed below, and are discussed in greater detail in Section 6.
5.2 User Evaluations

The goal of the user evaluations was to assess whether the prototype facilitated parent/child interaction and engagement. Target users were recruited to take part in evaluating the final prototype as parent-child pairs. Five participant pairs were recruited through social media postings (10 participants in total). Participants were entered into a draw to win a £25 Amazon voucher. None of the participating parents had a STEM background, nor did they regularly participate in STEM-related activities such as hobbyist electronics or programming.

5.2.1 Questionnaire

Parents were asked to complete a pre-study questionnaire to assess their engagement with STEM learning by analysing their attitude and behaviour. The questionnaire was distributed online and results were recorded anonymously, using an assigned participant number. Parents were also asked to complete a similar, post-study version of the questionnaire to measure any changes following the evaluation activity. Pilot versions of the questionnaires were evaluated by a fellow classmate and refined prior to distribution, in order to maximise the usability of the questionnaire format and the clarity of questions.

5.2.1.1 Participants

All 5 parents (2 male, 3 female) completed both questionnaires. Children were not asked to complete a questionnaire because their change in attitude was not being evaluated and therefore a pre-interview baseline was not required.

5.2.1.2 Design

The pre-study questionnaire contained 13 questions and took an average of ten minutes to complete. The first section contained closed questions to gather demographic information about the participant, such as age range, gender, and occupational background. The second section contained both open and closed questions to assess the participant’s general attitude towards STEM and specific information about their level of engagement with their child’s STEM learning.

Care was taken to formulate the questions and response choices in an impartial manner to avoid insulting or intimidating the parent – one example of this is the response choice: “I do not usually participate in their extra-curricular activities - they have their own hobbies and interests.” A sample of the questionnaire can be found in appendix (i).

5.2.1.3 Materials

The questionnaire was conducted online using Google Forms. A link was sent via email to each participant.

5.2.1.4 Procedure

The questionnaire was distributed to participants one day before their evaluation was scheduled. Participants were asked to complete the questionnaire in advance of the evaluation. Participants were provided with a unique participation number, which allowed anonymization when recording the data. Informed consent was provided by all participants.

5.2.1.5 Analysis and Results

The questionnaire results were analysed to 1) identify parents’ attitudes towards STEM and behaviours in relation to their child’s STEM learning (pre-study questionnaire), and 2) measure any changes following the prototype evaluation (post-study questionnaire).

Attitudes towards STEM were categorised as either positive or negative. A narrow range of attitudes were identified; participants were allowed to choose as many as they wished out of a list of ten, yet only four were chosen.

Chart 1: Parents’ pre-study attitudes towards STEM subjects

All 5 respondents said they felt that learning STEM subjects is “very important” (4), or “quite important” (1). Those who felt positively towards STEM primarily cited “learning new things” as a contributing factor. Negative attitudes featured two key attributes:
1) Self-confidence relating to perceived difficulty.
   “I am not very science or technology savvy.”
   “…computer science and physics, for example, totally baffle, frustrate and give me a lot of stress.”
2) Access to resources.
   “…not much knowledge and I wouldn’t know how to access games, etc.”

These findings are in accordance with the results of the NESTA report as discussed in Section 1; overall, parents want to be involved in STEM learning, but for various reasons are not following through. This is demonstrated by the parents’ behaviour in relation to STEM activities. Despite stated interest, only one parent reported participating in what was termed a STEM hobby – woodworking in this case. Another parent brought their child to Coder Dojo – a weekly extra-curricular code club in Ireland aimed at young children. Two parents reported using educational technologies at home – one parent had bought a littleBits kit, and one had tried Scratch programming with their child.

Chart 2: Parents’ pre-study behaviours in relation to STEM subjects

Finally, the post-evaluation attitude and behaviour was measured to identify whether there were any changes following the activities. One parent reported a change in attitude from frustration to confidence towards STEM subjects:

Chart 3: Parents’ post-study attitudes towards STEM subjects

Following the prototype evaluation, all parents reported that they would now consider taking part in STEM activities with their child and taking their child to extra-curricular activities. Two parents reported that they would now consider playing with STEM educational technologies in their home. One parent did not report a change in attitude or intention to use educational technologies in the home, but did report they would now consider taking their child to extra-curricular STEM activities:

Chart 4: Parents’ post-study planned behaviours in relation to STEM subjects

5.2.2 Observation and Interview
Participants were asked to evaluate the prototype as pairs; one parent with their child. During this time, they were discreetly observed and recorded. The goal was to measure whether the prototype met the design goals by facilitating parent/child interaction and engagement. Following the evaluation, they completed a semi-structured interview about their experience. The fourth and final iteration of the prototype (as discussed in Section 4) was used for this evaluation.

5.2.2.1 Participants
Five parent-child pairs participated in the evaluation. All participants were native English speakers. Two pairs lived in London, UK, the other 3 pairs lived in Ireland. It may have been possible to include both parents or multiple children, however pairs were chosen for reasons of availability, practicality, and consistency.

<table>
<thead>
<tr>
<th>P#</th>
<th>Age Range</th>
<th>Parent / Child</th>
<th>Gender</th>
<th>Occupational background</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36-45</td>
<td>Parent</td>
<td>F</td>
<td>Arts and media</td>
</tr>
<tr>
<td>A</td>
<td>6</td>
<td>Child</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>36-45</td>
<td>Parent</td>
<td>F</td>
<td>Healthcare</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>Child</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36-45</td>
<td>Parent</td>
<td>M</td>
<td>Tax manager</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>Child</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36-45</td>
<td>Parent</td>
<td>M</td>
<td>Sport</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>Child</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>36-45</td>
<td>Parent</td>
<td>F</td>
<td>Teacher</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>Child</td>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Participant pairs demographic information
5.2.2 Design

Each pair of participants experienced the same study conditions. Evaluations were conducted in the homes of each participant, on different days, and at different times, due to participant location and availability. No other devices such as computers or TVs were present in the rooms. Participants were asked to refrain from using their phones during the evaluation.

5.2.3 Materials

The fourth iteration of the prototype was used in each evaluation. Participants were discreetly observed and video recorded during the evaluation, and notes were taken on paper. Audio recordings of the interviews were made, and notes were taken on paper.

5.2.4 Procedure

Participants were provided with an information sheet describing the experiment (with a simplified explanation for children), and all provided written consent. Participants were then presented with the prototype and were told that it contained a series of activities based on planning a birthday party, and were asked to complete these activities as they wished, with no set time limit. They were assured that they were not being judged on their ability to complete the prototype, and that any confusion or failure to carry out the activities would not be their fault, but rather due to prototype issues. Children were invited to examine the video camera being used in order to feel comfortable with its presence in the room [3].

Following the prototype evaluation, semi-structured interviews were conducted in pairs. As the goal of the design was to encourage collaborative engagement, it was important to obtain the shared opinions of both parent and child. During the interview, children were provided with a Smileyometer in order to allow them to express their opinions and feelings about the activity in a manner that negated the use of complex vocabulary.

5.2.5 Analysis and Results

The results of the observation and interview were coded using thematic analysis. The resulting themes were grouped into categories, which are presented below:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent&lt;&gt;Child Interaction</td>
<td>• Parent prompts the child through the activity.</td>
</tr>
<tr>
<td></td>
<td>• Child demonstrates and explains actions to the parent.</td>
</tr>
<tr>
<td>Parent&lt;&gt;Prototype engagement</td>
<td>• Parents primarily focus on written instructions and information.</td>
</tr>
<tr>
<td>Child&lt;&gt;Prototype engagement</td>
<td>• Children primarily focus on activities and tangibles.</td>
</tr>
</tbody>
</table>

Table 6: Categories and themes from user evaluations

Two important themes emerged regarding parent/child interaction. The first was that all parents frequently prompted their child by relating the activity to a memory of carrying out a similar real-life task, or by relaying the instructions to the child, e.g.:

“OK, remember when we wrote a Christmas card to granny and grandad last year? What did we do first?”

Using this method, the parent would help the child to start the task, but in all 5 cases the parent did not complete the task for the child; instead they allowed the child to try it themselves, with some further prompts if necessary.

“What do we need to do...see, it says take blank steps in blank direction.”

In three cases (children aged 5-7), activity two was notably difficult for the child and prompting was required throughout. This may be expected as pattern matching and abstraction the concept is particularly difficult for these ages. By activity 3, in four cases the parent gave very little prompting; the child had figured out the structure at this point and needed less assistance. (In one case, the child was very distracted and the parent used prompts throughout to keep them focused.)

The second important theme was that children often explained to the parent what they were doing, using the tangible pieces of the activities.

“Look Daddy – we need to go in this direction, and we need to go one…two…three…three steps.”

During interviews, three of the children stated that they enjoyed working with their parents because they liked to show them or tell them about what they learned.

“Um...I liked telling her what to do! [Laughter].”

Parents and children engaged with the book in very different ways. All parents began by reading the activity instructions aloud, or by asking their child to read them. During observation, it was noted that all parents looked under the information flaps to read about further resources, although one (participant 1) merely glanced briefly.

In contrast, children rarely read the instructions, usually going straight for the activities and examining the moving parts to assess their possible uses before starting the activity itself.

“Ooh! What does this one do?”

Children were not afraid to try different approaches to completing the activity, using tangible components to trial different options.

“Oh, this one doesn’t fit here...it goes here.”
In general, parents only physically engaged with the activities either after the child was finished or when taking something that the child was showing them.

This meant that children relied heavily on feedback to steer their exploration:

“Mum! This one plays music when you pull it!”

“Oooh the light turned on! So they’re in the right place.”

Children generally seemed to enjoy motion more than other forms of feedback, particularly when they could control the motion as was the case for the gears in activity 1 and the neopixel lights in activity 3. These activities were also rated highest and received the most positive feedback in the interviews.

Children rated the activities using the Smileyometer. In keeping with studies on use of this tool, they rated all activities highly, and reliability of these results should be considered in this context [41]. However, there is some consistency between comparison ratings of each activity.

![Chart 5: Children’s activity ratings](image)

### 5.3 Expert Evaluation

An expert evaluation was conducted to assess the prototype as a learning tool for children and to elicit feedback for future iterations of the design.

#### 5.3.1 Participants

There was one participant; an academic who holds a PhD in Science Education and who currently works as a science education researcher and outreach officer. She also has a number of years’ experience teaching science in schools at secondary level. This participant was chosen as she has experience designing science outreach workshops, and as such is familiar with the issues surrounding STEM learning and engagement.

#### 5.3.2 Design

The evaluation was designed as a think-aloud walkthrough of the final iteration of the prototype. The participant was asked follow-up questions on completion of each activity.

Then followed a mini design workshop. The participant and researcher collaborated to answer a design challenge. The challenge began with a brainstorming session, followed by a prototyping session using the prototype and a kit containing basic materials.

#### 5.3.3 Materials

The final iteration of the prototype was used during the think-aloud evaluation. Audio was recorded throughout the session. Notes were taken on paper during the think-aloud and the interview.

A kit was prepared for the design challenge. This was a bag containing post-it notes, paper, pencils, tape, string, straws, cupcake holders, cardboard tubing, sponge, string, and lollipop sticks.

#### 5.3.4 Procedure

The purpose of the prototype as a STEM learning tool was explained to the participant. The participant was asked to then go through the activities and verbalise their thoughts throughout the process. The participant was then asked follow-up questions to elicit feedback about the effectiveness of the prototype as a STEM learning tool, and suggestions for changes or improvements.

Next, the concept of the design challenge was introduced. The participant was presented with the challenge – “I need to facilitate STEM learning in homes where parents are not interested in STEM.” The first 10 minutes were spent brainstorming reasons why people don’t like STEM and why parents may not engage in their child’s learning. The next 10 minutes were spent thinking of solutions to address these. The final 20 minutes were spent making sketches and prototypes of the solutions, using the prototype along with the prepared design kit. IDEO’s Design Kit brainstorm rules were followed in order to maximise the effectiveness of the brainstorming session [74].

#### 5.3.5 Results

General feedback was provided on the prototype as a learning tool, as well as specific feedback each prototype activity. The design challenge resulted in valuable input for future designs.

#### 5.3.5.1 Feedback from the think-aloud

**General:**

The physical form factor of the prototype has a number of benefits over a computer. For some, computer literacy can be a barrier to accessing educational tools and resources; this prototype eliminates that issue. Additionally, parents increasingly want to move their child away from sitting in front of a screen and are likely to be receptive to a tool that facilitates that. The book facilitates social constructivism [56], which is particularly good for young age-groups.

The scaffolding of the tasks as a familiar every-day activity is “superb”. Such a format makes these activities very accessible, regardless of education level or socio-economic background. It can be the case that when educators and
designers create STEM education materials, their perception of that person’s life may be inaccurate.

Anecdotal evidence suggests that parents can often lose confidence in their own abilities when the child has to explain the task to them; structuring the activities in a way that is familiar to the parent is thus helpful for overcoming this. However, it’s important that the social engagement is balanced – parents simply dictating to the child will hinder their learning.

The inclusion of computational thinking concepts and STEM curriculum activities is a good structure for learning activities. However, the current prototype is a one-off activity and as such there won’t be any measurable learning benefits. The activity should be sustained and should become increasingly challenging in order to have a measurable impact on learning. It would be beneficial to further narrow the target age-groups to address varying levels of cognitive abilities.

**Activity #1 (decomposition):**
The representation of tasks as gears is very relatable. Order is important in this case; it may make more sense to have subtasks building up into the bigger task. Concept mapping may be a good structure to inform the layout of this activity.

**Activity #2 (pattern matching and abstraction):**
Pattern matching is usually beyond the abilities of children aged 5-7. Having physical representations for them to hold and view is beneficial in this case. Future iterations may require deeper analysis of the target age-group’s working memory to account for their capacity.

**Activity #3 (algorithms):**
The increasing levels of complexity in this task is appropriate for the target age-groups.

### 5.3.5.2 Outcomes of the Design Challenge

The brainstorming and problem solving session resulted in identification of a number of themes for why parents may not be engaged in their child’s STEM learning, and associated solutions to address these.

**Self-perception**
Parents may have had previous negative experiences of STEM subjects, causing low self-efficacy. It is important to create a safe environment to explore STEM, where success is achieved early and where failure receives positive feedback.

**Parents are busy!**
Many parents can feel pulled in all directions, as their child’s after-school activities pile up. It is important to provide activities that can be done at home on a flexible timeline.

**What’s STEM got to do with me?**
It used to be possible to deconstruct electronics at home, e.g. transistor radios, and examine the parts to see how they work. This is no longer possible – taking apart an iPod would yield an incomprehensible array of microchips. It is important provide ways for people to explore relevant daily objects to garner interest in the construct and functionality of common technologies.

The prototyping session resulted in the following suggestions for future iterations of the design.

1) More activities that increased in complexity. For example, subsequent decomposition tasks could remove labelling, so that fitting the task in the correct sequence would be more difficult.

2) Flexibility of narrative – the structure of subsequent activities could be based on a task chosen by the users, for example “getting ready for school". Focus groups could be used to generate relevant ideas.

3) The book could be supplemented by a kit that contains additional items, such as electronic components. This would allow users to complete the increasingly complex activities in creative ways.

### 6 DISCUSSION

The aim of this study was to design a prototype that met three key design goals, and to evaluate its effectiveness. The design goals were to:

1. Facilitate interaction between parent and child.
2. Encourage future STEM exploration.
3. Advance cognition through STEM learning.

The evaluation findings demonstrate that the prototype effectively met the first goal of facilitating parent / child interaction and enabled parents to providing learning support to their child. Although longitudinal intervention would be required for accurate measurement of the effectiveness of the second and third design goals, initial results suggest that the current design provides a good basis upon which to build future iterations. Interview and questionnaire findings suggest that the prototype may positively influence parental attitude and future behaviour towards STEM learning with their child. Expert evaluation provided feedback that the structure of the activities forms a strong basis for designing further activities which advance cognition through educational technology. The following sections discuss the strengths of the design in the context of the evaluation results, and suggest future design and research.
recommendations to build on the initial findings of this study.

6.1 Facilitating Parent / Child Interaction

The most important finding of this of this study is the demonstration that activities can be designed to engage parents in collaborative learning with their child, without requiring them to have existing knowledge of the subject matter. This was primarily by achieved by relating new concepts to familiar examples, upon which the parent can draw from their existing knowledge to provide support to their child. Interestingly, the nature of this support primarily took the form of gentle prompts, which aimed to guide the child in the right direction or to keep the child’s focus from wandering. This contributes the first empirical demonstration that we can design to assist parents who do not have subject-matter knowledge in providing behavioural and intellectual-cognitive support for their child; a finding that supports Lee and Nie’s statement to the same effect [26]. This discovery was perhaps best demonstrated during activity 2, in which the complexity was a little too advanced for children aged 5-7. In all three cases for this age-group, parents were able to prompt their child to successful completion of the activity by drawing on their existing knowledge; a direct demonstration of the benefits of the Zone of Proximal Development [56].

The findings also reveal that the design successfully facilitated demonstration and verbalisation of children’s sense-making process through tangible objects-to-think-with and verbalisation. This is a promising affirmation of Piaget and Papert’s respective theories of constructivism constructionism [37][34]. Interview responses also revealed that children enjoyed working with their parents because they were able to tell them about or show them what they learned.

Findings also supported the flexible nature of the prototype. Interview data and expert evaluation data revealed the time constraints that often prevent parents from engaging in STEM activities. One parent had three young daughters, and wanted to prioritise sports as their extra-curricular activity. Sports participation comes with a time cost; children must attend scheduled practices and games. Another parent highly prioritised music and drama; both of which also require attendance at scheduled practices and performances. This leaves little time and cost for STEM activities, even though both parents recognised their importance. STEM activities that could be completed at home at flexible times were therefore preferable to attending classes or other scheduled events.

Finally, user evaluations and expert evaluation revealed parental concern that their children spend too much time in front of a screen. During interviews, four parents stated that they enjoyed the form-factor of the book primarily because it provided engaging activities away from a computer or game console. This should be considered in future iterations of the design, where temptation may lead to the design of software to accompany the book.

This work opens up new directions in the development of collaborative and tangible parent/child education technologies by using existing knowledge to structure the introduction of new concepts, thereby facilitating parents in supporting their child’s learning.

6.2 Encouraging future STEM Exploration

Questionnaire and interview results suggest that the prototype may positively influence future parental behaviour towards STEM learning with their child, although these results cannot be reliably generalised due to the short nature of the study and the low number of participants. Following the activity, all parents stated that they would consider engaging in extra-curricular STEM learning activities with their child. However, pre-study questionnaire results showed that four out of five parents reported positive attitudes (interest) towards STEM subjects prior to the evaluation activity, and so it is possible that they already intended to engage with STEM learning and thus that the prototype was not the only contributing factor.

During observation, four out of five parents spent time reading the provided information about the activity, and about where they could learn more. This finding points to interest in finding out how to engage in future, similar activities with their child. This was backed up by questionnaire and interview data; three parents stated that a major barrier preventing them from engaging in STEM learning was that they did not know where to start or how to access resources.

Key to supporting future STEM exploration was providing feedback and constraints to guide the user and increase confidence in their ability to complete the task. This seemed to benefit children more than parents in the evaluations; feedback and constraints were important to support exploration of various approaches to the activities without having to read instructions. Future, more complex activities could reduce instructions and seek ways to entice parents to also directly explore the activities.

6.3 Advancing Cognition through STEM Learning

The short nature of this study means that any learning effects could not be reliably measured. Nonetheless, feedback from the expert evaluation indicates that the prototype forms a good basis for imparting STEM learning through exploration. The key feedback note was that the structure relating each activity to a stage of computational thinking is beneficial by demonstrating the real life applications. This serves the purpose of removing abstraction for children, and of allowing adults to draw on existing knowledge. Therefore, the existing design should serve as a basis for future iterations. In order to maximise learning, the “Learning-Centred Design” process could be followed to include learning outcomes and assessment criteria in early design stages [51].
Some specific observations from each activity should be considered in future iterations. Particularly in activity 1, children tended to match the colour and icons on the gears to the corresponding location on the page. This matching may reduce the effectiveness of teaching decomposition; further iterations should reduce such cues as the activities grow more complex. Moreover, order is extremely important in this activity, and care should be taken to structure the tasks carefully in order to effectively teach the decomposition process.

6.4 Recommendations for Future Work
The following recommendations are suggested for future designs and evaluations of similar collaborative parent/child education technologies.

6.4.1 Design recommendations
- Increase the complexity of the activities:
  The activity structure should continue to be based on computational thinking stages. Future iterations should design for more activities which increase in complexity. Over time, the structure could change from using familiar concepts as a basis for learning computational thinking, to using computational thinking strategies for solving unfamiliar problems. A supplementary kit containing items such as electronic components could allow users to construct a variety of creative solutions [43]. For example, in activity #2, children could draw their own abstracted pattern and use it to build creative circuits. In activity #3, children could design their own, increasingly complex code structure e.g. “take two steps left, then take three steps down, then take one step right.”
- Feedback:
  Incorporate multiple feedback points throughout each activity, to encourage success and increase confidence. For example, in activity #1, each gear could be uniquely identified though RFID, providing feedback about individual gear placement. Further, each group of subtasks could have their own animation, so the user knows when they are on the right track. This would be particularly helpful in more complex activities where less cues are provided.
- Include the user:
  Future iterations should continue to include target users in subsequent stages of evaluations; perhaps even involving them in the design process [47].
- Create clearer signposting to further resources:
  The increasingly complex tasks could serve as stepping stones to support the user in moving on to future STEM activities, such as programming an Arduino. Activities should include clear information about relevant resources for further learning.
- Allow for a flexible narrative:
  The structure should continue to relate new concepts to familiar tasks. Future iterations could allow for a flexible design where the user could determine the narrative of those tasks themselves. This would cater for a wide range of socio-economic backgrounds and cultures. Suggestions for narratives could be elicited through focus groups.

6.4.2 Evaluation recommendations
- Measure attitude and behaviour change:
  In order to accurately measure effective attitude and behaviour changes in relation to STEM subjects, a longitudinal study should be carried out. This could involve deployment of a more advanced prototype to the home over a period of weeks or more. Behaviour and attitude change could be measured using surveys, interviews, or diary studies.
- Measure whether the activities advance cognition:
  A more advanced prototype with increasingly complex activities should ultimately advance cognition if the intervention is sustained; the effectiveness of this could be measured using pre- and post- tests [48].
- Strengthen analysis of data:
  Future data analysis could take a Grounded Theory [52] approach across a number of iterative evaluations of the activities. This would allow for complex analysis of relationships between individual attitudes, behaviours, backgrounds, cognitive abilities, etc. Ideally, several investigators would be involved in analysis to increase inter-rater reliability.

6.5 Limitations
The results of this study should be considered within the context of the small sample size and short nature of the evaluations. The designer was also led the evaluations, and as such some inherent bias is likely; particularly when evaluating with children, which requires extensive skill and experience. Finally, the prototype was developed under cost and time constraints and therefore did not contain enough activities to effectively influence learning.

7 CONCLUSION
This paper presented a series of STEM learning activities which successfully engaged parents in their child’s STEM learning and facilitated parent / child collaboration. The findings demonstrate that parents do not need prior subject matter expertise in order to effectively support their child in exploring new STEM concepts. The study also showed that children benefit from learning with tangible objects combined with a social environment. This work provides a unique contribution to the design of collaborative parent / child education technologies, and paves the way for future research to build on the findings of this study.

ACKNOWLEDGEMENTS
The author would like to sincerely thank the supervisors of this dissertation, Dr Nicolai Marguardt and Zuzanna Lechelt, for providing more support and encouragement throughout this project than anyone could reasonably expect. The good parts of this dissertation are thanks to their esteemed
guidance; any not-so-impressive parts are the fault of the author alone! Sincere thanks also to Dr Venus Shum and Nora Tejeda for their valuable feedback throughout the design of this project. Gratitude is extended to all participants for their help in evaluating this project – particularly to the children for their enthusiasm and entertainment! This project would not have materialised without the excellent resources at the Institute of Making at UCL. Finally, to all the family, friends, treasured classmates, and staff at UCLIC – thank you for your support.

REFERENCES


Appendix (i): Questionnaire

Pre-study STEM questionnaire

Your child is not required to complete this questionnaire. The acronym STEM, used throughout this study, stands for Science/Technology/Engineering/Maths. All responses will be anonymised

* Required

Ethics

We would like to invite you to participate in this research project directed by researchers at University College London (UCL). You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Contact us at jennifer.sheahan.15@ucl.ac.uk if there is anything that is not clear or if you would like more information.

In this questionnaire, we will ask about your background in STEM (science, technology, engineering, and maths), and we will ask you about factors that may affect your perceptions of STEM subjects.

All data and recordings will be handled according to the Data Protection Act 1998 and will be kept anonymous. With your permission, we may want to use an extract of the anonymised data for teaching, conferences, presentations, publications, and/or thesis work.

By clicking next, you give your permission to take part in this research. It is up to you to decide whether or not to take part. If you decide to take part you are still free to withdraw at any time and without giving a reason and without any consequence.

Background information

1. Please provide your participant number.*
   Mark only one oval.
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6

2. What is your age?*
   Mark only one oval.
   - 16-25
   - 26-35
   - 36-45
   - 46+
Appendix (i): Questionnaire

3. **What, broadly, is your area of occupation? * **
   If not listed, please select “other” and enter job title in the next section
   *Mark only one oval.*
   - Administration
   - Arts and media
   - Engineering
   - Technology sector
   - Healthcare
   - Homemaker
   - Humanities
   - HR and Recruitment
   - Law
   - Teaching
   - Technician
   - Tradesperson - plumber/electrician/builder etc
   - Other:

**STEM hobbies**

4. **Do you regularly partake in any STEM activities?**
   Examples include hobbyist electronics, making, coding, astronomy, botany, etc.
   *Mark only one oval.*
   - Yes   Skip to question 5.
   - No    Skip to question 7

*Skip to question 7.*

**STEM hobbies description**

5. **Please provide a short description and frequency of the STEM hobbies you partake in. * **
   For example, “I attend a local astronomy club once a week”.

   ……………………………………………………………………………………………………………………

   ……………………………………………………………………………………………………………………

   ……………………………………………………………………………………………………………………

6. **Does your child participate in these hobbies with you? * **
   *Mark only one oval.*
   - Yes - regularly
   - Yes - sometimes
   - Very rarely
   - Not at all
Appendix (i): Questionnaire

7. To what extent are you involved with your child's learning at home? *
   Please select all that apply.
   Check all that apply.
   - Sometimes I help them with homework.
   - They usually do homework on their own, they do not need my help.
   - I frequently do homework with them.
   - I regularly do extra-curricular activities with them, for example music practice or science experiments.
   - I do not usually participate in their extra-curricular activities - they have their own hobbies and interests.

8. Do you play with any educational STEM technologies with your child? *
   Please select all that apply.
   Check all that apply.
   - No, I don't use educational technologies at home.
   - Raspberry Pi
   - Arduino
   - Lego
   - Science Kits (e.g., chemistry sets, microscopes)
   - Little Bits
   - Makey Makey
   - K'Nex
   - Scratch
   - Other: ____________________________________________

9. Do you take your child to any extra-curricular STEM activities outside of school? *
   For example, code clubs or science events.
   Mark only one oval.
   - Yes   Skip to question 10.
   - No    Skip to question 11.
Appendix (i): Questionnaire

11 In general, what are your personal feelings towards STEM subjects? *
   For example; maths, science, computer science, etc. Please select all that apply. 
   Check all that apply.
   - Boredom
   - Interest
   - Frustration
   - Excitement
   - Anxiety
   - Confidence
   - Stress
   - Calmness
   - Indifference
   - Other:

12 Please describe what makes you feel this way towards STEM subjects. *

   .........................................................................................................................

   .........................................................................................................................

   .........................................................................................................................

13 How important do you think it is to learn STEM subjects? *
   Mark only one oval.
   - Very important - it teaches a way of thinking that applies to many other areas of life.
   - Quite important - it is useful for certain things.
   - Fairly important, but only if people are interested in STEM.
   - Not too important - there are other equally or more important subjects to learn.
   - Not important at all - there’s no need to learn STEM if people are not interested.
   - Other.
     .........................................................................................................................
Appendix ii: Information and Consent Forms

DIVISION OF PSYCHOLOGY AND LANGUAGE SCIENCES

Information Sheet for Parents
You will be given a copy of this information sheet.

Title of Project: Can we design a series of activities to engage parents with non-STEM backgrounds in their child’s STEM learning?

This study has been approved by the Psychology and Language Science Research Department’s Ethics Chair. Project ID No: 0077/001

Name, Address and Contact Details of Investigators:
Jennifer Sheahan
UCL Interaction Centre
UCL Gower Street
London WC1E 6BT
United Kingdom
+44 7490 397763

Principal Investigator (PI):
Dr Nicolai Marquardt

We would like to invite you to participate in this research project directed by researchers at UCL. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

What is the interactive book?
The interactive book is an exciting new electronics and programming activity workbook. It fuses creativity and computational thinking through collaborative activities. The workbook is a series of STEM-based activities (science, technology, engineering, and maths) involving electronic circuits and other interactive components, designed to allow parents and children to become familiar with computational thinking concepts in a fun and engaging way.

What are we researching?
The purpose of our research is to investigate whether the interactive book can help parents with non-STEM backgrounds become more engaged with their child’s STEM learning. We also want to assess whether the interactive book can help children learn computational thinking and other STEM concepts. Additionally, we aim to investigate what you and your child like or dislike about the activities, in order to improve them for future use.

What does the study involve?
If you agree to take part in the study, you will be invited to attend a session where you will be given an interactive book with electronic circuits, lights, gears, and programming tags. We will ask you both to complete playful, collaborative activities where you will both learn together about computational thinking and STEM concepts such as circuits and programming. We will ask about your background in STEM. We will also ask you about factors that may affect your perceptions of STEM using questionnaires and we will ask you, along with your child, to complete a series of activities using an interactive prototype. Following this activity, we will ask you questions about your experience.

We will video the sessions and take notes to study how you and your child use the interactive book so that we can learn how to improve it. The videos will not show your child’s face. We will also interview them about their experience of the activity.

The personal information you and your child provide will only be used for the purposes of this project and not transferred to an organisation outside of UCL. The information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998. With your permission, we may want to use an extract of the video recording for teaching, conferences, presentations, publications, and/or thesis work.

It is up to you to decide whether or not to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.
Appendix ii: Information and Consent Forms

DIVISION OF PSYCHOLOGY AND LANGUAGE SCIENCES

Informed Consent Form for Participants in Research Studies

Title of Project: Can we design a series of activities to engage parents with non-STEM backgrounds in their child's STEM learning?

This study has been approved by the Psychology and Language Science Research Department’s Ethics Chair. Project ID No: 8077/001

Parent’s statement

I ______________________ (parent/guardian name)

agree that my son/daughter ______________________ (child’s name)

may participate in this study if they consent.

I agree that I have:

• Read the information sheet which explains the purpose of the study and what it involves.
• I have had the opportunity to ask questions.
• All my questions have been answered to my satisfaction and I know who to contact if I have any further questions about the study.
• I understand that my child’s participation will be video-taped and photographed for research purposes.
• I understand that I may withdraw my child from the study without the need to give a reason.
• I understand that by completing and returning this form, I am giving consent that the personal information I or my child provides will only be used for the purposes of this project and not transferred to an organisation outside of UCL. The information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Optional consent (please tick if you consent)

☐ I give consent for photographs and videos of my son/daughter to be used in research publications (which may appear online)

Signed: ______________________  Dated: ______________________

Investigator’s Statement

I ______________________

confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: ______________________  Dated: ______________________
Appendix ii: Information and Consent Forms

Child Information Sheet

What is the interactive book?
The interactive book is a fun electronics and programming activity workbook. It has three activities involving lights, gears, and programming. You can interact with it and even draw your own circuit using electronic ink, to make a light turn on!

What are we researching?
We are testing the interactive book to learn how to make it better and to find out about how people learn. We want to discover how the book can be used for learning about how things in the real world work together and what new ideas you think of when you have learned to use it.

What does the study involve?
If you choose to take part, you will attend a session to do the activities in the book along with your mum or dad. We will video you and take notes during the workshop. We will also interview you to find your opinions about the book when you are finished the activities.

The personal information you provide will only be used for the purposes of this project and not transferred to an organisation outside of UCL. The information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998. You can stop at any time; you do not have to give a reason.

Child Consent Form

Participant statement

I __________________________ (participant's name)

agree to take part in this study.

☐ It has been explained to me

☐ I understand that videos and pictures will be taken

☐ I know that I can stop at any time

Signed: __________________________ (participant signature)

Dated: __________________________ (today's date)
Appendix iii: Code for Activity #3

```c
#include <SPI.h>
#include <MFRC522.h>
#include <Adafruit_NeoPixel.h>
#define RST_PIN  9
#define SS_PIN   10
#define PIN      6
#define NUM_LEDS 40
#define button_move 7

MFRC522 mfrc522(SS_PIN, RST_PIN); // Create MFRC522 instance
Adafruit_NeoPixel strip = Adafruit_NeoPixel(NUM_LEDS, PIN, NEO_GRB + NEO_KHZ800);
unsigned short data[2]={1,3};
unsigned int x=1, temp=3;

void setup() {
  pinMode(button_move, INPUT_PULLUP);
  pinMode(button_reset, INPUT_PULLUP);
  Serial.begin(9600); // Initialize serial communications
  SPI.begin(); // Init SPI bus
  mfrc522.PCD_Init(); // Init MFRC522
  mfrc522.PCD_DumpVersionToSerial(); // Show details of MFRC522 Card Reader
  strip.setBrightness(127);
  strip.begin(); // Initialize the NeoPixel library.
  strip.show();
}

void readUID(String uidString){
  for(int i = 0; i <lef(mfrc522.uid)->size; i++) {
    if((&mfrc522.uid)->uidByte[i] < 0x10) {
      Serial.print(F(" 0"));
      uidString = uidString + F(" 0");
    }
    else {
      Serial.print(F(" "));
      uidString = uidString + F(" ");
    }
    Serial.print((&mfrc522.uid)->uidByte[i], HEX);
    uidString = uidString + (&mfrc522.uid)->uidByte[i];
  }
  //Serial.println();
  return uidString;
}

void colorRing(int r, int g, int b) {
  for(int i=0;i<NUM_LEDS;i++){
    strip.setPixelColor(i, strip.Color(r, g, b));
    strip.show();
    delay(26);
  }
}

void clearRing(){
  for(int i=0;i<NUM_LEDS;i++){
    strip.setPixelColor(i, strip.Color(0, 0, 0));
  }
}

void move_up()
{
  if(x>15)
  {
    Serial.println("up");
    temp=-data[0]*8;
    for(int i=0;i<temp;i++)
    {
      strip.setPixelColor(i, strip.Color(255, 255, 255));
      strip.setPixelColor(i+18, strip.Color(0, 0, 0));
      strip.show();
      if(i<=8)
      { x=i; break; }
      else
      { x=temp; delay(500); }
    }
  }
}
```

Appendix (iii) – Page 1
void move_down()
{
    Serial.println("down");
    if(x<33)
    {
        temp=x-(data[0]*3);
        for(int i=x;i<temp;i++)
        {
            strip.setPixelColor(i, strip.Color(255, 255, 255));
            strip.setPixelColor(i-1, strip.Color(0, 0, 0));
            strip.show();
            if(i==33)
            { x=i; break; }
        }
        x=temp;
        delay(500);
    }
    else
    {
        x=temp;
        delay(500);
    }
}

void move_right()
{
    Serial.println("right");
    if((x%3) != 0)
    {
        temp=x-data[0];
        for(int i=x;i<temp;i++)
        {
            strip.setPixelColor(i, strip.Color(255, 255, 255));
            strip.setPixelColor(i-1, strip.Color(0, 0, 0));
            strip.show();
            if((x+8)==0)
            { x=i; break; }
        }
        x=temp;
        delay(500);
    }
}

void move_left()
{
    Serial.println("left");
    if((x!=mt) && (x%8) && (x%17) && (x%25) && (x%33))
    {
        temp=x-data[0];
        for(int i=x;i>x+temp;i--)
        {
            strip.setPixelColor(i, strip.Color(255, 255, 255));
            strip.setPixelColor(i+1, strip.Color(0, 0, 0));
            strip.show();
            if((x==1) && (x==9) && (x==17) && (x==25) && (x==33))
            { x=i; break; }
        }
        x=temp;
        delay(500);
    }
}

void loop() {
    if(digitalRead(button_move)==LOW)
    {
        Serial.println("Go button");
        if(data[1]==1)
            move_up();
        else if(data[1]==2)
            move_down();
        else if(data[1]==3)
            move_right();
        else if(data[1]==4)
            move_left();
        while(1)
        {
            if(digitalRead(button_reset)==LOW)
            { Serial.println("Reset button"); break; }
        }
    }
}