From Smart Homes to Smart Kids: Design Research for CataKit

Aviv Sheriff
Media Innovation Lab
Interdisciplinary Center
Herzliya, Israel
aviv.sheriff@post.idc.ac.il

Rona Sadan
Media Innovation Lab
Interdisciplinary Center
Herzliya, Israel
rona.sadan@idc.ac.il

Yasmin Keats
Media Innovation Lab
Interdisciplinary Center
Herzliya, Israel
yasmin.keats@post.idc.ac.il

Oren Zuckerman
Media Innovation Lab
Interdisciplinary Center
Herzliya, Israel
orenz@idc.ac.il

ABSTRACT

This paper presents the design research process of CataKit, a construction kit for children inspired by catapults, Rube-Goldberg chain reaction machines, and mechanical automata. We set out to promote children‘s initiative, positive risk-taking, and procedural thinking, all in the context of their bedrooms. Our motivation is to contrast the rising smart home movement in industry, which we fear may decrease children‘s initiative if children‘s bedrooms become too automated. We describe our design research process with six children followed by a low fidelity prototype design and evaluation. We present the qualitative analysis of children‘s reactions to the prototype and show support for our initial goals: encourage systematic exploration of mechanical concepts and initiative over automation. We hope that construction kits like Catakit will empower children to develop curiosity about the mechanical world around them, to think about risk taking as a potentially positive experience, and to think more critically about initiative in the smart home era.

ACM Classification Keywords

K.3.2 Computer and Information Science Education: Computer science education

Author Keywords

Construction Kit; Children; Computational Thinking; Learning; Positive Risk-Taking.

IDC '17, June 27-30, 2017, Stanford, CA, USA

ISBN 978-1-4503-4921-5/17/06. . . $15.00
DOI: http://dx.doi.org/10.1145/3078072.3079729

Figure 1. Girl looks on intently as she experiments with the CataKit prototype.

INTRODUCTION

In his well-known foreword to Mindstorms, ‘Gears of my Childhood‘, Seymour Papert details his early fascination with gears and how they sparked his love and understanding of math [30]. The gears, says Papert, were models that served as his ‘genesis of knowledge‘ and ultimately led to his theory of Constructionism. In the era of smartphones, smart homes, and upcoming autonomous technologies, children spend increasingly more time with digital devices, playing computer games, and consuming digital media [14], acting as consumers of media rather than creators. We fear that playful exploration of mechanisms in the physical world such as Papert‘s gears has lost its relevance in today‘s children culture. Resnick [32] exemplifies playful exploration beautifully with the case of Alexandra, a young girl who took on the project of constructing a “marble machine“, a device in which marbles are carried up and down various tracks and pathways, bouncing around and activating devices. The project engaged Alexandra for weeks, as she experimented and iterated her design, working hard but embracing the challenge due to the personal meaning of the project. Complex and meaningful projects such as Alexandra's marble machine engage children in what Papert called procedural thinking [30]. Children who learn and think procedurally connect abstract 'propositional' knowledge, as learned in classrooms, with the real world. Without the procedural and experiential element, learning may become dissociated, such that the learner cannot associate what he knows with personal experience.

Papert believed that children could develop procedural thinking by programming in LOGO [30]. More recently, in her influential 2006 article, Jeannette Wing [43] referred to this type of procedural problem-solving as 'computational thinking' (CT) and said that it "represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use". CT is a creative process that includes iteration, deconstructing problems, debugging, and generalization through patterns [17]. Bundy [9] reports that CT influences 'research in nearly all disciplines' and Wing [44] envisions that it will bring innovation to 'all fields of endeavor'. However, researchers are still looking for methods of instilling CT in children.

Computational thinking is most often associated with programming, but many of its core elements are also relevant to mechanical problem-solving and physical tinkering, such as iteration and debugging. Moreover, it has been shown that children have less knowledge of mechanical operations. One study, conducted with young children (ages 9-10), showed that children were unable to accurately explain mechanical concepts even after a robot building session that covered those concepts [10]. The modern digital lifestyle may not provide enough opportunities for kids to interact with, explore, or invent mechanisms. In a way, the digital world has moved the interiors of machines into what Paulo Blikstein refers to as the background [7], or 'black box' [33]. These trends might have negative implications in various domains. One concern in US college education is the steady decline in the number of engineering freshmen in the United States, with fewer than half of those students obtaining an engineering degree [6]. We hope that playful tinkering with physical mechanisms will promote procedural thinking and CT among children.

Positive Risk-Taking

Little [22] argues that the departure from physical play is depriving children of developmentally significant opportunities for positive risk-taking. Parents and society in general are increasingly overprotective [15, 16], which causes children to miss out on worthwhile risks that provide stimulating experiences [38]. By contrast, positive risk-taking promotes learning but minimizes the chance of injury. In addition, it allows children to learn about risk and risk evaluation, an important skill later on in life [22]. Children who engage in high positive risk-taking are "confident in challenging themselves to complete difficult tasks", whereas children who engage in high negative risk-taking "use equipment in a dangerous or inappropriate manner, contrary to intended uses" [23]. The first definition emphasizes that positive risk-taking experiences have the potential to give children perceptions of self-efficacy [3]. The second definition emphasizes the need to design construction kits in a way that scaffolds away from potential "dangerous or inappropriate" uses, commonly found in negative risk-taking. Finally, the lack of easily accessible urban outdoor play areas for children [39] suggests that indoor opportunities for positive risk-taking are a worthwhile alternative.

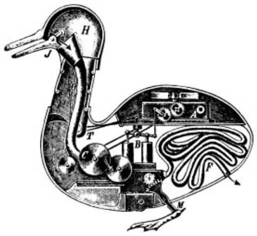

Figure 2. Jacques Vaucanson's mechanical digesting duck as depicted by an observer.

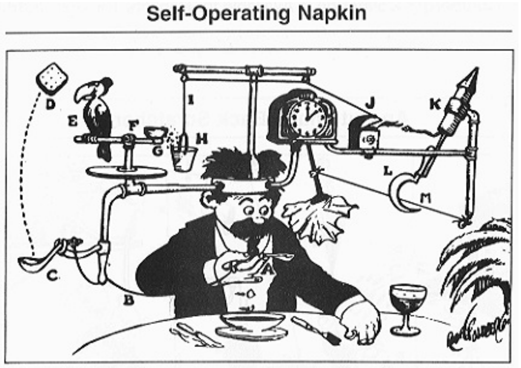

Figure 3. Rube Goldberg's Self-Operating Napkin.

Automata and Rube Goldberg

History is rife with examples of clever and creative mechanical engineering that intrigued children and adults alike. Early hydraulic and pneumatic mechanisms, or automata, have been designed as early as ancient Greece and that early work has inspired extensive creation during the Renaissance [4]. One notable example is Jacques Vaucanson (1709-1782), arguably the most important inventor in the history of automata and a key figure in the history of machine technology. Vaucanson spent his life constructing various novelties such as his first android - a life-sized figure of a musician that played the flute. His most famous creation was "an artificial duck of gilt brass which drinks, eats, flounders in water, digests and excretes like a live duck" (Fig. 2). The creation of automata that produce music has inspired the Academy of Sciences in St. Petersburg to host what may be considered an 'Enlightenment Age Hackathon' in 1779. The contest sought the creation of a speaking head that could utter the five vowels, but no winner was declared, although the contest inspired many to construct speaking heads over the following decades. Modern artists have, around the turn of the previous century, built certain automata as a commentary and satire on the advent of modern technology, namely - Rube Goldberg machines [24]. Rube Goldberg studied engineering but eventually became a newspaper cartoonist [42] who sketched various absurdly complex mechanisms that perform mundane tasks, such as the self-operating napkin with rocket and parrot (Fig. 3; [42]). "An illogical bunch of things that are put in a logical sequence", is how Goldberg once described his inventions in an interview. This quote portrays Goldberg as a proponent of tinkering for its own sake, much like modern Makers.

Kim and Park [20] have advocated the use of Rube Goldberg machines as an exciting means of captivating young minds while promoting important abilities, such as design aptitude, engineering skills, and creativity. O'Connor [27] describes a Rube-Goldberg-based course for fifth graders set to cover math (metric system), science (simple machines), and history (the industrial revolution). The students responded with excitement and recruited their families to assist.

Smart Homes - Friend or Foe?

Chain reaction machines such as Rube Goldberg's present an opportunity for children to actively design their personally meaningful spaces rather than passively use smart technologies. Smart home technology, in particular, is on the rise [2] and is beginning to penetrate the lives of children and adults alike. Personal assistants, automated kitchens, and self-adjusting light bulbs are offering to take over manual tasks. As wonderful as smart homes technology can be, we see a downside in a gradual process that can lead people to decrease in initiative. As our homes become automated, various functions are taken out of our control and we risk becoming passive and sedentary. As Yvonne Rogers stated in her 2006 paper [36], there is a need to be engaged by technology, rather than subdued, and we need to shift 'from proactive computers to proactive people'. We strongly support this agenda. Moreover, kids may be at a particular risk in this context; the more black boxes around them, the fewer opportunities they'll have for exploration and for acquiring an intuitive understanding of the world around them. We believe that the smart homes trend should be leveraged to excite children who are fascinated by such technologies with the possibility of personally designing machines that control their homes and rooms.

CataKit

We present the design research process of a new construction kit, called CataKit (Fig.1), a set of components that allows kids to construct and use catapult-style small machines to design and implement their own smart room experience.

RELATED WORK

In our design of the CataKit, we found inspiration in previous work on automata and the literature on scaffolding. Within the Human Computer Interaction (HCI) literature, we found related work on construction kits, with a specific focus on mechanism construction.

Mechanisms and Automata

Henry T. Brown's 1868 classic technical book "507 Mechanical Movements" is now available online including illustrations and some animations [8, 26]. Modern authors have noted the educational potential and have developed instructional books for children, such as Robert Adam's 'How to Make and Design Automata' [1]. Within the HCI community, important work has recently been published on 'Paper Mechatronics' by the Craft Technology Team at the University of Boulder, Colorado [28]. Their project began with simple paper-based mechanisms and has evolved into a cardboard-based mechanical kit with Arduino circuit boards for designing percussion instruments [29]. The Craft Technology Team has gathered insights from workshops using the kit and note the importance of the mechanisms' physicality in facilitating iterative learning and problem-solving. Some notable commercial kits have also inspired us, such as Lakeshore Learning's 'Create-A-Chain Reaction STEM Kit' that uses a small ball-throwing mechanism as the primary component [21], Learning Resource's various 'Gears! Gears! Gears!' sets [35], and Pathfinder's hydraulic catapults and machines [11].

Guidelines of Construction Kit Design

In our work, we were deeply influenced by the work of the lifelong kindergarten group at MIT Media Lab and the insights gathered there following decades of construction kit design. Specifically, we drew inspiration from the guidelines described by Resnick and Silverman [34], which include: 'Design for Designers', 'Low Floors and Wide Walls', and 'Make Powerful Ideas Salient - Not Forced'. Additional guidelines came from our own previous work; Zuckerman [46] drew a classification from the distinct philosophies of Montessori and Froebel, and described the design principles that underlie their work. In our Catakit, we drew inspiration from the following of those principles: 'An open-ended system with minimal constraints', 'isolation of properties', and 'conceptual manipulation'.

Scaffolding

In his influential sociocultural theory, Lev Vygotsky introduced the concept of the Zone of Proximal Development (ZPD; [41]). The ZPD is the difference between an individual's personal ability and what he can achieve when supported, or scaffolded, by someone else. Vygotsky influenced learning theorists greatly and today the support described in his theory is most commonly termed 'Scaffolding'. The term scaffolding was first coined by Wood, Bruner, and Ross [45] and originally referred strictly to tutoring given to a child by a teacher. The term has since expanded to various contexts of learning support, including in the absence of any social interaction. Podolefsky, Moore, and Perkins [31] have developed interactive simulations based on a framework of implicit scaffolding. Implicit scaffolding is "built into the tool itself - using affordances, constraints, cueing and feedback" and should be seamless, without the explicit attention of the learner to the fact that he or she is being directed. For example, one important idea adopted in their framework is 'framing', in which the construction kit designer answers the question "what sort of activity is this?" and communicates the answer through the design [19, 40]. Hadwin and Winne [18] make a similar distinction between tacit and explicit scaffolding and propose that tacit scaffolds promote self-regulated learning. This may occur because users tend to attribute positive external events to themselves [25], such that a user will self-attribute interface successes and get motivated.

DESIGN RESEARCH

Our goal was to design a construction kit that will encourage children‘s systematic exploration of mechanical concepts, initiative over automation, and positive risk-taking in a home context. To better understand children‘s preferences and attitudes on these topics, we defined three components of the kit - a thrower, a catcher, and a pusher. We did not design the components, rather we integrated them into our interviews as a research probe.

Method and Procedure

We obtained institutional review board approval, parental consent, and interviewed three boys and three girls, ages 8-12. The children were recruited through an ad on social media and through personal acquaintance with the researchers. The interviews were conducted in the children‘s homes, in their rooms. Previous work indicates that collecting data in kids‘ own environment produces insights that may otherwise be missed [12, 5]. In addition, following Druin‘s [12] recommendations, one researcher transcribed the interaction while another researcher served as the interactor so that he could talk naturally with the kids. The interviews lasted between 45 minutes and an hour. The interviews followed a semi-structured format. At first, we only gave the children a simple verbal description of the three basic components and sticky papers that represented the various components (with the name of each component printed on the paper), so that the kids could use them to act out their ideas and plans. We also mentioned that the components could connect anywhere in their rooms. As the interview progressed, we showed the kids some pictures that illustrated possible implementations of each component, as well as an inspiration video that shows a Rube-Goldberg type chain reaction machine in a breakfast context.

Findings

We present the qualitative analysis of children‘s reactions to the concept of CataKit and the components we described. In line with our research goal, we analyzed our interviews with the following questions in mind: whether children envision the kit as more functional or playful, do they see the kit as smart/automated or as requiring manual initiative, and do they have more positive-risk or negative-risk ideas for using the kit.

Functional versus Fun Ideas

We wanted to see whether children desire functional, “smart home“, uses for the kit or whether they are more interested in fun and games. Children‘s ideas were classified into functional/fun and then counted for each child. We also asked them to indicate and detail their preference for functional/fun uses for the kit.

Four out of the six children had notably more functional than fun ideas for using the kit.

> Jim (10): “It can turn the computer on and off, for example. I throw it outside (away from the table) and then back to the computer‘s button. It saves you the need to bend. (Fig. 4)

Two children had an equal mix of functional and fun ideas:

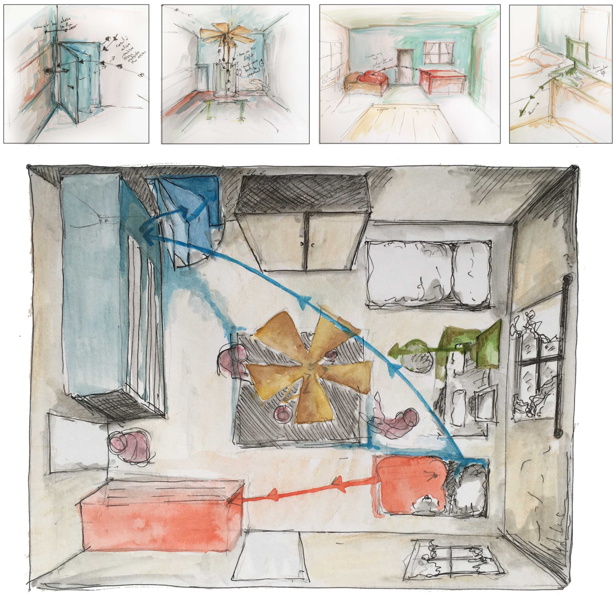

Figure 4. Depiction of Jim‘s bedroom and ideas. Blue - closing the door. Green - switching the computer on and off. Red - pulling off the blanket to wake up. Yellow - turning the light on and off

> Jane (8): “It can play catch and you can play piggy in the middle with no friends.“ (fun); “She (her mother) presses it and it releases the bottle and it flies (to her bed).“ (functional)

When asked whether they prefer the functional or the fun ideas, four of the six children firmly supported the functional ideas.

> Bill (12): “I think it would be mainly for practicality and on the way it has some fun.“

Two children said they liked both functional and fun uses:

> Jane (8): “Both. Kids need to have fun sometimes. Mostly. The useful stuff can help the parents and help educate the kids. But (with) the fun stuff you can play tricks on them.“

Initiative versus Automation

The children referred to buttons, remote controls, robots, and similar automated digital devices when describing the kit. We counted the number of those references to assess the extent to which children envisioned the kit as automated.

Four of the six children mentioned electronics between one and four times, which we define as a low amount of references. The two remaining children mentioned electronics eight and twelve times, which we define as a high amount of references.

Out of the two children with a high amount of references, one of them, a girl, was very much into robotics and mentioned them multiple times. The second of the two, a boy, mentioned all types of technology - sensors, holograms, and electronics.

Four out of the six children mentioned using a remote with the kit at least once.

> (How do you make it throw the cup?) Jane (8): “There‘s a remote control in your pocket.“

Positive versus Negative Risk-Taking

We used Little, Wyver, and Gibson‘s [23] guidelines to classify children‘s ideas for using the kit as positive or negative risk-taking and as constituting high risk, moderate risk, low risk, or very low/no-risk. In addition, we asked children who is responsible if the kit broke something in the house, in order to assess their risk-awareness.

Most of the children‘s ideas were very-low/no-risk.

> Jim (10): “I want it to push the door.“

> Bill (12): “Maybe it could sense if someone was coming in.“

The second most common type of idea was low-risk positive.

> Jane (8): “There‘s a remote control in your pocket. One hand pressing the remote control. You get ready and then you catch (the glass), and it can have juice inside it. And then you can pretend you didn‘t know about this and just drink it.“

Overall, there were only four negative risk ideas out of about 45 ideas.

> Jim (10): “You can come home and it‘ll toss the lunch food in your face, or upside down on the table.“

All of the children were aware of the potential risks of throwing things with the kit, such as interrupting others and breaking things.

> Mary (10) suggested throwing a sponge. When asked why, she said “Because it doesn‘t break anything, it‘s harmless, it‘s a sponge.“

DESIGN GUIDELINES

In the interviews, the children treated the concept of CataKit with great consideration and thought carefully about their answers. They showed a “tech-mindset“ and mentioned several times that the kit should be electronic in nature. Interestingly, their ideas were mostly safe or involved positive low risk. Based on our interview findings and related work, we defined the following design guidelines as a base for our CataKit design process.

1. **Meaningful Connection with the Room**. Kids found their rooms to be fertile soil for ideas. Siblings who were interviewed in joint rooms had ideas that centered around their own personal space - mainly their beds. The guideline we derived from this insight is that CataKit components should attach to as many surfaces as possible within the room.

2. **Perceived Usefulness, Actual Playfulness**. The children expressed a desire for the kit to serve a functional use, or in other words - to serve a real purpose in their daily lives. However, when they acted out their scenarios it was clear that they were quite playful. For instance, shutting down the computer by constructing a complex chain reaction is a playful but inefficient way of turning it off. We decided that the CataKit should balance between ‘perceived usefulness‘ and actual playfulness.

3. **Initiative over Automation**. Children‘s desire for remote controls and robots strengthened our position that CataKit should be designed primarily with mechanisms. We believe that, with the right design and playful affordances, children would be motivated to design complex mechanisms in order to reach their goal of automation.

4. **Positive Risk-Taking**. In our interviews, we found that kids‘ ideas were safe or low in risk. The Catakit should encourage them to take more risks but in a safe and playful way.

5. **Low floor, Wide Walls**. Building on Resnick [34], we wish that the kit be easy to start with and require little prior knowledge so that kids can start experimenting right away (low floors). At the same time, it should allow for many diverse creations (wide walls).

6. **Systematic Exploration**. The kit should allow children to explore mechanical ideas through iteration, debugging, problem-solving, and planning. We hope that exploration of mechanical concepts and the relationship between cause and effect will encourage an ‘engineer‘s mindset‘ of playful design and promote CT skills at an early age.

PROTOTYPE DESIGN AND IMPLEMENTATION

Based on our design guidelines and related work, we designed a low fidelity prototype of one of the CataKit components, the thrower, which is a catapult. In this work, we chose to focus on the catapult component because it resonates with the concept of risk-taking, even to the point of vandalism. We felt that the catapult metaphor captures the imagination of kids and adults alike. Finally, the mechanism of the catapult is not so complex as to obscure the underlying mechanical operations, which corresponds with our goal of encouraging systematic exploration of mechanical concepts.

After iterating several versions of the catapult (Fig. 5), we built a moldable, minimal, and ‘simple as possible‘ [34] prototype. The prototype (Fig. 6) allows for a meaningful connection with the room (guideline 1) via suction mechanisms fitted to the component‘s sides and bottom (Fig. 6; A) that attach to smooth surfaces. In addition, we minimized the size of the base (Fig. 6; B) so as not to block the view for the child or serve as an obstacle in the room.

To promote systematic exploration (guideline 6), the cup (Fig. 6; C) and the rod (Fig. 6; D) are adjustable. The cup can be moved up and down the rod and little cubes at the top and bottom can be used to fixate its position. The adjustability of the tossing mechanism invites experimentation with different tensions, and as a result different kinetic energy that results in various throwing distances.

We used scrap materials to make the kit accessible and less intimidating. We wanted kids to feel free to modify and even break some of the kit‘s parts during the testing sessions, as they explored various uses.

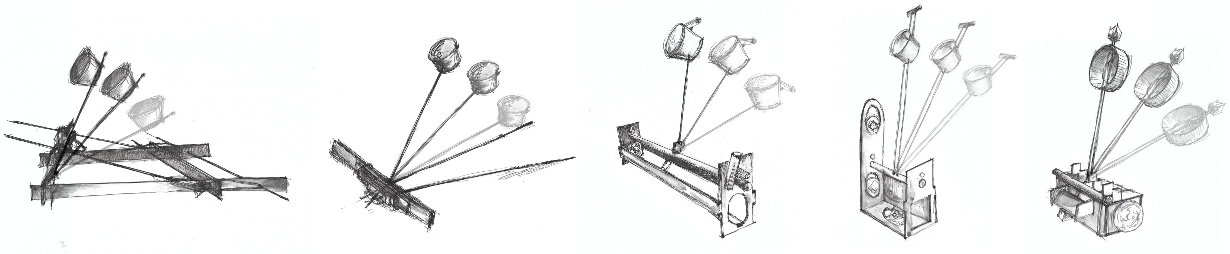

Figure 5. Iterations of the catapult, starting from earliest (left) to latest (right). Model 2 added the adjustability of the cup. Model 3 added connectivity via suction mechanisms. Model 4 condensed the design. Model 5 added vacuums and sturdiness via wood construction.

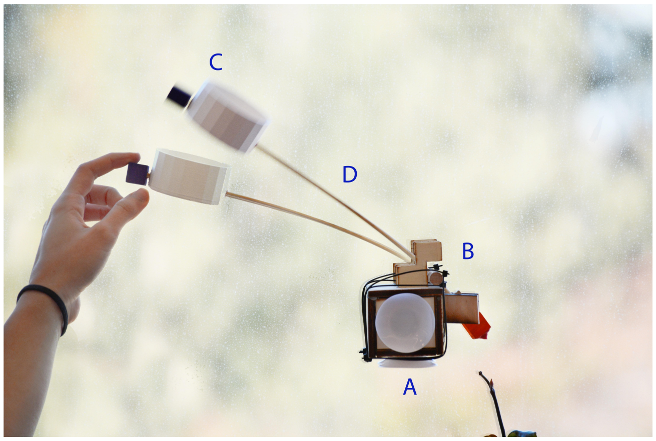

Figure 6. Final catapult prototype.

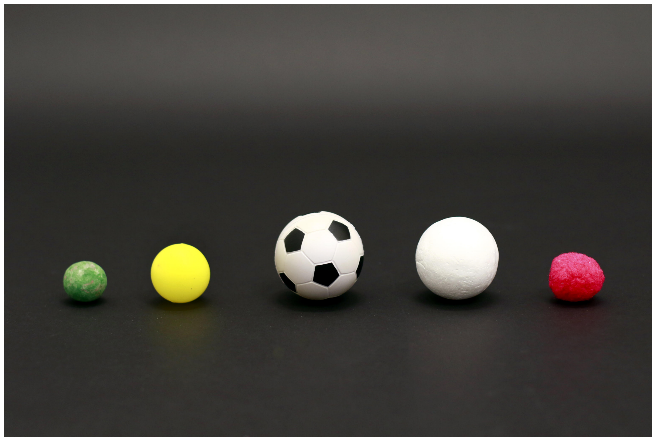

Figure 7. The arsenal of balls. Hard and heavy ball on the left, followed by rubber yellow ball, sponge soccer ball, styrofoam ball, and fluffy ball.

In order to ensure 'low floor' (guideline 5), we wanted the mechanism to be completely visible. This serves as an affordance for the main operation of pulling and releasing the rod (Fig. 6; D). In addition, the high visibility minimizes the number of black boxes.

To encourage positive risk-taking (guideline 4), the catapult was accompanied by an arsenal of five balls that varied in softness, weight, and size (Fig. 7). The green ball is the hardest, heaviest, and produces a loud sound when it falls on hard surfaces. By contrast, the red ball is the lightest, softest, and fluffiest.

The perceived usefulness (guideline 2) of the kit is contextual, in the sense that connecting it to the environment and using it to activate other objects makes it useful. Without connectivity, the catapult on its own has no purpose.

We intentionally created tension between the immediate association of the catapult as a destructive machine and our desire to create a kit for positive risk-taking within the house. We believe that this tension creates playfulness and adds an element of whimsical humor.

USER STUDY

Using our prototype, we revisited five of the original six children from the design research phase, in their homes. The sixth child was not interviewed for logistical reasons. The interviews took place in the same rooms as the original interviews. We displayed the catapult and the arsenal of balls and asked the kids to explore and use the prototype. As in the design research phase, one interviewer focused on interacting with the child and one was a designated transcriber. We analyzed the interviews according to the themes presented below.

Low Floors and Wide Walls

To evaluate this design guideline, we observed children's activity, especially at the beginning of the activity, to see whether they found the kit accessible and easy to start using (low floor). In addition, we looked for a variety of uses for the kit (wide walls).

Three of the five children did not intuitively understand that the rod needs to be pulled back in order to throw, a design flaw that prevented the children from using the system as planned. At this point, the researcher explained the mechanism so that the user testing could proceed. The two other children understood straight away, without any explanation.

In addition, four of the five children were at first scared to break the kit, either by having it fall from a high place or by pulling the rod too far back.

All five children said the rod wasn't flexible enough. They suggested using alternative materials such as rubber or other tension mechanisms, such as springs.

> Jane (8): “Maybe make it more flexible. So you can bend it and there‘s a spring you can fold down and it makes it jump up.“

In terms of connectivity, all five children intuitively grasped the purpose of the suction mechanisms and successfully connected the catapult to various surfaces in their room, such as windows, cupboards, tables, the floor, their bed, a mirror, a computer, and a computer monitor. This indicates that the connectivity aspect is easy to start using and works with diverse surfaces. When asked to rate “to what extent they would be able to connect the kit wherever they wanted“, from 1 (very low) to 5 (very high), three children answered 3 and two children answered 4.

> Jane (8): “3, It needs to be stickier.“ Jody (11): “3, It can connect to some places and some places it can‘t.“ Bill (12): “4, basically there‘s no place I need to stick it and it can‘t (connect).“

The children had a diverse range of new ideas for the kit (wide walls), which were also related to their personal interests.

> Jane (8), who likes to draw and paint: “It will throw a ball and it will activate a giant Ferris wheel and it‘ll pour a little bit of every color to the palette and then I can paint.“

> Bill (12): “Oh! It can work like an alarm clock. Sometimes I hit snooze three times... I‘ll throw and if I hit it‘ll stop ringing. If it doesn‘t, I have to get up and so I‘m up.“

> Jody (11): “Put the dog‘s ball in (the prototype) and make him go fetch.“

> John (10), who plays the violin, said: “This part looks a bit like a flute. Maybe it can play a little tune... The rod can activate something that creates a flow of air or an exploding balloon or something.“

We asked the children whether they could build their own prototype, like ours, from 1 (no way) to 5 (absolutely). All five children answered 4.

> Jody (11): “4, because I‘m good at building things.“

Systematic Exploration

We wanted to see how quickly and extensively the children would engage in a systematic exploration of the kit‘s uses, as evidenced by adjusting the rod, connecting the kit, firing various objects, implementing their original ideas, iterating, and debugging.

Once we assured the children that it was fine if they broke the kit, they began experimenting freely. Each child made dozens of attempts to throw the various balls around the room freely or to hit specific targets that they conjured up (Fig. 1). Each of the five children made dozens of attempts as they practiced their aim while trying to hit their marks.

> When asked how many times he tried to hit the computer switch, Jim (10) said:, “More than twenty I think. But it was before we got closer. Otherwise, it would take me seven.“

> Jane (8), when throwing the ball for the first time: (excited) “That‘s exactly where I was trying to aim!“

All of the children made use of the rod‘s adjustability mechanism systematically, in order to help them improve their aim. When asked why, they were able to correctly explain the logic.

> (Why do you take it up and down?) John (10): “If it‘s longer it can throw harder and better. And higher. If it‘s shorter it‘s harder to throw.“

> Jody (11): “If you move it closer it changes the force because then it (the rod) goes less backward and if you put it really far it can go more backward and get more leverage.“

Two of the children asked for built-in instruments to help them measure distances or adjust the catapult, thus allowing for even greater systematic exploration.

> John (10): “You can create a gauge that will indicate the distances. Here it will say ten and that way you know it‘s ten meters.“

One child had a completely different idea for how the kit would operate. He suggested that the cup would catch a ball, rather than throwing it, which would push the rod down and press a button.

> Bill (12): “You can throw a weight here (into the cup), or something heavy and then it‘ll drop down (the rod), and then activate something. But then I need the cube to be like a touch (softer).“, When asked what ball would do the trick, “A ball that had enough weight to make it drop down. I think it could also help you learn about different weights.“

Positive Risk-Taking

As previously stated, the children were initially afraid to break the kit, which is a design flaw because it discouraged risk-taking. Once we alleviated their concerns, they began to take more risks. We presented them with the arsenal of five balls and assessed their risk-taking using Little, Wyver, and Gibson‘s [23] guidelines of positive or negative risk-taking and as constituting high risk, moderate risk, low risk, or very low/no-risk.

Much like their ideas in the design research stage, most of the children‘s uses were no-risk/low risk. They mostly used the lighter balls, generally avoided aim at breakable objects, and rarely placed the kit in dangerous places.

The second most common uses were low-risk positive, such as throwing balls at pictures on the wall and connecting the kit to sensitive surfaces such as computer monitors and mirrors.

When they examined the hardest, heaviest ball, three children appropriately expressed risk avoidance - a reluctance to engage in the task with it.

> Jane (8), when asked whether she wants to throw the heavy ball, said “No, it‘s a little dangerous. It can hurt.“

> John (10), when asked why he won‘t use the heavy ball, said “It‘s too heavy and it can break something, even the kit itself and something in the room.“

Two children attempted to throw the heavy ball on a hard floor, a moderate negative risk that produced considerable noise. One child threw the heavy ball on the carpet, which indicates preparedness and a moderate positive risk.

We asked the children to rate how dangerous the kit was from 1 (not dangerous) to 5 (very dangerous). They rated it 2, 2, 2, 1.5 and 2.5.

> Bill (12): “2.5, if people are stupid and put it in dangerous places then yes, it‘ll be dangerous.“ Jane (8): “1.5 You can throw the hard ball by mistake.“

We also asked the parents to evaluate how dangerous the kit was. None of them expressed apprehension.

> Mother 1 said “About 2 or 3 out of 5, only the hard ball is dangerous.“ Mother 2 said “1 in my opinion.“, and proceeded to play around with the kit and with the heavy ball.

Automation versus Initiative

We revisited the concept of automation and initiative by asking the children, at the end of the interview, whether they would prefer an electronic or mechanical smart room system. In contrast to the kids‘ answers in the design research stage, where they expressed an explicit desire for remotes, robots, electronics, and automation, the kids changed their mind. Having played with the kit, all five children were now leaning towards mechanical usage and initiative.

> Jane (8): “To make it more interesting and not boring you want to activate it. If you click on the remote it‘s pretty boring. In order for it to be interesting, you can use your hands.“
>
> Bill (12): “Personally? I don‘t know how it would work with something electric. With the alarm clock, the whole idea is that you do it yourself so that you wake up.“
>
> John (10): “I would prefer a string (and not a remote). Or a rubber band. Because that‘s the most convenient, and to know that you activated it. And it can be fun to try and hit the mark.“
>
> Jody (11): “If everything is robotic, then what is it good for? It‘s more practical (manually) and instead of a robot doing it and you just sit and watch and get bored.“
>
> Jim (10): “I prefer this one. If it does the same thing anyway then this one is better because you see how everything works. It (automatic) would be more boring, basically.“

DISCUSSION

We set out to design a construction kit that will encourage children‘s systematic exploration of mechanical concepts, initiative, and positive risk-taking. We performed a design research process, defined six design guidelines, and implemented a low fidelity prototype. We tested our prototype in a qualitative study with the same children as in the design research and found encouraging support, detailed below.

Design principle	How it was manifested in the user testing
Ease of Use / Low floor	The children found the mechanism inaccessible at first but were able to use it after a short explanation. The children were afraid to break the kit. The children found the use of the suction mechanisms intuitive and had many diverse ideas for using it.
Systematic Exploration	The children adjusted the rod‘s length to achieve different trajectories. The children asked for additional tools of systematic exploration, such as distance gauges. The children experimented with throwing the differently weighted balls.
Positive Risk-Taking	Most of the children‘s ideas were low-risk, rather than positive or negative risk. The children all thought the kit is safe and, on average, rated it 2 (safe) out 5 (risky) on “risk“. Children‘s parents rated the kit as low on risk.
Automation-Initiative	Children progressed from a pro-automation stance in the design interviews to a pro-initiative stance after using the initial prototype.

Table 1. Summary of user testing findings.

Construction Kits in a Meaningful Context

Designing their own smart rooms using chain reaction mechanisms requires that children use their ingenuity and creativity. Indeed, the children we interviewed came up with a variety of ideas that would provide a stimulating challenge for them to execute, such as the chain reaction dog feeder, and the bunk-bed bottle delivery system. The children intuitively grasped the concept of the suction mechanisms and connected the prototype all over their rooms, even requesting additional connectivity with magnets and strings. Traditionally, construction kits are designed as stand-alone and independent of the environment. CataKit contributes in this regard by adding integration with the surrounding as a key affordance, specifically within the child‘s own meaningful and personal context - his or her room.

Mischievous Scientists

Piaget famously described children as little scientists, who ceaselessly conduct experiments [37]. Some of these experiments, alas, cause mischief and are often viewed with suspicion by parents and adults. We believe that this precise element constitutes excitement and interest for the child - to discover boundaries and have safe fun while doing it. We see CataKit as a catalyst for positive risk-taking in the home, that allows children to expand the repertoire of what is allowed indoors, in a safe and playful way. Our findings are in line with those of previous researchers [23] - children are taking very little risks in their play activities. Designers of construction kits should take this into their attention and create more opportunities for positive risk-taking.

Inspiring the ‘Engineer Mindset‘

Our construction kit targets important mechanical concepts such as cause-and-effect, tension, force, trajectory, and mechanical advantage - the ratio of the force produced by a mechanism to the force applied to it. Oh et al. [29, 28] have also noted the potential of mechanical automata for construction kits and Exploratorium [13] have developed projects in which kids build both automata and Rube Goldberg chain reaction machines. We contribute by adding, on top of the construction, the systematic exploration of mechanical concepts. The children we interviewed explored various uses. For instance, the children iterated with the tension produced by the catapult‘s rod in order to vary the force and trajectory of the toss. In addition, they experimented with different payloads, which introduced the interaction of weight. Finally, they explored cause-and-effect as they attempted to create chain reactions. For example, eight-year-old Jim threw the ball well over twenty times at a funnel that he placed over his older brother‘s computer power switch. Eventually, he succeeded in producing sufficient force and precision to shut down the computer, which resulted in an all-too-familiar sibling ordeal.

From Smart Homes to Smart Kids

Yvonne Rogers [36] makes a strong case for technologies that engage us rather than sedate us. In our paper, we took that approach to the extreme by foregoing the use of electronics in our prototype. Further development and research are required to assess whether this approach has merit or whether digital components are compulsory at one stage or another when designing an ambitious kit. Nonetheless, our findings show that children were captivated by the low-tech, mechanical prototype, despite its simple nature and design shortcomings. Even as we subtly emphasized the advantages of smart appliances in completing the same tasks - efficiency, time, and effort, they countered with their own arguments in favor of manual construction - that passivity is boring, and that “It kind of doesn‘t make sense. It‘s like robots took over the world. We have to do things on our own.“

Conclusion

Our findings show support for our initial goals: encourage systematic exploration of mechanical concepts, initiative over automation, and positive risk-taking in a home context. In addition, we would like to highlight that most of the children expressed a preference towards usefulness of the kit. As we described in our initial interview analysis, we interpret this finding as ‘perceived usefulness‘ because the children‘s ideas were, in essence, not really useful. For instance, one child‘s idea to turn off his personal computer with a chain reaction system is not really useful but was perceived as such by the child. We believe that designers of technology for children should consider perceived usefulness as a design guideline in their work.

The study had several limitations. First, the sample we used was small and we did not utilize random sampling or quantitative research methods. In addition, our decision to design just one component of the kit limited the extent of user-testing. Finally, most of our findings are limited to the context of children‘s bedrooms.

In sum, we believe that our research brings value to the HCI community and can inform designers and educators. We hope that construction kits like Catakit will empower kids to think more critically about life in an ultra-digital era, to take initiative in their daily lives using technology, to develop curiosity about the mechanical world around them, and to think about risk taking as a potentially positive experience, if done within safe limits.

ACKNOWLEDGMENTS

We thank all the children who participated in this study and shared their creative insights with us. This research was supported by the I-CORE Program of the Planning and Budgeting Committee, the ISF grant #1716/12 and the Sarah Fine Foundation.

REFERENCES

1. Robert Addams. 2003. *How to Design and Make Simple Automata*. Craft Education.
2. Muhammad Raisul Alam, Mamun Bin Ibne Reaz, and Mohd Alauddin Mohd Ali. 2012. A review of smart homes - Past, present, and future. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 42, 6 (2012), 1190–1203.
3. Albert Bandura. 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psychological review* 84, 2 (1977), 191.
4. Silvio A Bedini. 1964. The role of automata in the history of technology. *Technology and Culture* 5, 1 (1964), 24–42.
5. Hugh Beyer and Karen Holtzblatt. 1997. *Contextual design: defining customer-centered systems*. Elsevier.
6. Glenn Blauvelt, Michael Eisenberg, and others. 2006. Computer aided design of mechanical automata: Engineering education for children. In *Proceedings of International Conference on Education and Technology*. 61–66.
7. Paulo Blikstein. 2013. Gears of our childhood: constructionist toolkits, robotics, and physical computing, past and future. In *Proceedings of the 12th international conference on interaction design and children*. ACM, 173–182.
8. Henry T Brown. 1881. *Five Hundred and Seven Mechanical Movements: Embracing All Those which are Most Important in Dynamics, Hydraulics, Hydrostatics, Pneumatics, Steam Engines, Mill and Other Gearing, Presses, Horology, and Miscellaneous Machinery; and Including Many Movements Never Before Published, and Several which Have Only Recently Come Into Use*. Brown & Brown.

9. Alan Bundy. 2007. Computational thinking is pervasive. *Journal of Scientific and Practical Computing* 1, 2 (2007), 67–69.
10. Joan M Chambers, Mike Carbonaro, and Hana Murray. 2008. Developing conceptual understanding of mechanical advantage through the use of Lego robotic technology. *Australasian Journal of Educational Technology* 24, 4 (2008).
11. Pathfinders Design and Technology. 2017 (accessed January 31, 2017). `http://www.pathfindersdesignandtechnology.com`
12. Allison Druin. 1999. Cooperative inquiry: developing new technologies for children with children. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, 592–599.
13. Exploratorium. 2017 (accessed January 31, 2017). `http://tinkering.exploratorium.edu`
14. Ingunn Fjørtoft. 2001. The natural environment as a playground for children: The impact of outdoor play activities in pre-primary school children. *Early childhood education journal* 29, 2 (2001), 111–117.
15. Frank Furedi. 2001. *Paranoid parenting: Abandon your anxieties and be a good parent*. Allen Lane.
16. Cheryl Greenfield. 2004. ‘Can run, play on bikes, jump the zoom slide, and play on the swings‘: exploring the value of outdoor play. *Australian Journal of Early Childhood* 29, 2 (2004), 1–6.
17. Shuchi Grover and Roy Pea. 2013. Computational Thinking in K–12 A Review of the State of the Field. *Educational Researcher* 42, 1 (2013), 38–43.
18. Allyson Fiona Hadwin and Philip H Winne. 2001. CoNoteS2: A software tool for promoting self-regulation. *Educational Research and Evaluation* 7, 2-3 (2001), 313–334.
19. David Hammer, Andrew Elby, Rachel E Scherr, and Edward F Redish. 2005. Resources, framing, and transfer. *Transfer of learning from a modern multidisciplinary perspective* 89 (2005).
20. Yilip Kim and Namje Park. 2012. Development and application of STEAM teaching model based on the Rube Goldberg‘s invention. In *Computer science and its applications*. Springer, 693–698.
21. Lakeshore Learning. 2017 (accessed January 31, 2017). `http://www.lakeshorelearning.com`
22. Helen Little. 2006. Children‘s risk-taking behaviour: Implications for early childhood policy and practice. *International Journal of Early Years Education* 14, 2 (2006), 141–154.
23. Helen Little, Shirley Wyver, and Frances Gibson. 2011. The influence of play context and adult attitudes on young children‘s physical risk-taking during outdoor play. *European Early Childhood Education Research Journal* 19, 1 (2011), 113–131.
24. Peter C Marzio. 1972. Art, Technology and Satire: The Legacy of Rube Goldberg. *Leonardo* (1972), 315–324.
25. Youngme Moon. 2003. Don‘t blame the computer: When self-disclosure moderates the self-serving bias. *Journal of Consumer Psychology* 13, 1-2 (2003), 125–137.
26. 507 movements. 2017 (accessed January 31, 2017). `http://507movements.com/`
27. Debra O‘Connor. 2003. Application sharing in K-12 education: Teaching and learning with Rube Goldberg. *TechTrends* 47, 5 (2003), 6–13.
28. Hyunjoo Oh, Michael Eisenberg, Mark D Gross, and Sherry Hsi. 2015. Paper mechatronics: a design case study for a young medium. In *Proceedings of the 14th International Conference on Interaction Design and Children*. ACM, 371–374.
29. Hyunjoo Oh, Jiffer Harriman, Abhishek Narula, Mark D Gross, Michael Eisenberg, and Sherry Hsi. 2016. Crafting Mechatronic Percussion with Everyday Materials. In *Proceedings of the TEI‘16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 340–348.
30. Seymour Papert. 1980. *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.
31. Noah S Podolefsky, Emily B Moore, and Katherine K Perkins. 2013. Implicit scaffolding in interactive simulations: Design strategies to support multiple educational goals. *arXiv preprint arXiv:1306.6544* (2013).
32. Mitchel Resnick. 2004. Edutainment? No thanks. I prefer playful learning. *Associazione Civita Report on Edutainment* 14 (2004), 1–4.
33. Mitchel Resnick, Robbie Berg, and Michael Eisenberg. 2000. Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. *The Journal of the Learning Sciences* 9, 1 (2000), 7–30.
34. Mitchel Resnick and Brian Silverman. 2005. Some reflections on designing construction kits for kids. In *Proceedings of the 2005 conference on Interaction design and children*. ACM, 117–122.
35. Learning Resources. 2017 (accessed January 31, 2017). `http://www.learningresources.com`
36. Yvonne Rogers. 2006. Moving on from Weiser‘s vision of calm computing: Engaging ubicomp experiences. In *International conference on Ubiquitous computing*. Springer, 404–421.
37. Robert S Siegler, Judy S DeLoache, and Nancy Eisenberg. 2003. *How children develop*. Macmillan.
38. Alison Stephenson. 2003. Physical risk-taking: dangerous or endangered? *Early Years: An International Journal of Research and Development* 23, 1 (2003), 35–43.

39. Ch A Tandy. 1999. Children‘s Diminishing Play Space: a Study of Inter-generational Change in Children‘s Use of their Neighbourhoods. *Australian geographical studies* 37, 2 (1999), 154–164.
40. Deborah Tannen. 1993. *Framing in discourse*. Oxford University Press on Demand.
41. Janneke Van de Pol, Monique Volman, and Jos Beishuizen. 2010. Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review* 22, 3 (2010), 271–296.
42. Official Rube Goldberg Website. 2017 (accessed January 31, 2017). `https://www.rubegoldberg.com/`
43. Jeannette M Wing. 2006. Computational thinking. *Commun. ACM* 49, 3 (2006), 33–35.
44. Jeannette M Wing. 2008. Computational thinking and thinking about computing. *Philosophical transactions of the royal society of London A: mathematical, physical and engineering sciences* 366, 1881 (2008), 3717–3725.
45. David Wood, Jerome S Bruner, and Gail Ross. 1976. The role of tutoring in problem solving. *Journal of child psychology and psychiatry* 17, 2 (1976), 89–100.
46. Oren Zuckerman. 2009. Designing digital objects for learning: lessons from Froebel and Montessori. *International Journal of Arts and Technology* 3, 1 (2009), 124–135.