Digital Outdoor Play: Benefits and Risks from an Interaction Design Perspective

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ABSTRACT

Outdoor play has been proven to be beneficial for children's development. HCI research on Heads-Up Games suggests that the well-known decline in outdoor play can be addressed by adding technology to such activities. However, outdoor play benefits such as social interaction, creative thinking, and physical activity may be compromised when digital features are added. We present the design & implementation of a novel digitally-enhanced outdoor-play prototype. Our evaluation with 48 children revealed that a non-digital version of the novel outdoor play object afforded social play and game invention. Evaluation of the digitally-enhanced version showed reduced collaborative social interaction and reduced creative thinking when compared with baseline. However, we showed that specific sensing and feedback features better supported outdoor play benefits. For example non-accumulated feedback was shown to increase collaborative play and creative thinking in comparison to accumulated feedback. We provide evidence-based recommendations for designers of outdoor play technologies.

ACM Classification Keywords

(H: .5.1)Multimedia Information Systems (e.g. HCI)

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Outdoor Play; Head Up Games; Transparent Technology; Interaction Design.

INTRODUCTION

Outdoor play is known to positively influence children's development [1]. Three important benefits of outdoor play are social interaction, creative thinking, and physical activity [9, 12]. By playing outdoors in groups or teams, children engage in social interaction both by competing and collaborating, developing empathy, and increasing their social competence accordingly [1, 9, 18, 24, 31, 39]. When considering the distinction between competition and collaboration, researchers attributed different values to each. Competitive games were shown to have both positive and negative effects, depending on the child's personal characteristics. For some children, competition leads to strong individual motivation, while for children who feel less competent, it may have an opposite effect [29, 54]. Collaborative games require working towards a common goal and were shown to have an important role in the development of social skills [29]. Collaboration in outdoor games also influences creative thinking [4, 22, 52]. Games such as chase and flee, ball play, and imaginative outdoor games represent the open-ended unstructured nature of outdoor activities. An open-ended environment setting is conducive to creative thinking [6, 12]. Physical activity is another well-known benefit of outdoor play and is associated with improved health, cognition, emotional regulation and well-being [13, 46, 50]. Taken together, social interaction, creative thinking, and physical activity are well-documented benefits of outdoor play. Moreover, these benefits are of special importance as they play a major role in the development of adult-life skills, such as social competence and problem solving [39].

Compared with children in the 1970's, children today spend 50% less time in unstructured outdoor activities [26]. Time spent with technology is [49] overtaking time previously spent playing outdoors [30, 45]. This could be attributed to the ambient, easily accessible nature of technology [40]. The implications of the well-known decrease in outdoor play range from lack of physical activity [30] to negative consequences on children's social skills and social life [19].

In light of these concerns, the HCI community has shown a growing interest in addressing the decline in outdoor play. Leading research in this domain includes Exertion games, Pervasive games, and Head Up Games. Embedding elements of social interaction and physical activity in technology-enhanced outdoor play is considered a key factor in addressing the decrease in outdoor play [48]. Having said that, certain outdoor technologies may capture children's attention and change natural outdoor play patterns [47].

To summarize, outdoor play is clearly a desired, healthy activity with many well-documented benefits, and yet, in recent decades, outdoor play has consistently decreased. To address these issues, HCI researchers have presented prototypes and studies of technologically-enhanced outdoor games, specifically within the Pervasive games and Head Up Games communities. At the same time, there is a rising concern that technology may have a negative impact on natural outdoor play patterns, to a point that the well-known benefits of outdoor play may be compromised.

RELATED WORK

The HCI community has proposed several approaches for enhancing outdoor play with technology [3, 34]. Most related to our work are Pervasive games and Head Up Games (HUG) [48]. Pervasive games merge physical and digital experiences, while HUG are technology-based outdoor play activities designed to make minimal use of screens, hence the "Heads Up" definition. Our work lies within the HUG domain.

Pervasive Games

Pervasive games take gaming away from the computer screen and back into the real world [38]. Within Pervasive games, designers leverage technologies to create new and exciting gaming experiences that merge physical and virtual game elements [32]. Including sensors in games has led designers to develop multi-player technologies [32] that require physical effort. Research in the field of Pervasive games also emphasizes the potential of changing players' traditional perceptions that games are confined to certain spaces, times, and players [38]. Notable example of Pervasive games are: "Joust", a set of baton-shaped controllers, designed to augment social interaction in the physical world. In Joust, players compete against each other to the sound of Bach music, by keeping their controller still. The first to move the controller, loses [58]. Another example is PacMap, a location-based variant of the classical game PacMan, in which players need to avoid enemies and collect reward in the physical world, with streets and roads as the game map [11].

Heads Up Games

Pervasive games commonly involve screens and hand-held devices that may interfere with natural play patterns [37] and are thought to compromise the known benefits of natural play [48]. To address these concerns, Markopoplus & Soute pioneered a sub-category of Pervasive games coined Head Up Games [47]. HUG principles promote outdoor social interaction with the support of digital devices while keeping the player's head "up" for natural outdoor navigation and interaction. These principles are evident in the Camelot project [55]. Camelot is a screenless outdoor game device for children. Children collect virtual resources to earn construction materials for building a physical castle. The resources are collected with the help of a dedicated physical device that consists of Infrared (IR) detectors and IR LEDs. In a qualitative study, the authors found that children communicated, debated, and cheered on one another as they collaborated towards a common goal, thus gaining the benefits of social interaction.

Another aspect of outdoor play addressed by HUG is children's tendency to change rules and to create new games [23]. Rule generation is considered a significant feature of creative thinking [10]. Soute et al. developed RaPIDO, a sensor-based prototype, and GameBaker, an accompanying platform for rule changing [2]. By changing parameters such as buzzing duration and the number of participating teams, children could create various outdoor games for RaPIDO, based on their own ideas. The authors reported that children were interested in making their own rules. Hitron et al.'s preliminary work extended this approach by designing a Scratch-based coding platform for children to change rules in outdoor play. Their prototype enabled children to control events and define thresholds, thus creating their own local game experiences [21].

Some HUG games were compared with non-digital play activities. Stop The Bomb [20], a sensor-enabled belt with vibration motors indicates the location of 'bombs'- electronically enhanced cardboards. Two different versions of the prototype were designed and compared: a "paper" version using cardboard box , and a "digital" version that uses LEDs and vibration motors. The researchers showed that in comparison to a non-digital version of the game (different in design but similar in functionality), levels of physical activity and social interaction were not compromised by technology.

Another study presenting a comparison of digital and non-digital outdoor play is the Lighthouse project. In the Lighthouse game [5], children play as pirates, trying to collect gold coins while avoiding digital obstacles. The authors used the OPOS observational method [5] and reported that the game increased social interaction as compared to a standard soccer game, but decreased social interaction relative to a traditional game of tag. Overall, these comparisons of HUG to non-digital outdoor play activities imply that the influence of technology on outdoor play benefits is not clear cut.

Transparent Technology & Outdoor Play

According to design guidelines presented by HUG researchers, technology should be reliable and simple, so that its usage becomes transparent [47]. A transparent interaction with technology corresponds with a larger framework of Ubiquitous Computing. In his seminal work, Mark Weiser argued that ubiquitous technologies should be "transparent" [57], i.e., "weave themselves into the fabric of everyday life". Ishii designed the Bottles prototype as a tribute to Weiser, clarifying that Transparent Technology leverages affordances and metaphors of existing objects [25]. Moreover, Rogers argues that designers should "engage people more actively with what they currently do" [43]. These aspects of Transparent Technology support Marazano's (2006) indication that transparent integration of technology in everyday life may result in future products that are more similar to products of the past [35]. In the context of outdoor play, Transparent Technology means that new technology should be inspired by and based on an existing outdoor play object, which is commonly used by children outdoors [47]. Several researchers have presented prototypes that embed technology in traditional outdoor play objects [7]. Swinxsbee is a computational Frisbee-like object that children use to play a digital version of Ultimate Frisbee; Feedball is a digital ball developed to improve children's soccer performance. Another notable example that inspired our work is the BitBall [42], a silicone-covered electronic-shaped ball that includes an accelerometer and colored LEDs. The BitBall has the affordance of a traditional outdoor play object (i.e., a ball), while also being enhanced with digital feedback, changing the color of the internal LED in accordance with the BitBall's acceleration.

Our Approach

We strongly affiliate with the pioneering work of the "Transparent Technologies" school of thought and wish to apply it to outdoor play, extending HUG to what Rogers recently coined as a "Heads Up Arms Out" interaction [44]. We initiated our design process with objects such as sticks and stones, which are commonly used by children and are readily available in outdoor environments [27], with an emphasis on objects that afford basic outdoor play activities such as throwing and catching. We hoped such a design process would lead to play patterns that are analogous to those of traditional outdoor games.

Digitally enhancing outdoor play is both a design challenge and a behavioral challenge. While the HCI community addresses the decline in outdoor play through a range of prototypes, limited research exists comparing digital and non-digital play patterns. Therefore, comparisons between identical versions of the exact same play object are needed to better understand technology's influence on outdoor play benefits.

Towards this end, we extend Hitron et al.'s preliminary work [21] by presenting a design process, implementation, and experimental study of a digitally-enhanced outdoor play prototype, reminiscent of a stick. Our design followed the "Transparent Technology" and "Engaging Ubicomp" approaches. Unlike Hitron et al. [21], our focus in this study was on the influence of the digital aspects of the prototype and not on the effect of programming. Hence, a Scratch-based coding platform, which controlled the prototype's behavior, was used by our research team and not by the children. In Study 1(a), we report a design validation study. In Study 1(b), we present an

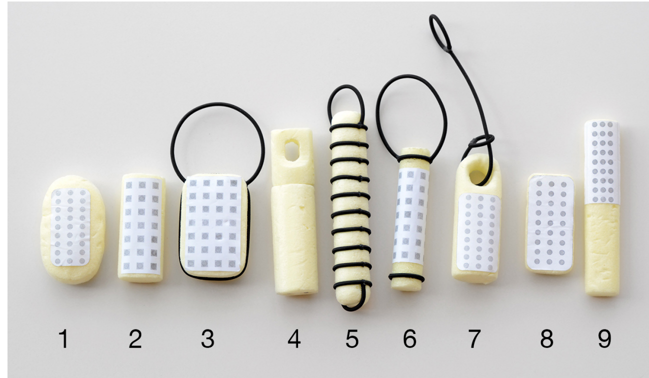

Figure 1. Selection of foam prototypes used in the design research process.

Figure 2. Selection of 3D printed prototypes inspired by the shape of a "stick" and tested for robustness.

experimental study comparing digital and non-digital versions of our outdoor play object (baseline). To better understand the digital impact on play patterns we further compare between core interaction design aspects (sensing events and user feedback) to evaluate the implications they haŒŠ on known outdoor play benefits.

DESIGN AND IMPLEMENTATION

Building on outdoor play literature, extending Hitron et al.'s [21] preliminary work, and following the "Transparent Technologies" school of thought, we defined the following design principles for a new digitally-enhanced outdoor play object (Scratch Nodes): (1) The design should afford throwing and catching; (2) The design should afford social interaction between children; (3) The design should be robust and afford intense physical usage, meaning that children should feel comfortable throwing it on the ground or to extreme heights; (4) The design should promote the generation of outdoor games that resemble traditional outdoor play.

Our design process started with a set of low-fidelity prototypes in which we evaluated children's reactions and associations in response to the form of the object. We then continued with the hardware implementation and design of the high-fidelity prototype. We focused on details of shape, material, and inner structure, designed to support the electronic components.

Low Fidelity Prototype

We started with a form study using foam as the prototyping material, to quickly generate a wide range of shapes and evaluate children's reactions to them (see Figure 1). The foam-based prototypes varied in size and shape. Some had a rubber string for holding or connecting to the body or other objects, and some had a hole. We made sure to include a variety of forms. Some resembled well-known outdoor play objects such as balls or sticks, some resembled day-to-day objects like a flashlight or a key chain, and some had no direct associations. All forms afforded different holding options.

We tested the various forms in a short exploratory evaluation with six children aged 8-12, divided into two groups (similar to previous design evaluation with children) [20, 33]. We placed the various forms on a tray and presented them to the children, asking them to describe their functions. We then asked them specifically which form they thought was more appropriate for outdoor play and asked them to demonstrate how they would use it.

Children had clear preferences for some of the forms while ignoring others. Some picked up the string-enabled form (see object 7 in Figure 1), wrapped it around their hand and tried to spin it. Others used the ball or rock-based forms, but then determined it "looks like a soap bar" and lost interest. The form that garnered the most interest was the stick-shaped foam (see object 9 in Figure 1). Children described it as a stick and said it was easy to grab and throw. When they used it, many tried to flip it by throwing and catching, much like throwing a stick in the air. One boy demonstrated running with the stick, repeatedly swinging his hand: "This could be used in running contests, like relay races". One girl had a different association, singing while holding the form like a microphone.

Our conclusion from the low-fidelity prototype testing was that the stick-like form was the most relevant. Children associated it with an outdoor play object, naturally suitable for throwing and catching.

High Fidelity Prototype

Following the insights gathered from the low-fidelity prototype testing, we initiated a detailed design process. This process included three main parts: (1) Designing inner and outer cases, informed by the low-fidelity prototype testing, suitable for outdoor play; (2) Enhancing the Nodes with digital sensing and feedback using custom-designed hardware; (3) Developing a software research platform for controlling the devices.

Outer and Inner Case

Through experimentation, we reached a design of an inner and outer Nodes case. This mix creates a very robust design that also feels solid and sealed, while enabling the pulling out of the inner case and exposing the electronics. For the outer case, we experimented with many possible shapes and styles, starting from the stick-inspired shape of the foam prototype and extending it in various ways (See Figure 2). Our main focus was on the affordance and the robustness of the object. We tested robustness outdoors by throwing the case high in the air and letting it fall on the ground, until we reached a model that did not easily break. Material wise, we used 3D printing

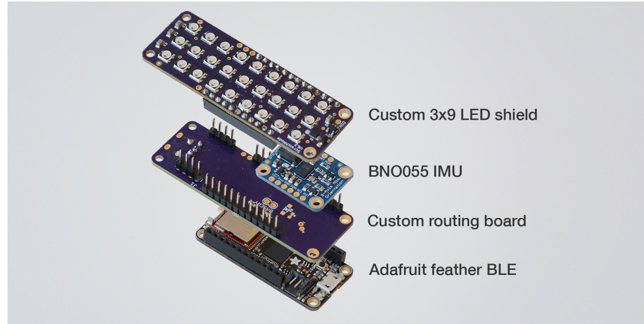

Figure 3. Hardware components stacked together using two custom PCBs to produce a minimal footprint.

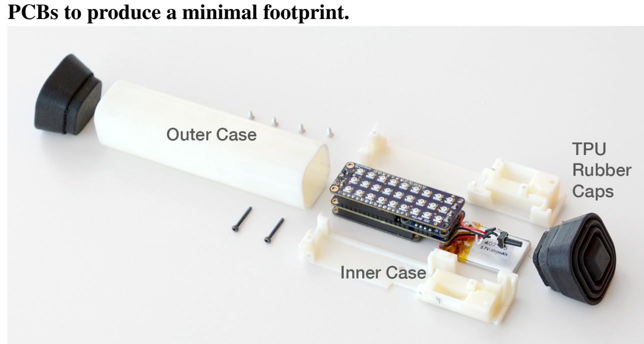

Figure 4. Outer case, inner case, and rubber caps that enable shock absorption when the device sustains a strong hit.

and experimented with several types of plastic. We learned that by using soft rubber caps that are slightly wider than the case design on both ends of the form (see Figure 4), the Node could be protected, as the caps absorb the hit. We built an inner case to prevent any movement of the electronic boards and other components by holding them securely in place. The Node's inner case was composed of two parts (see Figure 4) that hold the electronic boards, battery and push button. At the same time, it exposes the circuits to enable exploration and shows annotations such as on/off for the switch and Bluetooth indicator light.

The inner case can be pulled out from the outer case, exposing the electronics and the LED display. This enables easy debugging & charging, and allows children to freely explore the electronics. This combination created a solid 16cm long and 3.2cm wide water resistant case that affords intensive usage while still revealing the inner circuits.

Hardware Implementation

With the aim of digitally enhancing the Nodes, we constructed a flexible, small footprint hardware device that includes sensors and feedback - an Inertial Measurement Unit (IMU), push button and LED display (see Figure 3). The LED display is a 3x9 LED array, designed with an Abacus metaphor in mind. Each line of nine LEDs can represent singles, tens, or hundreds, so lights can represent numbers from 1 to 999.

As a control board, we used Adafruit Feather BLE board (a small footprint Arduino clone with BLE connectivity). For sensors we used a BNO055 IMU and a momentary push button. We fabricated a custom 3x9 RGB LED shield design based on the Adafruit Neopixel Featherwing, and a custom board for routing the different component signals, allowing a clean, stackable design. (See appendix for schematics and layout.) We placed surface-mount components and stacked the boards using low footprint 0.1” pitch, 5.0mm tall headers to enable a modular design. The custom routing board routes all signals to the matching Feather pins and houses the power switch. The IMU is placed on top of the routing board, in-between layers to minimize footprint. The push button, and a 3.7V LiPo battery with a mounted power switch are connected to the board by wires and held in place by the inner case (see Figure 3).

Platform & Firmware Implementation
We set out to implement a coding platform for our research team, to enable easy coding of the Scratch Node devices during the various prototype research stages. The platform is based on an Android tablet device that communicates with the Node devices. We implemented a flexible architecture that allows non-coders to modify the program in two ways: (1) Modify blocks and define their behavior using Blockly’s JSON syntax, without writing any code. (2) Creating simple use cases for user testing with a limited set of visual blocks, utilizing Blockly’s ability to load Toolbox and Workspace configuration from an xml. This way, each researcher could program, save, and load various use cases at any given user study, without the limitation of recompiling the code.

We implemented a compact visual block-based programming language inspired by Scratch 3.0. Our implementation included a minimal virtual machine (VM) for Android-based tablets. Our system is comprised of three modules (see Figure 5): the Code Generator (based on Google Blockly, the underlying technology of Scratch 3.0); the minimal Java-based VM; and the Java-based transport layer (implemented as a star topology pub/sub). The architecture we chose to implement follows a "dumb device, smart tablet" approach, transferring as much computation as possible from the Nodes to the tablet, as memory and computing power are limited on the devices. The three modules interact in the following way: the Code Generator translates the visual blocks into Java-based code snippets. The code snippets are processed by the minimal VM and converted to a set of events. The transport layer sends the events to the Nodes via Bluetooth Low Energy (BLE). A listening service (firmware on the Arduino) runs on the Nodes hardware with a set of predefined behaviors, such as acceleration threshold. The Nodes receive the event parameters and when an event occurs, the appropriate data is sent back to the VM through the Transport Layer. The VM evaluates the code or data and selects the appropriate action for each of the Nodes. The action data is sent back to the Nodes through the Transport Layer: e.g., "Set Node ID to X", "Set LED display to X points", "Set threshold to X".

The code primitives
We implemented three Events and two Feedback primitives, which together can generate the use cases needed for our research. Event 1: When Shake. Triggered when acceleration value exceeds a predefined threshold set using the blocks. Event 2: When Throw. Triggered when acceleration value exceeds a predefined threshold and automatically starts a timer. This results in measurement of the "Air Time" of a Node

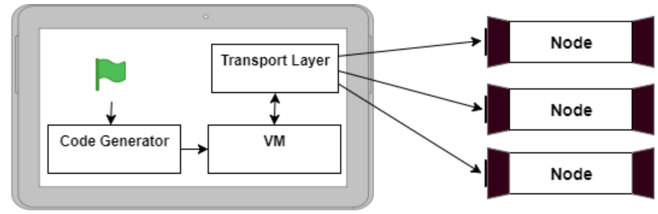

Figure 5. System diagram, represents communication flow between the tablet software modules and the Node devices.

device. Feedback 1: Set LED count. Sets an LED on or off, user can set a positive or negative integer to be added or subtracted from the LED Abacus display. Feedback 2: Set LED animation. Sets one of four possible LED animation effects. For example a "wave" animation of lights moving up and down along the display.

Example use-cases
We utilized Blockly’s code generation ability to create "use cases" using the code primitives. Each use case consists of an event primitive and a feedback primitive.

Use case 1: When Shake, play an animation on the LED display of the Node. Use case 2: When Thrown, increase the LED count by one light every second.

USER STUDY
The challenge in digital enhancements of outdoor play is both a design & behavior challenge. We conducted a study including two phases: 1(a) and 1(b). In Study 1(a), we set out to evaluate the Nodes’ design, and in Study 1(b) we tested the influence of digital-enhancement on outdoor play benefits.

User Study 1(a): Design Validation
In this study we tested whether the affordance of the design promotes traditional outdoor play patterns, like throwing and catching, social activities, and game generation. Hence, we used the design principles as validation criteria.

Method
Participants
The participants were 48 children, 26 girls and 22 boys, divided into 16 groups of 3. The children’s ages were 8-12. Prior acquaintance between the group members was a requirement, ensuring natural social interaction. Participants were recruited from two sources: personal acquaintance with the researchers (and their friends), and participants of the Scratch Day activity. In both cases, children’s parents were contacted via email inviting the children to participate in a study testing a new game. As compensation, children received a guided tour at the research lab during the day of the study. We followed ethics guidelines including IRB, parental consents, children consent, and parental approval for pictures and videos. In addition, we followed Read’s (2015) guidelines for research with children.

Procedure
The sessions were conducted in three play areas sharing similar characteristics, pre-defined by the researchers: a play area of approximately 450 square meters marked by a red-white ribbon to encourage children to explore the field but at the same time keep them in sight of the researchers. The play areas

were grass-covered to reduce safety concerns and not limited by major constraints to enable running and jumping freely. All sessions were documented by a video camera and all children wore small wireless microphones for clear audio recording. In each session, three children arrived at the play area and were informed of the play area border. Then, they were asked to perform light physical activities with the microphones to verify ease of movement. To evaluate the design as a traditional outdoor play object, we switched the device off so the children could experience it without the digital features, merely as a non-digital play object. All sessions were 10 minutes long.

At the beginning of each session, a researcher presented the device to participants, naming it a "stick" to prevent associations to a digital device: "This is a stick which was 3D-printed in our lab and you can play with it here in this play area". The researcher handed one stick to each child, one after the other. Children were instructed as follows: "feel it, touch it, you have 10 minutes to play with it." No further instructions were given, in order to observe the children's intuitive interaction with the design. Two groups (six children) were disqualified due to technical errors with the video equipment (not included in the 48 participating children).

FINDINGS

Video data analysis was performed by two researchers, starting with initial coding and followed by thematics analysis of all videos.

A small sample of the videos was analyzed by one researcher, who identified meaningful events related to the design principles: how children used the device in the first interaction; how they used it individually vs. socially; whether there was any evidence of intense physical usage of the device; and did children invent their own games. Following this initial analysis, both researchers discussed the various events identified, and selected a subset of events to be coded from all videos. The list of events defined for coding were:

- Distinct events of "individual throw" and "individual catch" of the device. For example, flipping the device in the air. In accordance with the "Individual throw and catch" design principle.
- Distinct events of social interaction between the children that include the device in a play activity. For example, throwing the device to a friend. In accordance with the "Social interaction" design principle.
- Distinct events of intense physical usage with the device. For example, throwing it very high or powerfully on the ground. In accordance with the "Intensive physical usage" design principle.
- Distinct events in which children invent their own games that involve the device. In accordance with the "Game generation" principle.

Following this definition of events, both researchers analyzed four videos to establish reliability, resolved any disagreements, and then proceeded to analyze all 16 videos. Results are presented below.

Figure 6. Children performing "Throw" and "Catch" activities with the Nodes.

Design Principle	Observed Play Activity	Number of observation
Individual Throwing and catching	Throw on first interaction	24/48
Individual Throwing and catching	"Throw and Catch"	42/48
Social Play	Couple "Throw and "Catch"	18/48
Social Play	Triple "Throw and Catch"	24/48
Intensive physical usage	Physical Intensive Interaction with the Node	39/48
Game generation	Inventing games and rules for a traditional game	45/48

Table 1. Study findings showing design principles and the number of children performing related activities.

Individual "Throw" and "Catch"

On first interaction with the non-digital Nodes (up to 10 seconds), half of the children (24/48) performed individual throw and catch activity, exploring the capabilities of the device. During the whole 10-minute session, the vast majority of children performed an individual throw and catch activity (42/48). The most common activity was flipping the device in the air several times.

Social Interaction

A common play pattern was a shift from an initial individual exploration activity to a group activity, after about two minutes of exploration. Half of the children engaged in a social "Throw" and "Catch" game with three devices (24/48): While standing in a circle, all three tossed their devices simultaneously to the person on their right. Another play pattern was playing in pairs (18/48), both throwing their devices simultaneously from one to the other, while the third participant engaged in individual play. Some groups further developed social throw and catch games: adding levels (one device, two devices etc.), scores and time limit.

Intense Physical Usage
A majority of the children (39/48) performed intensive physical usage with the device. Common play patterns included: throwing the device high in the air and letting it fall to the ground; deliberately throwing the device to the ground, with some adding a time limit and trying to hit the ground as fast as possible. Children felt comfortable with the device's robustness and did not hesitate slamming it.

Game Generation
A vast majority of children engaged in game generation (45/48), either by adapting rules of traditional games or inventing new ones. We classified the invented games into categories:

Invented game type I: Role play. Children used the Nodes to perform a wide range of role play activities: sword battles, fencing duels, a bat as in a baseball game, a microphone, or a dance accessory.

Invented game type II: Traditional games. Children used the device to invent adapted versions of traditional outdoor games: playing tag using the device as an extension of their hand to tag someone; playing "Monkey in the Middle" by passing the stick between two players trying to avoid the third player from catching it; holding a relay race with the three devices;

Invented game type III: Challenges (both individual and social). Children invented physical tasks, challenging themselves and their friends: continuously juggling the device without dropping it; continuously flipping the device towards the ground trying to make it stand vertically on one edge (calling it "Bottle Flip"); cartwheels with the device in their hand; complex throwing and catching (e.g., behind the shoulder, between the legs).

To conclude, these results validate our design principles, as children used the non-digital Nodes as a traditional outdoor play object. Our design led to play patterns that corresponded with natural outdoor play. In the following second phase of the study we added the digitally-enhanced aspects to the Nodes and evaluated the influences of sensing and feedback on outdoor play benefits.

User Study 1(b)

In this second phase of the Study, we added digitally-enhanced aspects to the Nodes and evaluated their influence on known outdoor play benefits. Sensing events and types of feedback were added to the Nodes, creating a digitally-enhanced outdoor play object. Sensing and user feedback were chosen as they are core characteristics of interaction design. We defined two types of sensing events and two types of user feedback. The sensing events were Shake vs. Throw and the types of user feedback were Accumulated feedback (Score) vs. Non-accumulated feedback (Animation). Together, the digitally-enhanced aspects formed four conditions (See Table 1). The dependent measures were the known outdoor

Sensing / Feedback	Throw	Shake
Score	Accumulated Score on Throw event	Accumulated Score on Shake event
Animation	Non accumulated Animation on Throw event	Non accumulated Animation on Shake event

Table 2. Experimental design layout, comparing two types of sensing events and two types of feedback.

play benefits reported in the literature: Social interaction, Creative thinking, and Physical activity. As outdoor benefits are known to be easily compromised, we conducted two types of comparisons: We started with a high-level comparison between all digitally enhanced conditions (grouped together for simplification) to a baseline condition. For the baseline, we utilized the data from the non-digital condition in Study 1(a), in which outdoor play benefits were evident. Following this high-level comparison, we conducted a more detailed comparison focusing on aspects that are useful for interaction designers: the two types of sensing events and the two types of feedback in a 2X2 experimental design. Feedback types were chosen based on previous literature, which indicated the profound impact of feedback on children's behavior [7, 31]. Accumulated Feedback represents a "score", and was shown (in non-children context) to shift social interaction toward competition rather than collaboration [36] and to increase physical activity [53, 59]. Accumulated score feedback is also often referred to as a reward [15, 56]. Rewards have been shown to compromise creative thinking in children's activities [29, 31]. These studies suggest that Accumulated Score feedback may influence children's outdoor play activities and as a result may hinder some of the outdoor play benefits. For the second type of feedback, we looked for a non-accumulated feedback, which would have lower chances of being associated with score. Based on the technical features available in our system, we defined this feedback as an "animation", an LED animation effect presented on the device 3X9 LED board. Animation feedback may be considered open-ended as it doesn't apply to specific rules and children can contextualize it with different meanings [14]. Such open-end feedback was referred by Segura et al. as qualitative, enabling the user to appropriate the technology and games [34]. Open-ended play is considered to encourage creative thinking by leaving room for players' interpretation. Collaborative social interaction is also associated with open-ended play but experimental evidence is inconclusive [8].

Sensing events were chosen based on the "Transparent Technology" approach and the observations from an earlier user testing, as prior literature on this subject was hard to find. We focused on sensing events that were observed in the user testing sessions conducted during our design process. "Throw" gestures were the most common gestures children performed intuitively when using the device for the first time. In the same way, "Shake" gestures were also performed intuitively, but much less frequently. Following the "Transparent Technology" school of thought, we assumed Throw is a more natural gesture for this specific design and Shake is a less natural one, and decided to compare between them and validate their different effects on outdoor play benefits.

Method

Participants

As this was the second phase of the study, the participants were the same participants as in study 1(a).

Procedure

Each group of children participated in two conditions, the baseline condition in Study 1(a) and one of the digitally enhanced conditions in Study 1(b). The digitally enhanced condition followed the baseline condition. The duration of each condition was 10 minutes with a short break in between. Children were informed that the non-digital device they had just used also had digitally-enhanced features, including a movement sensor and an LED display. The instructions given to each group of children were:

- "Shake" sensing condition: Children were informed that whenever they shook the device hard enough, it would trigger digital feedback.
- "Throw" sensing condition: Children were informed that whenever they threw the device in the air for a sufficient amount of time, it would trigger digital feedback.
- Accumulated Score feedback condition: For each event, one light would appear on the LED display according to the Abacus metaphor, lights representing numbers from 1 to 999.
- Non-accumulated Animation feedback condition: For each event, an effect of moving colored lights would appear on the display, forming an animation.

The interaction was demonstrated, and children were instructed to play freely with the device in the play area without any further instructions. All sessions were videotaped and audio was recorded using the individual wireless microphones. An observer took notes and reported qualitative impression. The observer used a form to describe their impression based on a list of guiding questions: "What types of games do the children create?" "Do they look interested in the game?" "What kind of interaction do they initiate?" "Do they play by themselves or with the group members?" The observer produced a written report for each session.

Figure 7. The Scratch-based research platform used to select an animation feedback in one of the Nodes devices.

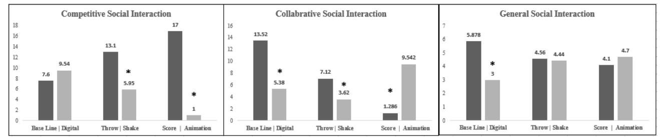

Figure 8. Difference between baseline & digitally-enhanced conditions; Throw and Shake; Score and Animation; Effects on three social interaction measures; Competitive(left), Collaborative(Right), General(Down)

FINDINGS

Videos from the 16 sessions were coded per participant, using the "Boris Observer", an open-source event-logging software [17]. Social interaction and Physical activity events were coded according to the OPOS scheme. We further coded Social interaction as one of three categories: competitive (coded according to Tsiakara and Digelidis [51]; collaborative (coded according to Parten's [41]; or general (non-competitive or non-collaborative). Social interaction was coded by event sampling and physical activity by time sampling. Creative thinking was measured by rule generation, a known indicator of creativity [10, 16, 28]. Rule generation was coded by counting the number of events in which children generated a new game rule. We followed the OPOS scheme guidelines for intercoder reliability [5]: a primary coder coded all videos; a second coder coded 25% of the videos independently, and compared the coding with the first coder. Pearson correlation analysis indicated the following intercoder reliability: Social Interaction R=0.779; Rules R=0.852; Physical activity R=0.883.

We performed two quantitative analyses for every dependent measure. A 1-way-ANOVA tested the mere effect of digitally enhancing the Nodes. We compared the difference between playing with the non-digital Nodes (baseline) to playing with the digitally-enhanced conditions (grouped together for simplification). In the second analysis, we performed a 2-way-ANOVA comparing the different types of sensing and feedback (See Table 2). In addition, we analyzed the qualitative data and identified a set of prototypical examples for each condition. In the following section, we present each dependent measure with quantitative analysis and prototypical qualitative examples.

Social Interaction

We present findings for social interaction activity classified into three categories: competitive play, collaborative play and general social interaction (non-competitive, non-collaborative).

Competitive Social Interaction (see Figure 8 Left)

Comparing the digitally-enhanced conditions to baseline, Competitive social interaction was preserved (F<1). Further analysis of the different sensing events and user feedback revealed more complex patterns. With regards to sensing events, Throw event significantly increased Competitive social interaction compared with Shake event ($F(1,44) = 7.606$ $p<0.05$). With regards to feedback types, Accumulated Score significantly increased Competitive social interaction compared with Non-accumulated Animation ($F(1,44) = 36.34$ $p<0.05$).

Qualitative insights: The Accumulated Score seemed to have a drastic influence on children's play patterns. Even though no specific instructions were given regarding a game objective, children in the Accumulated Score condition immediately treated it as an implicit goal, and associated it with contests. Children repeatedly shouted their score to each other, competing towards reaching a higher score. For example: Shirley, a 9-year-old girl, responded to her friend asking about the purpose of the game: "The purpose is to get as many points as you can."

Collaborative Social Interaction (see Figure 8 Right)

Comparing the digitally-enhanced conditions to baseline indicated a decrease in Collaborative social interaction (F(1,47)=34.846, p=0). Further analysis of the different sensing events and user feedback revealed that Throw events significantly increased collaborative play as compared with Shake events (F(1,44) = 7.606 p<0.05), and the Non-accumulated Animation feedback significantly increased Collaborative social interaction compared with Accumulated Score feedback (F(1,44) = 36.34 p<0.05).

Qualitative insights: The Non-accumulative Animation feedback seemed to encourage children to invent a common goal and play together, usually trying to trigger an animation. Children collaborated by throwing and catching the Nodes between each other, usually trying to trigger multiple animations. They also used the Nodes as an accessory in a collaborative dance, or in team games. For example: Daniel and Ben, two 10-year-old boys, played together: "Go far, I am going to throw it to you, this will make the animation stay for a longer time".

General Social Interaction (see Figure 8 Down)

Comparing the digitally-enhanced conditions to the baseline condition, General Social interaction was preserved (F<1). Further analysis of the different sensing events and user feedback revealed no difference between the two sensing events (F<1). However, the Non-accumulated Animation significantly increased General Social Interaction compared with Accumulated Score (F(1,44) = 5.87 P<0.05).

Qualitative insights: Children in the Non-accumulated Animation condition were generally more attentive to their friends. Children commonly approached each other and presented their devices' animations. For example, Ron, a 10-year-old boy, turned to his friend saying: "Come watch the colors, let's try to count the number of colors".

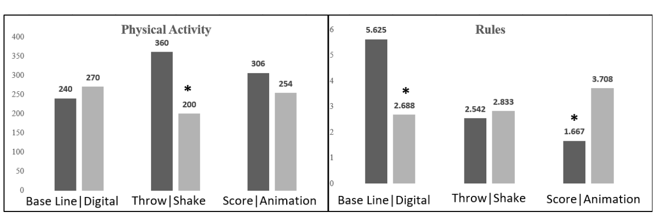

Figure 9. Difference between baseline & digitally-enhanced conditions; Throw and Shake; Score and Animation; Effects on Rule generation (Left) and Physical activity (Right).

Creative Thinking (Rule Generation) (see Figure 9 Left)

Creative thinking was measured by the number of rules each child generated while playing with the Nodes. Comparing the digitally-enhanced conditions to baseline revealed a decrease in the amount of rules generated (F(1,47) = 26.8 P<0.05). Further analysis of the different sensing events and user feedback revealed no difference between the sensing events (F<1). However, the Non-accumulated Animation significantly increased rule generation compared with Accumulated Score feedback (F(1,44) = 15.882 P<0.05) .

Qualitative insights: Children in the Non-accumulated Animation condition used the Nodes in creative ways. They added custom rules to traditional games by including the Nodes as an integral part of the game. For example, children used the Nodes to play a custom version of "Hide and Seek": one child hid one of the Nodes while the others searched for it by looking for the lights of the Animation feedback. Another common example was when children used the Nodes in role playing activities like sword fighting, acting out scenes from "Star Wars" with the Nodes as "Lightsabers".

Physical Activity (see Figure 9 Right)

According to the OPOS scheme [5] we analyzed the time children spent in intense and light physical activity and grouped them together to "general physical activity". Comparing the digitally-enhanced conditions to the baseline condition revealed that time spent in General Physical Activity was not compromised (n.s). Further analysis of the different sensing events and user feedback revealed that Throw events led to significantly longer periods of physical activity compared with Shake events (F(1,44) = 9.542 P<0.05). No effect was found for user feedback (n.s).

Qualitative insights: Children in the Throw sensing event condition engaged in various physical activities. One of the most common activities was throwing the device in the air in an effort to trigger digital feedback. For example, Gil, an 11-year-old boy in the Throw condition, threw the Node as far as he could many times to get all the points. In comparison, children in the Shake condition were significantly less active. A recurrent activity in this condition was standing in a circle, repeatedly shaking the Node to get as many points as they could.

DISCUSSION

Study 1(a) validated our design principles. Without any specific instructions or encouragement, the non-digital Node afforded a variety of traditional outdoor play patterns. Children engaged in individual "Throw" and "Catch" activities, in social interaction while throwing the Nodes to one another, in intense physical usage as they threw the Nodes high in the air or let them fall on the ground, and in game generation as they invented a wide variety of games using the Nodes. These findings validated the affordances of the non-digital Node as an outdoor play object.

In Study 1(b) the comparison between the digitally-enhanced conditions to a baseline condition indicated the fragility of outdoor play benefits. Collaborative Social interaction and rule generation were compromised, while competitive Social interaction, and Physical activity were preserved. Looking into the influence of different sensing events and types of feedback revealed varied impact on outdoor play benefits. The feedback types comparison showed that Animation feedback increased collaborative play, general social interaction, and creative thinking. This could be attributed to the open-ended characteristics of the Animation feedback [8]. In addition, Score feedback drastically increased competitive social interaction. It is possible that by its goal-oriented nature, children treated it as a reward and it affected their motivation to succeed [36]. In the sensing events comparison, Throw events increased Physical activity as well as Social interaction (both competitive and collaborative play). We believe that the Throw sensing event was superior in the context of outdoor play benefits, as it was more natural for children in that specific context, as observed in the baseline condition.

More broadly, our studies revealed that:

- Children love to engage in open-ended outdoor play, and properly designed objects can help: When the 48 children played with the non-digital Nodes, they immediately challenged themselves, improvised, and created new games and rules. The non-digital play object weaved successfully into their natural play patterns. Without explanations or instructions, children used it in a variety of physical ways, led by the affordances of the object and their natural motivation to play, socialize, and challenge themselves.

- Outdoor play & Technology, a love/hate relationship: Outdoor play is in decline, and its benefits are easily compromised. Technology is a powerful tool that can motivate children to engage in social interaction and physical activity outdoors. Having said that, integrating technology into outdoor play experiences should be done wisely. Our study showed that children "followed the lead" of the technology. The integration of technology had a profound influence on children's play choices. In contrast to the non-digital baseline condition, where children were in command and led the activity, children in the digitally-enhanced conditions showed a different mindset. They were extremely engaged, but in understanding "how to win" and how to uncover the "hidden" goal, then striving to achieve that goal. Technology designers set implicit rules through their designs and greater care should be given to the impact these implicit rules have on sensitive outdoor play benefits.

- Digital feedback is captivating but can backfire: Our study clearly showed that Accumulated feedback was immediately perceived by children as a score, and converted any activity into a goal-based activity with one rule only: collect all the "points". The effect of this "score" was so profound that in some cases children played while sitting, shaking their devices continuously in an effort to "collect" more points than their friends. In contrast, the non-accumulated animation served as an open-ended feedback that empowered children to attach their own meaning to the activity. Children collaborated more, competed less, and invented rules in creative ways. Therefore, interaction designers should carefully select digital feedback while considering its potential outcomes. Accumulated feedback is highly engaging and should be used only when its implications are carefully considered; Non-accumulated feedback is open-ended and promotes outdoor play benefits, specifically: collaboration and creative thinking.

- "Transparent" sensing: In accordance with the "Transparent Technologies" school of thought, sensing events in outdoor play technologies should "match what children already do". This implies that technology should be seamlessly integrated into children's play activities. In our case, throw and shake events led to different results. Throw, which was based on "what children already do" with a Stick-like device, proved to be a "Transparent Sensing". Throw events led to a variety of throw and catch games, both individually and socially, and increased outdoor play benefits (social interaction and physical activity). On the other hand, Shake events, which were less "Transparent", led to decreased social interaction and physical activity. Our recommendation for interaction designers is to first thoroughly study what children do naturally without technology, and then match the sensing events to these activities.

CONCLUSION

This paper presents evidence-based recommendations for designers of outdoor play devices based on design, implementation and evaluation of a digitally enhanced outdoor play object. Our findings revealed the fragility of outdoor play benefits when digital features are added. We showed that different types of sensing and feedback have different impact on outdoor play. For example, Accumulated feedback strengthened competitive play while and Non-accumulated feedback promoted collaborative play and creative thinking. Our study clearly shows that designers should carefully evaluate the implications of integrating sensing and feedback to outdoor play, to make sure their devices do not compromise outdoor play benefits.

LIMITATIONS

Our research has a few limitations. The choice of features (sensing and feedback) was based on our design goals and on the most common digital features found in commercial interactive products. Clearly these features do not cover all possible sensing and feedback options. In the design evaluation of the foam prototypes, we had a predefined weight for the electronics and specific material constraints for the 3D printed case, which may have influenced children's' preferences during that stage in the design process. In addition, some of the digitally-enhanced features could have been implemented with analog components, yet our focus was on digital implementation that would allow future development of new sensing and feedback features.

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