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Designing IoT Resources to Support Outdoor Play for Children

Thomas Dylan[1], Gavin Wood[1], Abigail C. Durrant[1], John Vines[1], Pablo E. Torres[2], Philip Ulrich[3], Mutlu Cukurova[2], Amanda Carr[3], Sena Çerçi[1], Shaun Lawson[1]

1 Northumbria University, Newcastle upon Tyne, UK, first.last@northumbria.ac.uk

2 University College London, London, UK, first.last@ucl.ac.uk

3 Canterbury Christ Church University, Canterbury, UK, first.last@canterbury.ac.uk

ABSTRACT
We describe a Research-through-Design (RtD) project that explores the Internet of Things (IoT) as a resource for children's free play outdoors. Based on initial insights from a design ethnography, we developed four RtD prototypes for social play in different scenarios of use outdoors, including congregating on a street or in a park to play physical games with IoT. We observed these prototypes in use by children in their free play in two community settings, and report on the qualitative analysis of our fieldwork. Our findings highlight the designs' material qualities that encouraged social and physical play under certain conditions, suggesting social affordances that are central to the success of IoT designs for free play outdoors. We provide directions for future research that addresses the challenges faced when deploying IoT with children, contributing new considerations for interaction design with children in outdoor settings and free play contexts.

Author Keywords
Digital playing out; children; outdoor play; free play, pervasive play; Internet of Things

INTRODUCTION
Outdoor play is widely understood to be an important part of childhood that, for many of us, is closely tied to fond memories of the people and places we knew when growing up. Playing outside is about having fun, but is also proven to be beneficial for children's well-being because it provides opportunity for physical, social and personal development [6,8,17,23,34]. Despite the many benefits of outdoor play, social commentators in the UK have reported a substantial decline in the number of children playing outdoors [30]. Adults are often seen to be gatekeepers to the outdoors and their fears about safety, or own lack of physical activity, can play a major role in determining whether or not children play outdoors [14]. Research in the UK suggests that children from lower-socioeconomic backgrounds are less likely to have access to suitable green spaces and are more likely to engage in 'street play' nearby their home [40]. Related research also argues that children in the UK have become more reliant on activity centres because they provide supervised outdoor play experiences in a safe environment [29]. It is reasoned that children are therefore more constrained and supervised in their outdoor play than they used to be [29].

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In this paper we investigate the potential role of Internet of Things (IoT) technologies as a resource within active free play amongst groups of children outdoors. Children are consuming more screen-based media than ever [31] and this is often correlated with a decline in outdoor play. Herewith, in contrast, we consider if physical-digital interaction with IoT could incentivise outdoor play through the design of interactive resources that enable new kinds of play experiences. We build on our previous work [43] and an ongoing Research through Design (RtD) process with two community centres in the UK that provide activities for children during the school holidays. Over a period of 24 months, we have conducted a design ethnography at two geographical sites in the UK, which includes prototyping activities with children and play facilitators. This paper reports on these prototyping activities that have seen us designing and iterating physical-digital designs, through which we endeavour to augment the children's play without detracting from their interaction with each other and the outdoors. By observing and gaining feedback from children and facilitators across the two sites, we have been able to consider challenges, opportunities and social situations in which IoT might support active-free play outdoors [9].

By reporting on our prototypes and our analysis of observational, audio and video data of their use, we offer a three-fold contribution to the field of Human Computer Interaction (HCI). First, we deliver qualitative insights about the role of IoT in facilitating active free play and associated social and physical interactions between participating children. Second, we provide lessons for future interaction design by proposing ways of enabling children to configure and control IoT resources. Third, we report on social situations and environmental constraints that promoted and hindered active free play with our IoT prototypes. We discuss these findings and derive a broader set of concerns for future HCI research, beyond designing for play experiences specifically, and instead enabling conditions in which active free play outdoors can thrive. Our contributions aim to advance knowledge in the cross-disciplinary field of Interaction Design with Children, specifically as it relates to play and game design and the role of digital technology in active free play.

BACKGROUND

The literature on play has evidenced multiple benefits of children's outdoor play. Maynard [41] suggest that playing outdoors is restorative for children and makes them feel more confident socially. When playing outdoors, children tend to engage in more physical activity [39], which is not only good for their own physical health [39] but has also been found to relate to higher levels of psychosocial wellbeing, especially during early childhood [20]. Additionally, outdoor play promotes children's management of physical risks and, as a consequence, the development of emotional and intellectual capacities supporting children's independence [28], such as making choices about alternative courses of action [27]. Furthermore, when children play outdoors with other children, they will find many opportunities to practice their social skills [4], which might be why the less children engage with screens and the more they play outdoors, the higher their levels of adaptive social behaviour [19].

Free play has also been found to have important benefits for children. Free collaborative play, for example, has been linked to children's learning about how to become social. This includes learning about socially appropriate behaviours, ways to negotiate access to resources, individual recognition, as well as sharing and collaborating to build and sustain shared narratives [24]. When play is not directed by adults, children have been found to develop the skills required to learn how to work in groups, share, resolve conflicts and even self-advocate [13]. Children also develop specific skills and adopt learning that relate to the different types of activities and contents they engage with during their free play experiences. For example, according to Ginsburg [13], they develop cognitive skills such as creativity and imagination, as well as decision making skills. Moreover, when children can shape their own play environments by exerting their own agency, shaping and authoring their environment, their motivation for creating and exploring possibilities offered by such an environment is boosted [41]. Under such agentic conditions, children persist more in their explorations [35] and develop motivational dispositions beneficial for learning, such as curiosity, resilience, and responsiveness [1,33].

Building on this evidence, we draw from HCI research which has facilitated, mediated and otherwise supported how we might use technology (and relatedly IoT) in outdoor and active free play. These communities are learning about outdoor play by asking three key questions. Where can we support children at play [2,3]? What kinds of play can we support? And: how can we support children in creating their own play [32]? Back *et al*.'s [3] work is particularly relevant to our inquiry. They describe opportunities when designing for close-to-home play with digital technologies that help foster reoccurring play patterns within public spaces and invite players to get back together. These designs are realised further in [2], which looks at supporting play with technology in a school yard. Here digital interactive installations are mixed with more natural materials that provide a multitude of possibilities for free play outdoors.

In our research, we are interested in designing physical-digital resources that encourage creative free play over more passive or prescribed play. This presents a clear challenge for digital technology where we must balance prescriptiveness with configurability. Soute's 'heads up games' [38] suggest we use material and functional qualities in our technologies to reimagine traditional games and play so as to avoid the pitfall of children becoming fixated by computer screens. This balance is addressed by researchers who suggest we create platforms for game creation where children are provided a starting point but can alter existing mechanics or rules [1]. For example, the RaPIDO platform [37] allows children to change rules and games 'in the wild'. This work was originally written using a textual language, however Soute *et al.* [37] suggest ModKit and Scratch are more suitable options for future work. This is realised by [32] who present a coding platform for outdoor free play using a graphical user interface for their connected play devices. These authors suggest that we create tools and provide opportunities for children to become their own experience creators. This is also echoed in [21] which uses block coding for play with an emphasis on movement and measurement to encourage more co-located physical and social play. In contrast, however, Hitron [22] found that advanced versions of outdoor games can reduce collaborative social interaction, as well as creative thinking, when compared with traditional play resources without technology.

Rather than focus on the design of 'programming' tools or specific rules and mechanics, this work looks at the use of bespoke IoT prototypes within a community setting and their role as a resource within existing free play activities. While there is a growing emphasis on outdoor games and play in the CHI community, little is known about how IoT might promote active free play outdoors in community settings.

OUR INQUIRY

This paper reports ongoing research into outdoor play that first began at Birch Tree (all names have been pseudonymised to preserve anonymity), a community centre in the North of England. Birch Tree is a community development charity that provides, amongst other services, activities for children from the local area during the school holidays. The CEO of Birch Tree was keenly interested in our research from the outset and had himself witnessed a decline in children playing out in what is a socio-economically disadvantaged community. During our research, the CEO has emphasised the importance of Play Champions (i.e. trained play professionals) who schedule creative and themed activities that are chosen by the children alongside free play in the yard. We have found Play Champions to be of great importance because they enhance the children's experience by ensuring they get as much as possible from their time together, while at the same time understanding the value of enabling free play outdoors.

Over the last 24 months we have conducted a design ethnography at Birch Tree in order to learn about playing out in the local community. Our first phase of work, which we have reported previously [43], involved a series of workshops at Birch Tree. Our previous paper reported design research findings about barriers to play, as well as where and how children play in their local area. While holding workshops we also spent time with Play Champions and children in order to observe and learn about how the children played. We subsequently introduced off-the-shelf microcontrollers that allowed children to prototype new play experiences when playing out. This current paper builds on our previously reported work [11,43] but focuses on subsequent engagements with children and Play Champions where we have iteratively developed and field-evaluated four play prototypes.

This subsequent phase of work did not only take place at Birch Tree. To explore the wider adoption and use of the prototype designs, and the transferability of our developing research insights, we worked with a second community centre in the South of England, BeKids, and therefore a different group of children in another setting. Like Birch Tree, BeKids is a charitable organisation that aims to provide a multitude of funded and volunteer provided services for adults and children in a socio-economically disadvantaged community. Both community centres share organisational features making them complementary sites for our fieldwork. For instance, they share the goal to provide activities for children during school holidays; are concerned with child-led play and understand the value of free play alongside more structured activities when appropriate. At Birch Tree and BeKids, the children have an indoor space and an outdoor space. At Birch Tree the indoor space is organised with a floorplan of tables and chairs, meaning that the adjacent yard provides more open ground space for play. Surrounding the tarmac in the yard at Birch Tree are bushes and a selection of raised planters for growing vegetables. BeKids have a large hall with open floorspace for running around indoors, as well as a garden consisting of long grass, raised beds and a small child-sized shed (the 'den').

Research-through-Design

We describe our approach as Research-through-Design (RtD) 'in the wild'. For us, this involved designing and making artefacts in response to time spent understanding people, environments and situations, which are relevant to a topic or research question with social significance and/or theoretical potential [12]. Our method involves: the iterative design and the making of artefacts that support in their use "*values and positions*" [15] held by those intended end users who we took insight from in the field; and the subsequent observed use of the designed artefacts 'in the wild' that leads to a range of *"procedural, pragmatic and conceptual insights*" [15] to inform further prototyping and further research [16]. The designed artefacts, when deployed, act as a "*lens*" through which we can further articulate an 'in the wild' setting and raise and address related research questions [42]. Our RtD inquiry involved design, making and adapting lo-fi working prototypes in response to suggestions made by the children, as well as our own observations and experiences. The prototypes were played with by the children and Play Champions, as part of their time at Birch Tree and BeKids, giving us the opportunity to make further iterations while learning about the role of IoT in these play settings.

Play Prototypes

Rather than create fixed play equipment like [2], in this project we consider IoT resources that children own and take outside themselves. In this way we envisage children using the prototypes to shape and create play spaces in their neighbourhood, by demarcating spaces, or through designs that are owned individually but played with collectively when they meet up outside. We are principally concerned with active group play outdoors as this has been central to our observations of how the children play at Birch Tree. An important concern throughout our work has therefore been ensuring our IoT prototypes do not detract from children's interaction with each other and the outdoors. In this way, we are keen to maintain the important benefits of free play outdoors, while providing novel resources that can perhaps make outdoor play more exciting.

The ultimate goal of the project is to provide a set of physically and digitally (re-)configurable, shareable resources for children to play with, and the prototypes reported in this paper reflect a development stage in that process. Therefore, each prototype has been envisioned as a 'kit of parts' for children to create play things with, potentially with some help from an adult. In this spirit, we have used laser cut wood, and off-the-shelf materials like copper pipe, that could feasibly form an Instructable or set of low-cost pre-manufactured parts. Relatedly, our prototypes use BBC micro:bit, which is a cheap and readily available IoT programming platform designed for children. Therefore, feasibly, each of our prototypes could be programmed by children, as well as being physically configured and built by them.

Internet of Things

The BBC micro:bit and our prototypes do not connect to the internet and so it is necessary to clarify how we have framed IoT for the purposes of this study. Firstly, the micro:bit foundation serves children by adopting a familiar vocabulary through its physical design and a block-based programming language. This includes communication protocols that use an in-built 2.4GHz radio module that allows simple and comprehensible local networks to be programmed by children. The micro:bit foundation has an ethical imperative to protect children by ensuring their safety, privacy and security, and chose to restrict functionality to "*safe educational (closed) environments*" [25]. Local networks are one way of dealing with security and privacy issues, where IoT represents an ecosystem of artefacts, but does not need to be 'internet enabled' and thus sharing consumer data [26]. In turn, our own work has been about IoT as an eco-system of connected prototypes that 'talk to each other' and speak to the IoT paradigm, but in a manner that is appropriate for young children and potentially programable by them in a closed-environments.

Based on our previous engagements with children and Play Champions, we have developed four play prototypes based on the micro:bit platform, detailed in the following sections.

Play Poles

The first prototype we describe are a set of six moveable poles that have discs on top, coloured on one side and blank on the other. An associated controller has six buttons with colours that match each coloured disc, when you press a button, the matching disc will spin around to reveal the coloured side. If you touch the pole (copper pipe) it will cause the disc to spin around again to show the blank side. There is also a reset button that causes all the discs to spin back around to the blank side. The Play Poles were created using the micro:bit, which allows us to read the capacitance of the copper pipe, as well as communicating with the controller and other Poles through a built-in radio. The disc was attached to a servo so it could spin around.

The Play Poles were informed by insights from our design ethnography and previously reported research at Birch Tree [43]. We observed how the children spend much of their time playing group games in the yard, some familiar and well-known, and others they have made up. This play often involves making visual markers, like drawing chalk on the ground and standing behind it, or making markers out of furniture like a shed or a fence to run around and touch in turn as part of a physical game. For instance, one of the children talked about a 'counting wall' on her street that was familiar to her and her friends. The 'counting wall' was a designated place to stand and count from in games of Hide-and-Seek. Similarly, another child talked about a telephone exchange box that her and her friends used as a base in various versions of 'tag'. Objects and visual markers situated on the street and around street furniture were commonly shared between children, representing a meeting point for games they enjoyed playing [43]. The Play Poles explored the idea of IoT that children might place and distribute as markers outdoors (e.g. on their street, or in a park), in order to demarcate and territorialise a location for games and play.

The Play Poles could be moved around Birch Tree allowing children to add to what was otherwise an empty yard. Building on our previous work, we kept the purpose of use open-ended, whilst making the functionality of the design clear, straightforward, and robust; in this way, we intended for the Poles to be easily relatable to the children so they could appropriate them for their own purposes. While experimenting with early prototypes we coded various functions that operated the discs on the Play Poles autonomously using the micro:bit radio and a simple networking protocol. While testing with the children we decided to use a controller, because it meant they had direct control over the Poles' behaviour, simply by pressing buttons. In this way, interactions could be structured and invented by the children, within play, as rules changed and as new opportunities emerged. The Play Poles used the radio function of the micro:bit to send messages to individual poles telling them to turn on.

Figure 1. Play Poles: (a) at Birch Tree, (b) coloured disc detail and (c) controller.

Play Cans

The Play Cans (Figure 2) were a direct iteration of the Play Poles that retained their basic functionality but offered some customisation through additional parts. Here we experimented with IoT that could be quickly adapted by children both physically and digitally. For example, building on the other prototypes, the Cans could be set up as poles that respond to touch and/or respond to the presence of other Cans through proximity using signal strength from the on-board radio. The enclosure was a tin can because it would be readily available to children or parents, and the inner workings were supported by a laser-cut structure that could be constructed and snapped into the tin can, by way of a magnet on the base.

The Cans have a magnet on the bottom, which allows people to connect it to magnetic surfaces, or different hangers, ground spikes and, like the Play Poles, copper poles. There is also a magnet on the top that rotates, allowing people to add a series of different dials and arrows, alongside the original coloured discs. We used a bulldog clip to hold the coloured discs (as described in Play Poles section), again attached with a magnet, meaning the children could add different drawings, images, or anything they found lying around. The use of magnets also meant we could avoid breakages; previously we found the children wanted to twist the top of the Play Poles, meaning they are prone to breaking off at the join between the disc and the servo itself.

Figure 2. (a) Internals (b) Play Cans (c) copper pipe detail

Beacon Boxes

The Beacon Boxes consist of four matt black boxes (so they could be easily hidden) and a ring of light that approximated how close you were to each box (Figure 3). Sixteen LED lights were mapped to the approximate signal strength giving a representation of proximity. To activate the next box in a sequence the child must deactivate the previous box by holding a button on the top. This meant that the boxes could be found in a temporal sequence. The box could be opened and would reveal a space to hide 'treasure' for other children. This prototype used the onboard radio of the micro:bit to determine the approximate signal strength of the box needing finding and a simple networking protocol to notify other boxes of their position in the sequence.

Figure 3. (a) Beacon Boxes (b) Light Meter

Like the preceding prototypes, we see the Beacon Boxes as something the children might take individual ownership of, perhaps hiding boxes on their street and inviting other children to find them. During our previous workshops, some of the children talked about play that involved hiding and finding things on their street. Eve explained for example how you play 'Hello Neighbour': "*Someone is the hello neighbour and they hide three things and other people who aren't the hello neighbour have find them... but the hello neighbour catches them, and they have to be dead.*" Eve talked about incidental 'green spaces' on her street where she would play 'Hello Neighbour' with her friends. While at Birch Tree, we thought the deployment of the Beacon Boxes would similarly encourage the children to make greater use of the peripheral space of the yard, where there are pockets of bushes, overgrown grassy edges to buildings, and vegetable planters, which beforehand had rarely been part of their play.

Play Watch

The Play Watch prototype (Figure 4) explored if IoT worn on a wrist, leg or arm, could be used by the children in free play outdoors. We facilitated children in creating their own Play Watch, which could encourage outdoor play by 'connecting' with other children who were also wearing a watch. To make the Play Watches we laser cut parts from plywood that allowed us to attach a Velcro strap, vibrating motor and battery to the micro:bit.

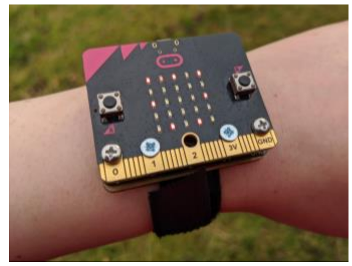

Figure 4. Play Watch

Two functional features were used with the children. First, the children could signal to each other by pressing either of the two buttons on the micro:bit, which would cause a vibration and one of two symbols to appear on another Watch (square or a circle). Second, the children had the ability to either 'heal' or 'infect' other children, depending on the symbol on their micro:bit (square/circle), and how close they were to other children. We used generic symbols because we never wanted to directly insinuate 'heal' or 'infect' and so left this open to interpretation. A different type of vibration was also felt when you were 'infected' or 'healed'. To respond to the proximity of other children and either 'heal' or 'infect' we used the micro:bit radio to determine signal strength (proximity) and created a simple networking protocol to share the state of the other Watches. Both features built on or extended the dynamics of 'tag', but were open to other kinds of play and games. We cannot emphasize enough how much the children love 'tag' and we have seen various versions of the game as reported in our previous work [43].

Data collection and analysis

Over the course of 10 full days spread over four months, we introduced the four prototypes as part of play sessions hosted at the two sites. We conducted 20 sessions in total, with each session between 1 and 3 hours in length. Our participants at Birch Tree were between the ages of 7 and 11 years old and at BeKids between 8 and 12 years old. Group sizes ranged from a maximum of 12 to a minimum of 4 children. As we conducted the sessions over a 4-month period, we often had new children participate in each session, although several children participated in every session at Birch Tree with many of the children knowing each other from school.

Children were introduced to the prototypes and given support so they could start to use them together. The Play Champions took a leading role in enabling the children to play together by adopting a child-led approach that values free play outdoors. At the children's request researchers did take part in some play activities, particularly group games that benefited from more players. We were also on-hand to support the use of prototypes technically and to make any alterations as and when required. Each prototype was used in a dedicated session by the children, though at times prototypes used earlier would be brought out again by the children and played with alongside others. Our intention was not to prescribe the children's use of one prototype over another and then compare findings; instead we were interested in observing the children using our prototypes naturalistically within the community setting.

Ethical approval was granted for this study through two of the collaborating institutions. Parents and children gave consent to participate and were fully aware of the nature of our study and that we were collecting data. This work was in compliment to existing play activities, conducted in close collaboration with the participating external partners, and at no point were the children at risk of harm over and above what would normally take place at either Birch Tree or BeKids. Our data collection involved video recording the children playing with our prototypes, taking photos from a distance, and making field notes. We took fieldnotes following our time at both community centres and recorded follow up discussions and interviews both with the children and Play Champions that were subsequently transcribed. We analysed the video by iteratively: coding segments of footage by interpreting and describing observed behaviours, identifying themes, and then collectively analysing these together with fieldnotes and other related observational data. All of our data was anonymised, and herein all research participants at both sites are pseudo-anonymised.

DESIGNING IOT FOR CHILDREN'S OUTDOOR PLAY

We now present qualitative insights supported by vignettes, through which we reflect on the use of our prototypes at both Birch Tree and BeKids. Our vignettes illuminate the diverse ways in which our prototypes became a resource in active free play for children. They also highlight the social behaviours that led them to being used (such as leadership), and that obstructed use (such as disputes), and the role of Play Champions in enabling active free play.

Spontaneously Motivating Active Free Play

The children at Birch Tree commonly start the day with indoor activities, but, after an hour or two, become restless and benefit from getting outside to burn off energy. It was during this time we introduced the Play Poles, by setting them up in the yard, in two parallel rows of three. Following a brief introduction, we left the Play Poles with the children and Play Champions. Initial interactions involved a child being given the controller, or asking for *"a shot"*, and subsequently pushing buttons and watching as others ran to touch poles that were currently flipped around (what became known as the game of "*catching all the targets*"). Play began quite orderly until one child realised that you could push as many buttons on the Play Pole controller as you like at the same time. Soon the children were running around, jumping and side-stepping between the poles, waving their arms and grabbing active poles to flip the coloured disks back around. A combination of the fresh air, open space and excess energy led them to engage excitedly with the Play Poles. The facilitator started *"egging them on"* (i.e. provoking them into game-play) by shouting colours as they flipped around, and the children responded with equal enthusiasm. The children were running around together, laughing, shouting things like, "*go, go go*" or "*I got it*" and working together to direct others to Poles that were still active, by shouting colours, and inciting urgency. They were clearly having fun, laughing if they went for the same Pole, or at the silly and playful ways that other children grabbed a Pole. In a notable moment of hilarity, Dan activated a pole, and then reset it, just before Jill could reach it and 'win' the game. We saw Dan revel in the laughter of the other children, occasionally repeating the same intervention when people were least expecting it.

In this case, the Play Poles didn't require much prior explanation of function to actively engage the children, with pushing buttons, flipping discs and running after them being an evident feature of their design and interaction. Though the children were playing freely together, this play was further incentivised by Play Champions, who have been frequently observed inciting playfulness with our prototypes, in this case by encouraging the children to go a bit faster. This unstructured running around was at times frantic and messy but was viewed positively by Play Champions as a way for the children to release their energy in an unprescribed way. Subsequently, two Play Champions described their surprise at how active Tom was: *"I know [Tom] doesn't like running, but he got involved without being told to get involved, or asked to get involved, and he just went and ran, which is quite an achievement for [Tom], because if [Tom] doesn't have to run he won't run."* In this case, unstructured running around was found to be willingly and spontaneously motived by our prototypes, without the children thinking of any negative associations with 'mandatory exercise'. This was especially true for children like Tom, who would very often be excluded, or excuse themselves, from such play.

Extending Known Forms of Play

We never gave the children games to play with our prototypes and so we observed them *orientating* themselves to the interactions by *experimenting* and *pre-planning* what they might do with them. Often this meant starting with forms of play they were familiar with and then extending or adapting this in response to the functionality of the prototypes. For example, while playing with the Watches most of the children played different versions of 'tag' that was supplemented by the symbols shown on the micro:bit.

In one session at BeKids, after experimenting with the Play Watches, four children spent some time discussing amongst themselves how they might play together. After experimenting they decided to keep the 'healing' device in a bucket they had found, "*just in case"*, and to wear the other devices as watches. As was common, the children had decided to play a tag style game, using the changing symbols on the watch and the bucket as "*a station*". Once the rules were confirmed, Sally asked the group if they were ready. Meanwhile Gina, who was showing as infected, postured and taunted the other children: "*I'm warning yaaa*". Shortly after, the game began with Gina pouncing and the other children spontaneously running away. While running around there were various forms of posturing: "*Sally is on the run...!*", "*She's coming. Lets' go..!*", and "*I can destroy you all - just by coming near you*". After playing for around fifteen minutes, the group came back together to discuss the rules again. Gina exclaimed to Sally *"you're not allowed to put it up your shirt"*. Gina had realised that by shielding the micro:bit it was possible to reduce the distance at which you could be 'infected'. Sally then told Gina and the others "*you're not allowed to go down there*", in turn asking everyone to keep within the main boundaries of the garden. Again, it became more difficult to 'infect' someone when everyone spread out over a larger distance. Running around franticly and trying not to get caught was tiring, so the bucket with the 'healing' device became a place where players could get some respite together ("*quick to the station*") because, "*you can't get me if I stay near the station*". Another place to hide was the shed. The only problem, as Sally discovered, was you could easily get "*cornered*" in the shed. On one occasion, Sally barricaded herself in the shed and meanwhile Gina and Zoe pressed themselves and the micro:bit against the outside of the door to get close enough for her to become 'infected'. This was deemed cheating by Sally who exclaimed, "*you got me, but that is cheating!*". The micro:bit working through a door seemed unfair to Sally because she had thought it would be safe. She explained subsequently that normally in 'tag' you had to be touched directly. Once everyone is caught the group congregated at the bucket, to further discuss the rules, swap devices and reset the symbols so they could start again.

Our observations show some ways that IoT can extend known forms of play. This vignette is typical of play we observed with the Watches, where children alternated between chasing, pursuing and resting and would continually adapt the rules in response to both the unfolding play dynamics and their developing understanding of the interactions we provided. Through our prototypes we commonly introduced alternative rules of engagement that were negotiated by the children. For example, Gina was *manipulating the system* by shielding the micro:bit, and Gina and Zoe were *making the most of new abilities* when they were able to "*get Sally*" without actually touching her.

Creating, Repeating and Owning Play

A group of children at Birch Tree settled on a game with the Play Poles that became known as the "C*olour Game"*. To play the game, the children would first decide who was going to have the controller. This player turns around so they cannot see the other children and randomly pushes a button. If a player is standing beside a Pole that flips, then that player is out of the game and must stand to one side. The remaining players then have to choose another Pole and the game continues until there is one 'winner' remaining.

On paper, the Colour Game appears very simple; however, the children brought it to life with rich and complex sociality, energy, enthusiasm and light-hearted banter. While picking a Pole, the children never stood in an orderly manner, but excitedly ran between the Poles, skipping and jumping, as if trying to decide which one will be safe this time around. Of course, in reality, it was randomly selected by the child with the controller, who was not meant to be looking at the other children. When a player is standing at a Pole, but changes their mind and moves quickly to another, the group laughs at how lucky they are to still be in the game. When waiting at a Pole, there is a degree of suspense that is heightened by the children eventually standing still, looking around and watching other players. If a player is out, everyone responds in some way: "*nooo!*", or "*aww*", or "*aww Jill is out*", or "*I am so lucky!*". As with all our prototypes the Play Poles and the rules of the Colour Game contributed to the experience, but the free play context was created by spontaneous gestures, humorous incidents and playful commentaries that were central to the children's social interaction. These playful group dynamics were not always evident and were dependent on a range of different factors that we consider throughout this paper.

Over the course of three days, these children played the Colour Game for approximately five hours. They enjoyed the game so much they would ask for the Play Poles even while engaged in other activities with the Play Champions. The game became well-rehearsed and like an 'inside joke', developed subtleties, rhythms and structures that the children had invented and could implement and share amongst themselves. As one Play Champion subsequently explained: "*This is our game now. They've created the game and so are going to play because they know exactly how to do it, nice to see actually*". The Play Poles [11] were found to be both accessible and open-ended, thus allowing the children to create their own meaning that was shared amongst friends. Though we have previously suggested that IoT frequently changes to provide a variety of experiences [43], in this case, *familiarity* and *ownership* through repetition was important in the prolonged use of the Play Poles. We suggest this was in part due to the meanings created by the children and the prototype remaining open to their own interpretation. Rather than being a hinderance to creativity, Cullen [10] provides evidence that repetition is an important part of free play that can lead to "*more complex combinations of materials, ideas and higher levels of learning*" (p.67).

Resolving Conflict in IoT Augmented Play

In contrast to the previous vignettes, we have encountered conflicts between the children at both Birch Tree and BeKids. Sustained use of our prototypes in group play was at times reliant on helping children resolve conflict, which benefited from the support of Play Champions and researchers. The first source of conflict we observed was *deciding what to play* and this emerged out of the freedom we gave children to choose for themselves how they wanted to play. This process was not always fairly negotiated and sometimes Play Champions and researchers had to help the children take turns suggesting ideas. For example, during a session at Birch Tree with the Play Poles, Max became upset and stormed out of the group in a huff because he wanted to play "*his game*". Max had felt the other children were not listening, and not wanting to play his game. In order to support Max by helping him resolve the situation, a researcher encouraged him to talk about his game so we could help introduce this to the rest of the group.

Despite initial excitement over the game Max had introduced, it soon led to us observing a second common example of conflict that relates to the *dynamics of play* and the *abilities* of individual children. Again, the game was based on 'tag' but this time when you stand next to an active Play Pole you cannot be tagged. One of the researchers was asked by Max to change the safe space at regular intervals using the Play Poles controller meaning the children had to be ready to run away at any moment. Despite having enjoyed playing with the Play Poles previously (as described in earlier vignettes), Tom got increasingly upset and eventually, like Max had earlier, disrupted the group by storming out of the game. Tom explained subsequently that he had felt "*picked on*" because he was not as good as the other children. The other children were older, faster and took advantage of this by ensuring Tom could not catch them.

A third source of conflict was people *being accused of cheating*. We discussed various disputes with Play Champions, who reportedly began to see our IoT prototypes as a way for them to make games fairer, thus avoiding common sources of conflict. For example, one Play Champion experimented with an augmented game of rounders, a game that was popular, but would lead to *"arguments, constant arguments. I was there before you even got to it. They throw the bat. Go away in huffs, you name it*." [Play Champion]. This Play Champion used individual Play Poles as bases in a game of rounders. The children had to touch the poles in sequence in order to clearly demonstrate to the group that they had 'hit base'. In this third example of conflict, the Play Champions saw IoT as a digital referee, or arbitrator that could govern the game in a neutral manner.

Leading Play

We have continued to observe a range of social roles [43] that support or hinder free play with our prototypes. Unlike the formal role of Play Champion, *leaders* are children who have been valuable in enabling play with our prototypes because they take responsibility for creating and sharing games with other children. Jess, for example, was found to exude confidence and enthusiasm about inventing play. Though Jess was sometimes bossy, she motivated the other children through her own desire to play, and would often instigate outdoor play by bringing children together.

For example, a group of children at Birch Tree were playing with the Play Cans and proximity code that caused an arrow to twitch when two or more Cans got close to each other. It was not immediately obvious how you might play with this interaction but when asked the children seemed happy "*just messing around*". Children often began by exploring how they might use our prototypes, before either moving on to play with something else, or coming together to play as a group. In this case, two of the children discovered that the magnets on the base of a Can would attach to the side of the activity centre (Figure 5). Jess had been watching the two friends and announced to the group, while excitedly jumping up and down, "*I know a game we can play on the wall*". She continued, "*Basically, what you have to do is move [the Play Can] about and then, whoever keeps it moving for the longest wins*". Jess began demonstrating the game, but had to raise her voice because she felt no one was listening: "*Can I just say what it is… we all start at the same place and then we move it away and then whoever keeps moving, or whoever moves for the longest wins.*" Jess persevered, "*everybody put yours in the middle! […] put it in the middle so we can play the game*". Finally, the other children listened to Jess and gathered around to play the game (Figure 5). On a number of occasions, we observed Jess suggesting ideas and subsequently bringing children together to play group games. We found Leaders to be important in the use of our prototypes within group play because they provided a degree of child-led facilitation.

Figure 5. Jess demonstrating her game with the Play Cans

Without a leader like Jess, we saw the children often benefitted from the Play Champions who would: help instigate and develop child-led ideas for play; mediate conflict between children; and ensure everyone had a role in games. However, we also saw situations where our prototypes enabled other children to have a stronger voice in leading group play. In contrast to Jess, Tom found it difficult to be assertive and frequently got upset while playing at Birch Tree (as described in earlier vignettes). For instance, during the Colour Game, the player with the controller tended to direct the other children and structured the game by pointing and repeating key phrases, like "*change*", "*ok, everyone pick a colour*", "*everyone ready*", and "*no one there*". Being in charge of the controller gave Tom a chance to lead the other children by putting him in a position of control. Tom clearly appreciated this opportunity and exuded enthusiasm and confidence around the other children. We asked one of the Play Champions about this observation, and whether computer control of the Play Poles would have been better than a controller operated by a child. They explained: "*If you've got kids like Tom that are able to figure things out, control the game, or even take a lead, this naturally encourages leadership in kids, which you have to do, and if you go automated it doesn't really have the same effect.*" Therefore, we suggest that IoT for outdoor play could integrate an understanding of social roles and associated skills in order to further support the needs of individual children when creating their own play.

Cooperative Play at the Boundaries

In contrast to other prototypes, finding the Beacon Boxes became a collaborative pursuit that brought children together through a shared goal. In the following vignettes the children had successfully found three Beacon Boxes. The children were checking all the boxes by holding down the buttons (Figure 6), but realised there was one still active. Tom deduced that, "*None of them are the right one!*" and so Jess announced excitedly "*Where is the other one!?*" This caused the children to run around together, with Dan holding the light meter and the others following alongside. Reaching the corner of the tarmac, near some bushes, Jess noticed a change on the light meter and announces "*We are nearly there! look it is full!*" (Figure 6). Her sister, Jill, responded "*Where is it?*". To have a closer look the children clambered in the bushes. Jess said "*we are so close*", at which point Ben, who was holding the light meter repeated "*I'm so close… oh my goodness*". Tom spotted an opening in the bushes and climbed in for a closer look "*I know where it is, it's got to be inside here*". Shortly after, Tom announced "*I found it!!*" and held the box up proudly. The rest of the children gathered around excitedly: "*Let me see it!*"; "*No, press the button, press the button!?*". Excitedly, Jess announced "*Can I hide them now? Can I hide them now?*"

Figure 6. Playing with the Beacon Boxes

Having played for a while, taking turns hiding the Beacon Boxes, the children were in an area of the garden with large vegetable planters. Ben had been boasting to the other children that he had found the best hiding spot and the other children were never going to find the last box. Tom asked "*is it somewhere around here?*" and Ben confirmed while laughing proudly "*This is going to be hard!*". After looking for some time, Tom noticed a patch of soil that looked like it had been turned over. He told the others "*everyone, I need help digging*". One of the researchers asked, surprised, "*did you actually bury it!?*". Tom responds, "*how am I supposed to get it if I can't dig?*". Determined to get the box, and holding the light meter, which was conveniently flat and round, he started digging with it, using it to find the box. "*Ahh, there it is…*" Jess stated, pulling it out of the soil as the other children laughed. The light meter only showed a general vicinity and this caused excitement because the children knew the box was close, but had to explore the area to find it. It was rare for many of the children to 'get their hands dirty' and play beyond the tarmac – indeed, the research team even got into trouble because some of the children got their clothing dirty.

DISCUSSION

We have reported on our RtD project and four exploratory prototypes that have allowed us to derive qualitative insights relevant to the design of IoT for free play outdoors. The prototypes derive from previous work [43] and contribute to future environments where children take IoT outside to create play experiences in places that are familiar and accessible to them – whether this is on their street, within 'incidental' green spaces, trees and bushes around their neighbourhood, or in the park itself. We have demonstrated how IoT can motivate children to create free play together; that IoT with open-ended functionality can enable children to extend play they already enjoy; that while variety and configurability is an important characteristic of IoT resources, the children also enjoyed repeating games that became familiar amongst groups of friends; and finally, we suggest that IoT could, given careful consideration, provide some support in leading and dealing with conflict in free play outdoors. The following sections synthesise these learnings and suggest areas for future research.

Qualities of IoT when Facilitating Active-Free Play

Our research has revealed how interactions with IoT can act as a valuable resource for active free play outdoors. Both the Play Poles and the Play Watches led children to run around and create play without detracting from their interaction with each other. We have shown different kinds of active free play as afforded by our prototypes and this includes running around without rules (Play Poles), running around because of the rules (Play Watches), through to cooperative play encouraged by the Beacon Boxes. Given the right dynamic (prototype qualities, social interaction, facilitation), play was generated by the children's enthusiasm and creativity, which was evident in their spontaneous gestures, playful commentaries and developing rules. Through the cases presented we continue to advocate for physical-digital designs that are open-ended, but provide a clear function that can be appropriated by the children [43]. This gives children space to adopt the designs within their own play as well as the potential to ascribe their own meaning over time through repeated use with friends. Our experiences suggest that providing a variety of resources, as well as the potential for customisation, is important as this can allow for varying needs, interests and abilities in outdoor play. We see the value of programming for outdoor play [32] as a way of allowing children to create their own play, but in our case the children have not shown an interest in programming, something they associate more with school and learning than free play outdoors. Exploring other kinds of control, or giving the children parameters that can be changed instantly while playing with IoT, has been be more appropriate when enabling the children to create interactions during play. The Play Poles, for example, provided direct control via a controller that flipped particular discs around. Though the mechanism for controlling them was very simple, it gave the children space to create a playful dynamic that was not overly directed, rigid, or prescribed. Ultimately, they could create their own play interactions, by pressing buttons, while allowing social interactions and negotiations to flourish according to the interests of the children.

The Role of Play Champions and the Local Community

During our fieldwork we have found the staff at Birch Tree and BeKids to be essential in providing a safe and friendly environment that can enable children to experience outdoor play in the local area. The children enthusiastically playing with our prototypes was dependent on positive group dynamics and although free play is child-led, adults (in this case Play Champions and the local community) still have a responsibility for providing environments, resources and facilitation that enables children to flourish by expressing themselves freely through play [36]. The use of our prototypes was interspersed with conflicts that often disrupted play or led the children to lose interest in playing as a group. We suggest that IoT might play a role in resolving such conflicts: it could help children negotiate what to play together; it could help balance out disparities in abilities; or it could reduce common points of friction in particular games. However, the literature on play commonly reports conflict within group play, where it is argued that conflict resolution allows children to learn important social skills, as well as fostering emotional resilience [20]. Play Champions would resolve conflict amicably with care and attention to the needs of individual children (who they knew well) and ensured lessons were being learnt by giving children the freedom to experience and resolve conflict for themselves. We argue that conflict resolution should be better understood in future design research and taken into account when augmenting play. However, it is important that children still have the freedom to play how they want, so they can experience and learn to deal with conflict as it emerges [36].

Barriers to Outdoor Play with IoT

There is a broader need to publicize and demonstrate the value of 'Playing Out', such that children can be encouraged and supported by adults. Prototypes like ours can only achieve so much because there are wider societal, cultural and environmental barriers to promoting outdoor play that must be addressed first. For example, some of the children got muddy as a result of playing with one of our prototypes: while a relatively small instance, it led to the children in question being told off, and the researchers being rebuked, with a lingering sense that such play was out of bounds. Further research should also position IoT within the homes, streets and estates of children, thus revealing the realities of 'Playing Out' for children and parents alike. To fully support outdoor play research should move beyond merely thinking about IoT *for play* and instead IoT that *enables play*. Whether this means providing ways for communities to intervene to create their own play spaces (e.g. supporting play in a similar way to Birch Tree and BeKids), enabling children to negotiate play outdoors on their own terms (e.g. by demarcating play spaces, using civic data to demonstrate neighbourhood safety), or supporting ways to address environmental barriers (i.e. through local campaigns around dog dirt and litter picking).

IoT for free play outdoors also introduces security and privacy barriers because children are likely 'Playing Out' with a minimum of adult supervision. There have been high-profile cases where vulnerabilities have been found in smart toys that could allow unknown adults to intrude on children at home by gaining access to personal data [18], or by activating speakers and microphones inside toys [5,7]. We chose to use the BBC micro:bit because it has been designed with an ethical imperative to protect children and although it is not internet enabled, we have considered prototypes that 'talk to each other' through the use of simple and easily understood local networks. These local networks could be owned by children, become active when they get together outdoors, and cease when they disperse and go home. In this way, IoT for free play outdoors does not lead to adult intervention or monitoring and does not leave a trace of data that others can use to intrude on children's lives. There is clearly a balance between restricting access to the latest technology and ensuring the security and privacy of children (both perceived and actual) while playing outdoors with IoT.

CONCLUSION

This paper has presented qualitative insights relating to the role of IoT in facilitating active free play and associated social and physical interactions between participating children. We have highlighted the various ways that IoT technologies can support new forms of free play, and some of the social roles and contexts that need to be considered when designing for playing outdoor among children. There is a wealth of opportunities for future research in this space, and opportunities to use technology to speak to some of the social, emotional and physical health benefits that comes from outdoor play. Future work on IoT for outdoor play can look at qualities of control, and the important role of children in acting as the controllers of the inputs and outputs of interconnected IoT devices, as a productive starting point for design. However, we stress the importance of engaging with the wider social, cultural and environmental dimensions that effect and impeded outdoor play for children, of which technology designs like ours can only address in a small way.

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