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Interacting with Computers 15 (2003) 169–185

Interacting with Computers

www.elsevier.com/locate/intcom

Using 'tangibles' to promote novel forms of playful learning

S. Price[a,*], Y. Rogers[a], M. Scaife[a,1], D. Stanton[b], H. Neale[b]

[a]*School of Cognitive and Computing Sciences, University of Sussex, Brighton BN1 9QH, UK*
[b]*School of Computer Science, University of Nottingham, Wollaton Road, Nottingham NG8 1BB, UK*

Abstract

Tangibles, in the form of physical artefacts that are electronically augmented and enhanced to trigger various digital events to happen, have the potential for providing innovative ways for children to play and learn, through novel forms of interacting and discovering. They offer, in addition, the scope for bringing playfulness back into learning. To this end, we designed an adventure game, where pairs of children have to discover as much as they can about a virtual imaginary creature called the Snark, through collaboratively interacting with a suite of tangibles. Underlying the design of the tangibles is a variety of transforms, which the children have to understand and reflect upon in order to make the Snark come alive and show itself in a variety of morphological and synaesthesic forms. The paper also reports on the findings of a study of the Snark game and discusses what it means to be engrossed in playful learning.

Keywords: Children; Collaborative discovery; Interactive learning environments; Interaction with tangibles pervasive computing; Playful learning

1. Introduction

"We are living in the age of the streamlined and 'delivered' curriculum and struggle with shoe string resources to engage the vast capabilities of children in a curriculum from which we have sidelined passion, playfulness and pleasure…" (Pompe, 1997; p. 124). It could just be, however, that the recent influx of new technologies, exemplified by ubiquitous computing, will provide us with ways of bringing the passion and pleasure back

* Corresponding author.
E-mail addresses: sarap@cogs.susx.ac.uk (S. Price), yvonner@cogs.susx.ac.uk (Y. Rogers), des@cs.nottingham.ac.uk (D. Stanton), helen.neale@nottingham.ac.uk (H. Neale).
[1] Mike Scaife died suddenly and unexpectedly during the writing of this paper. He was the inspiration behind the research.

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doi:10.1016/S0953-5438(03)00006-7

into learning. One such potential is the 'tangible bits' approach to computing (Dourish 2001), where the digital world of information is coupled with novel arrangements of electronically embedded physical objects, providing different forms of user interaction and system behaviour, in contest with the standard desktop set-up of keyboard, mouse and monitor. Everyday artefacts, like bricks, balls and tools are physically manipulated to make changes in an associated digital world, capitalizing on people's familiarity with their way of interacting in the physical world (Ishii, 1998). In so doing, it is assumed that more degrees of freedom are provided for exploring, manipulating and reflecting upon the behaviour of artefacts and their effects in the digital world. In relation to learning, such tangibles are thought to provide different kinds of opportunities for reasoning about the world through discovery and participation (Soloway et al., 1994; Tapscott, 1998; Forrester and Jantzie, 2000). Tangible-mediated learning also has the potential to allow children to combine and recombine the known and familiar in new and unfamiliar ways (Hoyles and Noss, 1999). "It is this dialectic between known and unknown, familiar and novel, that provides a motor for creativity" (Hoyles and Noss, 1999; p. 19). In addition, combining familiarity with unfamiliarity can also promote reflection by the child (Rogers et al., 2002a; Scaife, 2002), which is well known to stimulate awareness and enhance learning (Ackerman, 1996; Piaget and Inhelder, 1967).

However, little is known about the effectiveness of tangible-mediated learning, in terms of its particular benefits. The goal of our research is to investigate how various kinds of novel tangibles support playful learning. To do this, we designed a range of collaborative activities, requiring interaction with an assortment of tangibles, intended to stimulate engagement, reflection and understanding. Our vision of what playful learning should entail, is one where interaction with informational artefacts involves fun and where the boundaries between play and learning are blurred. Fun and enjoyment are well known to be effective in children's development (Clements, 1995), both supporting and deepening learning (Resnick et al., 1999) as well as facilitating engagement and motivation. In addition to fun, we believe that playful learning should encompass the following five core inter-related learning activities:

- Exploration through interaction
- Engagement
- Reflection
- Imagination, creativity and thinking at different levels of abstraction
- Collaboration

Being actively engaged in a learning activity has repeatedly been shown to be beneficial for learning. Engagement also comprises cognitive engagement which increases attention to the activity, concentration and promotes 'useful' learning (Stoney and Oliver, 1999). Engagement with a learning environment facilitates exploration and conversely exploration promotes engagement. Exploration is central to learning in that it seeks to reduce uncertainty in a novel situation (Diamond, 1996). Enabling explorative play also stimulates independent discovery (Playful Learning, 2002), a feature which our concept of 'playful learning' as a whole promotes. In addition, exploration facilitates both the acquisition of information about, and experience with, the environment, together with

the exploration of different combinations of information, which in turn can enhance creativity (Bruner 1985, cited Clements, 1995; Dansky and Silverman, 1973). Collaborative activity, particularly *collaborative discovery*, is also considered to be a key factor since it is not only a normal part of play, but also research has repeatedly demonstrated the benefits of children working together (Rogoff 1990; Wood and O'Malley 1996; Stanton et al., 2001). In particular, it helps children to learn to appreciate other's perspectives, and encourages negotiation, tolerance and the ability to listen to others (Ulicsak et al., 2001). The visibility of others actions also enables children to be aware of the effect of theirs and others actions, encouraging further exploration (Stanton et al., 2002a,b).

We propose that, likewise, tangibles can be used to create novel learning environments, which have the potential to make learning playful and pleasurable through engaging children in exploratory and reflective activities. All manner of physical objects can potentially be used, combined and digitally enhanced in different ways, providing interesting behaviours and unexpected outcomes. The key is to be able to design tangible arrangements by which the known and familiar can be recombined in new and unfamiliar ways. We argue that to facilitate this kind of playful learning requires disguising the technology so that the technology itself is not the primary focus for exploration, but rather the interactions with the tangibles and their effects in the digital environments. This paper provides an overview of how we designed a tangible-mediated, playful learning environment. Using a diversity of interactive technologies, we created a game called 'The hunting of the Snark', which involved pairs of children having to explore, interact and collaborate with various tangibles in order to find out about an elusive creature called the Snark. Below, we describe the development behind the tangible arrangements and what we hoped they would engender in the children. We then discuss the findings of a study where several pairs of children participated in exploring the 'tangible arrangements' in their quest to find the Snark.

2. The hunting of the Snark

The overall aim of the Snark adventure game is to enable pairs of children to collaboratively discover and reflect upon new kinds of experiences. Underlying these experiences are novel forms of causality between the physical and the digital, providing the basis from which the children are intended to develop models of what is happening and why, and from these plan their activities in order to precipitate further experiences and interactions.

The conceptual framework on which we based the design of our suite of tangible learning experiences stems from conceptualising mixed reality spaces. Previous research has focused on the concept of moving from a physical space to another virtual space through 'boundaries' that transparently connect the physical and virtual spaces, and specifies the degree to which the boundaries are traversable (Koleva et al., 2001), for example, the permeability of a boundary ascertains how information passes through that boundary. In addition to the concept of crossing boundaries is the idea of 'transforms' (Scaife, in press; Rogers et al., 2002b). Essentially, the term describes the changes that

occur to different states of the world which people encounter and represent routinely in their everyday life, for example in perception (e.g. seeing an object disappear and then reappear or changing one's viewpoint), in action (e.g. when the purpose of a gesture changes) and in cognition (as when we re-represent and re-interpret the state of the world). Dealing with such transforms involves some implicit or explicit theory of what causes changes of perceptual/cognitive states. It is these changes in state that we wanted to exploit in our design, creating novel forms, which combined the familiar and unfamiliar in novel and unexpected ways. This conceptual framework divides the conceptual space into four different kinds of transform types, according to different combinations of action and effect, and physical and digital dimensions. For example, moving a wand and an animation appearing would be defined as a physical action with a digital effect.

Using this framework, we designed and built a game where children had to find and capture as much as they could about the imaginary creature called the Snark. The Snark was developed as a complex fragmentary structure that never appeared in its entirety but sometimes appeared as an emotion and other times as a personality. It was also designed to only appear for short periods of time in a variety of magical spaces, including water, a cave and in the air. A main reason for designing the Snark in this format was to fire the children's imagination so as to infer for themselves from the different glimpses, what the Snark was and to understand why it behaved in certain ways in response to their various interactions. The glimpses of the Snark's personality and emotions that the children saw and heard were also deliberately designed to be abstract and at times ambiguous. These were portrayed through the depiction of noises using synthesized sounds, and animations and images, using abstract coloured shapes. Sometimes only oral expression and intonation were heard (e.g. laughing, sighing), other times visual expressions appeared (e.g. mouth eating), sometimes in combination with abstract representations of its emotions (e.g. explosive image of coloured shapes). This minimalist form of expression is in sharp contrast with the 3D realism typically used in most computer games—the aim, here, being to get the children to think and wonder rather than simply accept what is given.

To catch the glimpses of the Snark, the game was devised so that the children had to discover and use a variety of 'tangible' tools and tokens: these caused the Snark to come alive and do something (e.g. sing, fly, eat). Two core discoveries to be made were:

- Making the invisible visible.
- Bringing the far to the near.

Each of these required a different kind of tangible transform to be activated or set of transforms to be chained in order to make the Snark appear.

2.1. Making the invisible visible

The first novel collaborative activity we designed required the children to find some hidden invisible clues in a physical room using a handheld device called 'the Snooper' (Randell and Muller, 2001). The Snooper was a Jornada PocketPC interfaced with an ultrasonic indoor positioning sensor and an electronic compass (Fig. 1). Essentially, the tangible device allows the children to visualise where the clues might be in relation to

Fig. 1. The children using the Snooper tool to find virtual clues.

themselves as they walk around the physical room, providing a digital to digital transform. Thus, the children had to work out from the virtual representations on the device, where the hidden invisible objects were in the room. When they discovered the virtual objects, they were then transformed into facsimile physical objects. These physical tokens (embedded with RF tags) provided them with the means to go to other spaces and find out more about the Snark. When activated, the physical tokens caused digital animations and sounds to happen. These led them to where they could find and interact with the Snark. The children had to discover what to do with the physical tokens and reflect on why the Snark behaved in the way it did once the tokens were used accordingly. In one example, they were led to a well, where the Snark was swimming around. To bring the Snark to the surface, they had to feed it with various pieces of physical food. These were transformed into digital counterparts in the water, and could be eaten by the virtual Snark. Hence, a series of chained physical–digital transforms have to be discovered and understood by the children in order to proceed with the game. The Snark was designed to show its likes and dislikes of what the children have fed it, depending on its current internal state. The children have to work out why it behaves in a certain manner, each time it is given something to eat. Once the Snark is satiated it swims off and disappears. They then have to use other tokens they have collected to find it again in a different space.

2.2. Bringing the far to the near

In addition to providing physical artefacts as a form of tangibles with which to interact with the virtual Snark, we were interested in exploring new forms of physical embodiment as another way of engaging with the Snark. We designed two different

forms: one where the children have to move their feet in various combinations in a constrained space to make the Snark appear and another where they have to flap their arms as if flying—again to change the Snark's behaviour. In both instances, the Snark was initially far away, not doing anything, and the children have to discover ways of bringing it to the near. When they succeed it changes its behaviour, accordingly. In the first instance, we used pressure sensitive pads technology that was disguised as the base of a cave, which the children had to enter. On moving around, various noises were created. The children had to discover which kinds of sounds the Snark liked. It would then appear as a brilliant animation on the side of the cave, making laughing sounds if it liked the noises the children were making. In the second instance, the children were required to put on magical flying jackets. These were based on the Cyberjacket design built at Bristol (Randell and Muller, 2000), embedded with multiple context sensors, using a distributed architecture to gather data on where the wearer is and what they are doing. Accelerometers were mounted in the sleeves to also monitor the arm movements of the children. The children's arms are represented on a large display, so they can see what they are doing together. Their collaborative efforts affect the state of the Snark, for example whether it is happy, sad or bored. It is also the same representation that the Snark 'sees' and responds to. Hence, the children need to work out from the digital representations of themselves how to interact with the Snark to make it come nearer to them and show positive behaviour.

In sum, the Snark responds and shows fragmented aspects of itself in a variety of tantalizing and synaesthesic forms, depending on what the children do with the tangibles and their embodied movements. While interacting with the Snark the children have to capture as much of the Snark's behaviour, morphology and personality using a special device called a Snarkcam (Fig. 2). At the end of the adventure the children have to download what they have captured and also revisit all the places they encountered the Snark; the idea being to trigger reflections about the novel forms of causality and also to get them to articulate what it meant to them to engage in playful learning.

Fig. 2. A child holding the Snarkcam.

2.3. Design methodology

To create the Snark game, we used a user-centred design approach tailored for designing interactive learning environments (Scaife and Rogers, 2001). Essentially, we involved children, designers, and others at various stages of the design process. We also carried out a series of technology-inspired experiments, to teach ourselves what combinations of physical artefacts and digital information to use that would support our goal of facilitating reflection and engagement. For example, we looked at a range of devices such as RFID tags, GPS devices, handheld computers, accelerometers, pressure pads, and ways of networking these to traditional computer hardware, in addition to exploring ways of projecting sound, light and shadow (Rogers et al., 2002a,b).

The primary involvement of the children was in designing the Snark and trying out some of the tangibles as they evolved. In the end, however, we used only a small selection of the children's ideas for what the Snark should look like and behave, as many of the children's ideas turned out to be too constrained by their perception of the physical world. For example, when the children were invited to draw images of their conceptions of the Snark's appearance, they tended to draw stereotypical images of monsters, whereas we wanted a more abstract visualisation of the Snark, for the reasons stated earlier. Instead, we employed a graphic designer to create some abstract images and sounds to represent the Snark, portraying it in different moods with different attributes. The involvement of the children proved much more useful in actual user studies, investigating their interpretations of the abstract images and sounds, in terms of how indicative they were of the various attributes or emotive states of the Snark. The outcomes of these studies were used as a basis for selecting the most appropriate representations (visual and auditory) to convey the Snark and its attributes. Children were also involved in studies exploring physical movement. Specifically, we wanted to see whether physical embodiment was an effective way of interacting with the Snark. We began by experimenting with pressure-sensitive pads that are flat pieces of material that detect weight when stood on. We designed various combinations of these linked to a variety of sounds and wanted to see what the children would do—for example, would they run, jump, crawl or roll over them. We also wanted to see what would happen when two children were asked to move around on different sized matrices (e.g. 3×3) of the pressure pads, whether or not they could distinguish different sounds with different combinations of steps. Would they try to tread on the same ones, different ones or sequences of them? The children were indeed very exploratory and tried all sorts of combinations (Rogers et al., 2002b).

3. The children's experiences of the Snark game

To find out how far our 'game' was successful in achieving the concept of playful learning, and to discover what the children thought of the Snark game, we carried out a user study. Twelve children aged 6–10 years, from schools in Nottingham and Sussex, took part in the adventure game, hunting the Snark in pairs. Each session lasted approximately 40–50 min.

Each pair of children was told that their goal was to find and discover as much as they could about the Snark. They were told they could do this by exploring the environment around them and interacting with the Snark in different ways. At the outset of the game the children were given the Snarkcam, which shuddered whenever a snapshot was taken. The idea behind this was to give them a different kind of tactile feedback from a conventional camera, one which felt as if something really was being captured.

Having collected the various physical tokens, the children were led to a darkened space, where all they can see is a well. The Snark makes a noise to entice them to come over and they have to discover what to do next. Placing the tokens in the chute adjacent to the well, caused the Snark to respond either by eating with relish or making a rude noise (Fig. 3). In any one session the Snark liked or disliked the food according to the category of food it was fed (sweet, meat, vegetable). The response to each category of food randomly varied from one session to another, such that different children could experience a 'different' Snark. Once all of the food tokens had been given to the Snark, it disappeared and the children had to use another set of tokens to rediscover the Snark in a different space.

The children were then led to another dark area, this time an enclosed space representing a cave, where they had to work out how to enter it. This was achieved by placing a physical token outside the cave (Fig. 4). This opens the door to the cave and depending on what token they have used, various 'atmosphere' noises from inside the cave (e.g. jungle, water) are triggered. The floor space of the cave was visually divided into nine squares (that corresponded with nine readable pressure pad units), which cause the atmosphere sounds to change (e.g. get louder or softer) as the children move across them. To reveal the Snark both children had to find and stand on two squares from the matrix, which caused the atmosphere sound to be at its loudest. The Snark responded accordingly. Once the children had used up all their tokens, the Snark finally appeared as a flashing animation and disappeared with a bang.

Fig. 3. Feeding the Snark at the well.

Fig. 4. Using note tokens to enter the cave.

The final token the children had, allowed them to open a box where they found two magical flying jackets. The children had to discover more about the Snark by making body movements, such as flapping their arms, banking left or right like a plane (Fig. 5). The Snark responded differently according to the kinds of movements made and to the degree of collaboration, e.g. the Snark responded with more intense excitement when children made the same actions simultaneously. For example, if neither jacket registered arm movement then nothing happened, and the Snark was sad in the distance, or if both were flapping together then the Snark image came close, and was very happy, soaring swinging and gliding.

At the end of the game the children could download the images and sounds they had captured via the Snarkcam onto a computer. They were then encouraged to reflect and talk about the Snark, what they had learned and their experiences with the game.

Fig. 5. Using flying jackets to interact with the Snark.

4. Findings and discussion

Video recordings of all sessions of the children's experiences and interactions with the Snark were taken. As an exploratory study looking at the effectiveness of the use of tangibles for promoting playful learning, video analysis focused on observations of children's actions, interactions, gestures and spoken dialogue in terms of the five specified aspects of playful learning. General observations of the children showed that they were fully engrossed throughout their participation with the Snark game, interacting in different ways both with the tangibles and each other. They found it easy to seamlessly switch in and out of the different levels of the game, suspending disbelief when interacting with the Snark and reflecting on what to do with the various tokens and where to find the Snark next, when it disappeared. To analyse the various aspects of playful learning we describe our observations in terms of the five features described earlier: (i) excitement and engagement, (ii) exploration through interaction, (iii) reflection of their experience, (iv) creativity and imagination, and (v) collaboration.

4.1. Excitement and engagement

Excitement and engagement was assessed in terms of children's verbal expressions, consistent involvement and desire to continue interacting and playing. There was ongoing evidence of children expressing excitement, enjoyment, anticipation and engagement in their activities. Children were keen to use all of the tangibles they were provided with in the game without having to be coaxed. Apart from one child who was reluctant to wear a 'flying' jacket, all children were eager and keen to be involved in every aspect of the Snark experience. The Snarkcam elicited excited responses (giggles and delighted laughs) when it jiggled after the button was pressed. There were expressions of excitement, pleasure and thrill when they captured the Snark on the Snarkcam, for example, in the cave one child exclaimed "We *got* that!" Several children frantically clicked away with the Snarkcam, whenever the Snark appeared, with obvious enjoyment, demonstrating total involvement in the experience. All children were keen to try out the Snooper tool, exploring with it as instructed, holding it carefully and looking intently at the screen. They showed pleasure at finding clues e.g. one child cried "Wow" when they found objects on the floor after finding virtual tokens on the Snooper.

Furthermore, there was evidence of anticipation at finding the Snark. For example, at the well, one pair of children held the Snarkcam ready as they peered down the chute expectantly. Others called "Foody, foody, foody" with expectation in their voices. Excitement at the Snark's emergence was apparent in all parts of their experience. For instance, one child attracted the attention of his peer when the Snark first appeared in the well, another pair expressed awe and amazement when they "found" the Snark in the cave, and two pairs showed great excitement when the Snark first appeared with the flying jackets crying out "Look, look!" and "The Snark, J, the Snark". There was extensive excitement and anticipation when several children (three out of the four pairs at Nottingham) noticed 'something' in the pockets and sleeves of the flying jacket.

The children were also encouragingly responsive to the Snark's reactions in the different locations of the game. They laughed and giggled at the 'disgust' sound from

the Snark when it was fed something it did not like, and showed pleasure when the Snark ate noisily in the well. There were expressions of surprise at the responses in the cave, and frantic flying activity with the magic flying jackets. Above all, the download session, not only gave insight to children's understanding of their experiences, but also demonstrated the level of involvement, engagement and excitement of all of the children. They were instinctively keen to talk about what they had done and to show someone else what they had been doing during their Snark experience.

Overall, the children were captivated by finding and interacting with the Snark. This captivation appears to have increased the level of interest the children had in their activities, engendering a desire to continue to play the Snark game and explore further. Hence, the fun factor appeared not only to facilitate engagement and motivation within the 'playful learning' activity, but also encouraged exploration. More than this, it stimulated the children to share their experiences with others, which in turn may have beneficial effects in facilitating externalisation of thoughts and ideas, therefore consolidating their learning.

4.2. Exploration through interaction

The Snark game was designed to allow the children to explore through interacting with different tangible arrangements. In so doing, the children appeared to build models of action and interaction primarily from the causal relationships they made between their actions and the Snark responses. For each activity, specific models of causality were developed in terms of what the children had to do. For example, when interacting with the flying jacket all children learned that they had to flap their arms together in certain ways to elicit a desirable Snark response.

Some tangible arrangements initially instigated intuitive models of interaction. For example, all of the children intuitively put food directly onto the well, consistent with a real world model of 'feeding the ducks'. This was unexpected to us, as the design of this space had taken into consideration that the well was clearly a computer monitor, so alternative provision had been made for feeding the Snark (i.e. the chute). This is interesting because, despite the fact that children could see the well was a monitor, they still appeared to think that they could magically transform the physical food tokens into digital food that the Snark would eat. However, when this 'expected' transform failed, the children were unperturbed and merely explored other ways of achieving their goal. They subsequently looked into the chute (adjacent to the well), where they tried placing the food. Some children initially looked into the chute in an attempt to see the Snark, but were drawn by the Snark's response in the well. In this tangible arrangement there was a clear demonstration of a developing model of interaction, which advanced and changed through exploration and experience. In this way there is evidence that children were reflecting on what had happened in order to direct their subsequent actions and interactions.

In other settings, children's understanding of what to do and why was less clear. This may have been due to the unpredictability that had been a deliberate part of the design of the game or it may have been due to the design of the task and the feedback they received. For example, in the cave children had to collaboratively find the two squares that made the loudest sound, which required them to simultaneously stand on those particular squares. However, the feedback was sound alone until they simultaneously stood on both 'loud'

squares. It may be that enhanced feedback combining visual and audio cues supported the children more in this task. Nevertheless, the lack of clarity to the children in this activity appeared to elicit increased exploratory behaviour. Each time the children entered the cave they were required to stand on different squares to elicit a new Snark response. Some children initially tried standing on the same squares that they had previously found to be successful. When this was unsuccessful, they tried other combinations. Difficulty in eliciting the Snark response also prompted children to try out different ways of getting a response, such as, straddling across different squares and jumping or stamping on particular squares. Hence, when their first expectations were not met, it encouraged further exploration widening the children's perceptions of other causality possibilities. This instance highlights the issue of trade-off in design. Here there is a trade-off between on the one hand 'lack of clarity' and encouraging exploration and reflection on the way to reaching one's goal, and on the other hand clarity and quickly achieving a task goal.

As well as forming specific models of interaction children also formed more general models across the game as a whole. For example, in the flying jacket experience one pair of children particularly made reference to the possibility that if they were to wear the jackets it might help them to find the Snark. This suggests they had formed a more general model of 'physical action with tools' that the game had provided in order to achieve their goal of eliciting the Snark.

So, what enables these models to form and develop? The children's models seem to develop through their interactions, but appear to be based on certain contingencies. Here two kinds of contingencies were identifiable: current action being contingent on actions or schemas from the real world, and current action being contingent on previous action within the Snark game. As mentioned, the real world contingencies were most evident in the well where all children intuitively held the food directly over the pond. This action is contingent on a real world experience of feeding the ducks. Peering into the chute demonstrated expectations contingent on real world proceedings, the children expecting to see the Snark where they had put the food rather than in a different location.

In contrast to this, in the cave the children's understanding was less clear with no apparent real world contingencies. Children therefore had to form a new model of action, which guided their subsequent interactions in the cave. For example, some children tried out the same squares that had been loudest the previous time, thus subsequent action was contingent on previous successful action. This was also apparent in the well where all children went through a series of actions each of which appeared to be contingent on their previous action according to the response (or lack of) to each action. Subsequent actions were contingent on previous interactions in order to get the desired response (i.e. in this case the Snark appearing in the pond).

Our findings of the physical interaction with tangibles suggests that this way of interacting is physically engaging, can initiate unexpected events, thus facilitating inquiry and reflection, which guides action and interaction.

4.3. Reflection

The children's reflections and understanding of their experience were elicited both through verbal reflection during the game as well as during the download session at the end

of the game. Reflections during the game primarily comprised spontaneous verbal interactions between the children, whereas reflection during the download session was solicited by open ended questions, for example, "Where did you see that?" "What did that mean?" "Why did that happen?". Constructing some kind of understanding of the Snark creature required the children to place meanings on the different abstract depictions of the Snark, i.e. images and sounds. Not surprisingly some depictions had more 'obvious' meanings and were uniformly interpreted, while others had less obvious meanings, resulting in more varied interpretation. For example, the like/dislike sounds and images in the well were uniformly interpreted, as was the Snark's giggling and laughing during the flying jacket experience, while some of the Snark response sounds in the cave were perceived quite differently by different children. When the children described the Snark as a whole they did so in a variety of ways, often resorting to using analogy, e.g. a spider, a computer or "just a box". This suggests the success of using abstract representations to facilitate creative perceptions of the Snark by the children, where they were taking the same representations, but making novel associations and creating their own image.

Having the Snark respond in such abstract ways provided scope for promoting imagination and creativity, especially within a play environment, where the meaning was manipulated by the children as in pretend play. This may be a consequence of meanings being ambiguous, requiring more cognitive effort to interpret, and may be an important issue in contexts where ignoring (or not interpreting) an outcome affects a comprehensive perception of an activity or concept.

4.4. Imagination and creativity

In the context of playful learning and its relationship to imagination and creativity (Bruner, 1985; Dansky and Silverman, 1973) we were interested in the kinds of understanding or representations the children created of the Snark. After experiencing the game, the children's reflections on their experiences demonstrated that they not only had an understanding of the Snark and its moods/behaviours, but also were very imaginative in bringing the Snark back to life. In this section we focus on children's basic understanding of the Snark as well as their understanding at different levels of abstraction.

The children's reflections here suggest that they were able to think about the game and the Snark at different levels of abstraction. Primarily their understanding of the Snark was at a level of specific description of emotion, for example, the Snark was described as liking the wind or carrots, or as being happy or sad. However, some children generalised to a more abstract level of description of characteristics, stating that the Snark was 'cheeky' and 'mischievous'. The children were also able to make judgements of intensity of emotion as well as the emotion itself, with most pairs describing the Snark as being happiest when they flapped their arms quickly.

Exploring and interacting with our tangible arrangements enabled the children to reflect on their experience in different ways, serving not only to guide their actions and interactions, but also to enable them to build different, novel and creative understandings, of the Snark itself. Designing a dynamic abstract creature enabled children to form an understanding of the Snark at different levels of abstraction; describing its mood and behaviour on a specific level, e.g. liking/disliking something, as well as being able to

describe higher level general attributes, such as, cheeky and mischievous. This is beneficial in terms of promoting imagination and independent creative thinking, within a playful context.

4.5. Collaboration

Analysis of collaborative behaviour with each of the tangible arrangements suggested that interaction with tangibles encourages collaboration, and collaboration encourages communication between the pairs of children increasing the degree to which children have to externalise their thoughts, increasing their awareness of the experience. The tangible arrangements in some cases required collaborative activity, for example, the cave and the jacket required children to simultaneously act to elicit a Snark response. In other situations, collaboration was encouraged in that one child took responsibility for one part of an experience, while the other took responsibility for the other—for example, at the well one fed the Snark, while the other took pictures with the Snarkcam. In all cases the contribution of both children was important in achieving their goals. Collaboration seemed to enhance children's level of engagement, their ways of exploration and their ability to reflect on their experiences.

Engagement in the activities and excitement at events and discoveries was perpetuated and enhanced by interaction between the children themselves as well as with the tangibles. Children pointed things out to one another, sharing their findings ("Look! Look!"), instructed one another in their use of tangible 'bits', e.g. prompted one another to use the Snarkcam in appropriate places, and suggested which food token to feed to the Snark next. Having someone to share their excitement and pleasure increased their motivation and engagement in their experiences.

Collaboration also meant that children were having to share roles, to take turns, to think about the activity and events from another's perspective. They both had to participate to achieve their goals in the game, sharing their ideas of discovery. In this way they assisted each other in exploration, by having two of them contributing their ideas on how to interact with the tangible arrangements and achieve their goal of finding the Snark.

Not only was there evidence of children 'scaffolding' one another in their explorative activity, but it was clear from the download session that they collaboratively contributed to their perceptions of their experiences. Comments from one child would prompt alternative comments from another, or one child would remember something about their experience on the back of a recalled event by their peer. For example, when describing the sounds in the cave during the download session,

Child A: it means that it ate some of the food….
Child B: No. The…It likes the music…
Child A: …the noises.

In this way they help one another to build a more sophisticated picture of the Snark, collaboratively getting more out of the experience.

4.6. Improvements for design

Although the children enjoyed all activity spaces there were some design and technical difficulties that arose during these studies. The collaborative behaviour in some instances highlighted the importance of the physical design on the device in encouraging collaboration. For example, in the first activity where a Snooper tool was used to detect clues the child holding the device took charge of the activity, whilst their partner followed their lead. When the pairs attempted to view the display at the same time the child carrying the Snooper had to stand still. In order to make this task more collaborative both children need to be able to see the display to actively contribute to the task. In addition to this it was also observed that the feedback children received affected their ability to collaborate and to invoke all of the different responses from the Snark. For example, during the flying experience the children had different sets of collaborative actions e.g. flapping arms and banking at the same time. Not all pairs managed to achieve this, partly due to technical difficulties and partly due to their difficulties in understanding which actions they had to carry out. Future designs to improve collaborative behaviour should therefore focus on enabling both children to see their own actions as well as their partner's.

5. Conclusion

Overall, our study demonstrated the successful use of tangible arrangements for engendering playful learning in several ways. The tangible arrangements were designed to comprise physical artefacts that mediated different digital effects and outcomes. This enabled responses to physical interactions with artefacts and activities not possible with only 'real world' artefacts, thus providing the potential for news ways of interacting, exploring and learning. The combined use of physical artefacts and physical action means that the children themselves become a central part of the activity (rather than just watching something evolve like in computer games), which has a quite different form of immersion and engagement. In particular, throughout the game the children appeared to be able to seamlessly pass to and fro between the dual process of action and reflection—something which is aspired to in adult learning and referred to by Donald Shön as 'reflection in action'. Essentially, this involves the learners' experiencing something and then stepping back from the perspective of what they are doing and thinking about how it fits into the larger picture. Moreover, the level of engagement witnessed by the children in the game together with the various forms of collaboration they engaged in, seemed to facilitate unself-conscious, relaxed interaction with the environment and with one another. The children were evidently motivated and stimulated, wanting to go back to each arrangement during the download session, keenly showing us what they had been doing and what had taken place.

In sum, the level of engagement and reflection facilitated spontaneous exploration, which in turn promoted action and interaction. The use of tangibles appeared to increase the children's propensity to explore and wonder, through the provision of unexpected events causing them to find out new or other ways of achieving their goals. Reflection on what is taking place, on their own action and effect enabled the children's models of

interaction to develop. The children's reflective behaviour also heightened their awareness and stimulates them to question and speculate about their experiences. Throughout the Snark game, the children showed the ability to manage the unexpected, to piece together different pieces of information, to understand at different levels of abstraction, and to interpret abstract representations.

Acknowledgements

We would like to thank all of our partners on EQUATOR (http://www.equator.ac.uk), funded by the UK's Engineering and Physical Sciences Research Council (EPSRC), especially Cliff Randell, Henk Muller (Bristol), Claire O'Malley, Ian Taylor (Nottingham) and Greta Corke (RCA), as well as all of the children at Sussex and Nottingham who participated in the development of the Snark adventure game and the experience itself.

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