Things aren't what they seem to be: innovation through technology inspiration

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ABSTRACT
How does designing for novel experiences with largely untried technologies get its inspiration? Here we report on a project whose goal was to promote learning through novel, playful visions of technologies. To this end, we experimented with a diversity of ambient and pervasive technologies to inspire and drive our design. Working as a large multi-disciplinary group of researchers and designers we developed novel and imaginative experiences for children. To crystallise our ideas we designed, implemented and experimented with a mixed reality adventure game, where children had to hunt an elusive, virtual creature called the Snark, in a large interactive environment. We describe our experiences, reflecting on the process of design inspiration in an area where so much remains unknown.

Keywords
Innovation, technology inspiration, novel user experiences, blue-sky research, physical/virtual integration, tangibles, conceptual development, wearables, middleware infrastructure, devices

INTRODUCTION
"We can make amazing things, technically, but are often at a loss to understand what to make" (Thackara, 2000 [23]). This predicament is especially pertinent for those of us in the business of doing blue-sky research, where we seek to 'invent the future' (e.g. 1,2,3,4,5). Part of the issue, here, is that we are usually not working within a tightly-focused project where the development brief can be benchmarked against 'progress' towards a 'product'. Rather the position is one where our work is subject to far more intangible principles, harder to operationalise and evaluate, such as creating novelty for homes or leisure. This can mean losing the security blanket of conventional paradigms and 'tried and tested' methods. Instead we tend to be working more in terms of a mix of serendipity and invention where creative experimentation is what drives the research. We should not be overly alarmed by this. Airplanes did not begin due to a public demand for new means of transportation but from centuries of interest in whether people could emulate birds. Further, it is a commonplace observation that invaluable products have come from serendipitous discoveries in areas totally unrelated to them. For example X rays were discovered by a physicist observing discharges in vacuum tubes. Creative exploration with an eye to serendipity can be excellent heuristics for research work.

What this does not mean, however, is that 'blue skies' research should proceed without any guiding principles. Thackara's comment is, of course, a challenge to such an assumption: understanding what to make, requires us to be clear about our goals, i.e. what is it we are trying to conceive. In the context of his comment he argues for taking on board the social contexts in which products and services are used as an essential basis for pushing pervasive computing forward. In our case we are addressing the issue of how to design novel user experiences based on the possibilities of a new generation of ambient technologies. In doing this we have two, inter-linked research 'aesthetics'.

The first of these is to look at the technologies themselves as a source of inspiration to see what they might suggest to us, feeling free to configure and reconfigure them for emergent ideas. Such an approach might be considered by many as 'technology-led' and hence an anathema to the accepted way of doing interaction design. However, we would argue differently, rebadging this as a 'technology-inspired' approach, where the capabilities of new technologies are explored and experimented with to provide ideas for conceptual development. The potential of this relies on, rather than negates, the social context of technological innovation. We are all appropriators of technology, something that is a driving force in both human social and individual history (16,24). The intuitions of researchers are no less valid than those of others. To maximise the effectiveness of such a job however, relies on the pooling of multiple perspectives on what might be 'possibilities' for new experiences. For this reason, we do this exercise as part of a multi-background team. Technologists, designers, actors, artists, thinkers, doers and others, who typically would not normally work together, combine their skills and ideas to promote new views on what is possible.

Our second aesthetic is what we, somewhat tongue in cheek, call 'ludic engineering': promoting learning through novel, playful visions of technology. Part of the reason for this is the increased importance given to leisure, rather than work, in everyday life. The design lessons from applications for work do not generalise readily to 'fun' applications for outside (e.g. 17). More generally, however, much learning (adults as well as children) seems to be done – or best done – in a playful way (e.g. 8). For us this entails several goals in trying out new arrangements of technologies for users. One is to design the experience so that success/failure is not an issue. A second is that the technology should not be the focus of the experience. A third is that what we provide should be genuinely entertaining and, in some ways, challenging. However, we are also in the business of researching how users appropriate technology, what their understanding is of the 'how and why' of the new experiences that can be provided. For us producing designs that allow such reflections is a fourth characteristic of this kind of design project. In this respect we would argue that provoking responses to new arrangements of technology is not dissimilar in its aims to a familiar technique for innovation in modern art, where there is a history of experimenting with new combinations and juxtapositions. Consider for example Marcel Duschamp's 'ready made' objects, or his later products from collaborations with other disciplines within the emerging surrealist movement in Paris in the 1920s.

In this paper, we describe our approach in a project called 'the hunting of the Snark[1]'. We describe the 'hunt' at two levels: (i) our experiences as a motley bunch of designers, technologists, artists, psychologists etc., to show how we went about creating novel user experiences, through being both inspired and constrained by technical possibilities and conceptual concerns, and (ii) the novel user experiences we created for children, which involved an adventure game, hunting an elusive, virtual creature called the Snark, in a mixed reality environment.

THE MOTLEY CREW

We are involved in a six year, blue-sky interdisciplinary research collaboration, called Equator, involving eight British universities[2]. Our overarching goal is to innovate, around the common theme of exploring the 'physical and the digital'. In total there are about 50 researchers, working on a range of projects, having a broad spectrum of backgrounds (6). As part of this enterprise the authors are exploring new methods of playing and learning through technology innovation, and the Snark project is the first collaboration in that vein. It has been up and running for about eight months. At any one time anything from between 10 and 20 researchers are involved, including hardware engineers, sound experts, an artist-designer, software engineers and designers, developmental psychologists and interaction designers.

We work primarily as small clusters, focusing on particular research issues and technical challenges. At various intervals, we all come together for week-long workshops, which are held at the different sites, where much brainstorming, demonstrating, experimenting, constructing and collaborative coding takes place. Smaller gatherings then take place, between various individuals to develop and test specific aspects of the evolving user experience (e.g. getting middleware talking to Director).

BACKGROUND TO OUR PROJECT

Our overarching goal is to create new experiences for children that move beyond the existing genres of computer-based experiences, be it video games, virtual worlds, edutainment or commercial interactive toys. Recent developments in the design of interactive technologies for young children have emphasised the value of open-ended forms of play for facilitating the development of complex forms of thinking and acting (e.g. 9,15). A number of research projects in recent years have also begun to capitalise on the value of manipulative materials and objects to make more concrete and tangible children's playing and learning activities (e.g. 10,22). For example, much work at MIT has been to design physical toys embedded with computational and communication capabilities, aimed at enhancing interactivity and to engage children in new ways of thinking (e.g. 9,19).

Our work is in the spirit of these projects in that we wanted to design an interactive environment with a playful theme that would maximise children's imagination supported by new technology mechanisms (20). The specific design was to be done in accord with our research aesthetics. The Snark theme is one of discovery, it doesn't have the possibility of failure since the children always find the Snark. It is a challenging playful environment in that the Snark could change from one visit to the next and where children would be unable to know what to expect whenever they interacted with it. Finally, it employed new combinations of technology to allow this but these were used to provide invisible mechanisms and the Snark hunt itself remained the focus of the children's activities.

CONCEPTUAL IDEAS

Our vision, therefore, was to build an interactive environment that would enable young children to discover and reflect upon new kinds of experience. The challenge we set ourselves was to see if we could do this by linking Snark activities seamlessly between physical and digital worlds. We hoped that one consequence of this, bringing the two together in ways that were novel and unexpected, would be to make the children stop and wonder about how this 'could be'. Understanding their models of causality, here, is no less important than it is for desktop applications.

We used the nascent framework of mixed reality environments (MREs) to conceptualise our vision. Mixed reality has been described as something "in which views of the real world are combined in some

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[1] The hunting of the Snark is a poem written by Lewis Carroll in 1872. It is about a motley bunch of bankers, butchers, billiard ball makers, etc. who go on a voyage by sea to find the Snark.

[2] Bristol, Glasgow, Lancaster, Nottingham, RCA, Sussex, Southampton and UCL

proportion with views of a virtual environment" (Drascic & Milgram, 1996, p. 123 [11]). There are a number of ways of achieving these states, the commonest being augmented reality and augmented virtuality which both use overlay techniques with physical and virtual scenes or objects. Another idea is mixed reality *boundaries*, involving the creation of interfaces that transparently connect separate, non-overlayed physical and virtual spaces. Koleva et al (13, 14) describe the properties of a 'traversable' interface, as something which "gives the illusion of joining physical and virtual worlds together and that users can physically cross from one to the other" (13, p.233). This idea of moving from one physical place to another virtual one and vice versa has been a central focus of MRE research. A number of properties have been suggested that can affect the success of these kinds of traversal illusions, namely permeability (how information passes through a boundary), situation (the boundary's spatial properties) and dynamics (its temporal properties). Here, we are interested in how a conceptualisation of MREs can provide us with ways of thinking about how to provide novel user experiences that move across time, space and media. In particular, we are interested in the traversibility in situations where a variety of things - user actions, objects, effects of actions - would appear to seamlessly cross the physical/virtual boundary. In addition to the idea of crossing boundaries, we came up with the idea of *transforms* to inform design. By this we mean changes in the state of the world. People encounter, and represent, transforms between states of the world routinely in 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 transforms will involve some implicit or explicit theory of what causes changes of perceptual/cognitive states, i.e. some sort of causal link is usually involved. Transforms are a constant feature of ongoing perception and cognition and constitute the phenomenology of experience. Thus something could traverse the physical-virtual boundary but do so in different ways, resulting in different experiences (transforms).

Designing the novel user experience: hunting the Snark

Based on our conceptual framework, we began to brainstorm possible scenarios for novel user experiences that involved traversals and transforms in a mixed reality environment for young children (aged between 6-10 years). To ground these, we used the familiar orienting structure of an adventure game, whereby pairs of children would be asked to find a 'Snark' in a MRE. The idea behind having a Snark as the thing that the children have to hunt, is that we could mould and shape it to appear in all sorts of places and in different shapes and forms. Thus, we could create interactions in the MRE which involved something traversing a physical/virtual boundary and doing this by allowing different transforms, each of which would result in the Snark appearing or disappearing in different ways. Two over-riding concerns emerged in thinking about the design of the interactive environment. The first was that the series of activities involved in hunting the Snark should be coherent. We wanted to establish a unitary *identity* for the Snark, so that it did not appear as a series of unconnected and fragmented experiences to the children when encountering it in all of its physical and digital/virtual manifestations. The second concern was that the game should be playful and fit the genre of an adventure hunt. To move this forward we decided on a candidate set of activities. At a general level these were that the children have to (i) discover clues which will lead them to find out (ii) how to discover things about the Snark and then (iii) interact with it.

At the heart of our design, was the goal of exemplifying a variety of transforms, based on combinatorial possibilities of real, virtual and ubiquitous forms. It was at this stage that we looked at technology for inspiration for how to develop these. We needed to determine which to use, how to use them and be explicit about the rationale as to why we should use them (given the huge overhead involved in building and programming them). We carried out a series of technology experiments, which enabled us to understand better which kinds of transforms and traversals could be built or supported and what kinds of user experiences they might engender.

TECHNOLOGY INSPIRATION

We looked at a range of devices that were being promoted as new 'tools' to develop pervasive computing and ambient environments. These included (in no particular order) RFID Tags, barcodes, GPS devices, ultrasonics, beacons, pingers, handheld computers, accelerometers, pressure pads and aerials. In addition we looked at how these could be networked with traditional computing hardware, namely laptops, workstations and an assortment of back projected displays. We also explored new techniques of projecting sounds, lights and shadows onto different kinds of surfaces (cf. 14) . Our objective was to use combinations of these technologies together with 3D worlds, 3D audio and other mixed media projections and presentations. To guide our explorations we considered the potentials of each choice or combination in terms of a set of specific activities that would need to be supported during the game's phases. These were:

- Looking for and/or identifying something
- Using something to cause an effect
- Viewing or listening to something
- Collecting things
- Integrating the different views of things experienced

Not having much experience with what each was capable of doing alone or in conjunction with other technologies required us to do considerable experimenting as part of the process of technology inspiration. A summary of some of the key inspirations that arose out of this stage of the project are presented below (more detailed descriptions of the technologies and experiments carried out can be found in the design exhibit).

Physical/virtual transforms for changing the states of objects (RFID tags and barcodes)

We experimented with barcode and RFID technology as ways of changing the state of an object that could introduce digital responses (e.g. sounds, animations, lights) in an environment. We discovered that barcode technology, while being very robust was actually very inflexible, requiring that the reader or barcoded object to be held in a particular way. In contrast, RFID tag technology was much more flexible for being used in a mobile setting, allowing the person or an object to trigger digital events to happen that could be instantiated in all sorts of ways. The possibilities afforded by RFID technology, enabled us to conjure up many kinds of interactions that children could have with the Snark, based on tagging them or objects located in an environment. For example, it allowed us to explore the idea of a transform involving using different kinds of clues and tokens to activate or affect the Snark (e.g. waking it up, feeding it).

Virtual/physical transforms involving body movement and digital media (ultrasonics and handhelds)

We also experimented with handheld devices, combined with ultrasonics, that could detect the location of hidden, invisible objects in a room in relation to the whereabouts of the person holding the device. We looked at how the 'virtual' objects could be revealed based on where the person, holding the device, moves to. This led us to thinking about how this kind of cause-effect relationship could also be used to reveal physical instantiations of the virtual objects. Furthermore, it inspired us to think about how to provide virtual clues that the children would have to find, that once discovered, could be transformed into physical objects. Having also an understanding of the capabilities of RFID technology, also led us to thinking about what kind of properties to embed in the physical objects, which themselves could then be revealed, once placed elsewhere (i.e. passed a tag reader, disguised as something else in the environment). Thus we were able to start envisioning the sequencing of transforms in relation to the specifics of the user experience.

We tried developing various kinds of clues, representations of virtual objects and 'snooping' type activities to provide for the children to engage in. A handheld device was built for these experiments, based on two main components – the HP Jornada 548 palmtop PDA and an enhanced ultrasound position sensing device (18). The device was designed with various kinds of display formats to convey where the user and hidden objects are, with the use of both visual and audio feedback to the user.

Physical/virtual embodiments (wearables and pressure pads)

Another form of technology we explored was *wearables*. We considered how various items of 'intelligent' clothing (e.g. jacket, trousers, hat, gloves) could be worn by the children such that they could then move around in them, creating various gestures, that could be read and transformed into something else. A key concern was what kind of gestures could be recognized and were readily discriminable from each other that the children were able to understand and do for themselves. We also wanted to see how a combination of wearables could be used (e.g. two jackets), since we planned to have pairs of children collaborating in the Snark adventure game.

Another form of technology we explored was *pressure pads*. These are interactive devices, that when stood on by someone can be programmed to trigger a digital event. They also provided us with ideas of how to create a user experience, namely where children can make different kinds of sounds, depending on which pads they stand on. We were interested to see if it made sense to enable two children to walk on the pads at the same time to make combined sounds. This led us to designing an interaction space, where children could create sounds by walking around an enclosed space, which the Snark could respond to.

Instantiating the traversals and transforms

We had another week-long brainstorming session where we came up with a diverse range of specific ideas of what traversals and transforms to build. These included a variety of magical 'bases' where the children could interact with the Snark, e.g. a well, a wardrobe, a cave and a mouth. A number of tools were also outlined, which would allow the children to do things to find out more about the Snark, e.g. make invisible objects visible and allow users to perform actions 'at a distance'. These included a magic lens and a metal detector. Other ideas included a magical coat and a guiding cap. Of these, we decided to begin by designing and implementing only a small sub-set (since each by itself, required a huge effort to create): a well, a cave, a flying jacket and a magical lens tool. The idea, however, was that more and more discovery bases and tools could be added to the interactive space at later stages.

Actual examples of traversal we came up with were walking through a physical/virtual door and looking through a physical/virtual looking glass. By moving through these kinds of physical/virtual boundaries, various *transforms* would then become possible. Examples of these include passing physical tagged objects against a 'target' and the person moving themselves passed a target (embodied movement). The effect of such actions would be to elicit various visuals and sounds from the virtual Snark. Another idea was to design various kinds of clues to help the children discover where to hear and see the Snark. An idea was that strange and magical things would happen when the children transformed the clues from virtual to physical and physical to virtual representations. As mentioned earlier, the experiences were intended to provide novel forms of causality to provide a basis from which to enable children to plan their activities in order to provoke further experiences and interactions.

DESIGNING THE SNARK ADVENTURE GAME

While experimenting with the various technologies we began fleshing out more of the way the adventure game would be designed and conducted. We designed it so that pairs of children could collaboratively discover and reflect upon the new kinds of experiences. We thought it would be more enjoyable for them and also engender more reflection during and after the experience. We also designed the game to be played at different levels. The first level was planned to be fairly simple, involving pairs of children, discovering aspects of the Snark through the novel interactions, via the discovery bases and using the various magical tools and special clothing. A second level was envisioned, where the pairs of children would act as teams and play against each other at the same time. They would do this by choosing for themselves which of the various interaction spaces to engage in, in order to interact with the other team's Snark so as to change its mood, personality, etc., while also trying to maintain a desirable state in their own Snark.

Given that we now had the outline for the structure of the game we needed to identify the specific activities that were involved. These were:

- discovering virtual/physical clues and tokens
- discovering aspects about the Snark
- interacting with the Snark directly and indirectly
- downloading captured information
- reconstructing and representing a narrative about the Snark

In addition to deciding on activities we also had to work out how to depict the Snark. This included determining its appearance, personality and emotional states. We also needed to work out how much and what part of this structure to show at any one time. Our main idea was that each time it would be different, depending on what stage of the adventure the children were at and what base or tool they were using. We thus had to consider how the various visualizations and sonifications would relate, so that the Snark could appear to have a range of moods and other personality attributes. Essentially we decided to represent the Snark in an abstract form. This was to enable the children to use their imagination in order to determine from the minimalist abstractions what the Snark was like. In conjunction with input from children we developed a number of dynamic graphical abstractions and sounds, to depict what it looked like, how it felt, what it wanted to communicate, etc. The idea was that these would be projected onto various kinds of surfaces (e.g., on the floor, in the air, on a wall, in water) to convey its presence in different states (e.g. if it was flying, swimming, walking, hiding, sleepy, etc) (see design exhibit for details).

TECHNOLOGY CHALLENGES: INFRASTRUCTURE AND IMPLEMENTATION

Through experimenting with the various devices we quickly became aware of the technical challenges that would confront us once we started to think about how to 'stitch' the various technologies together to create the adventure game. Clearly, we needed to have some kind of integrated supporting infrastructure and middleware, in order to allow us to present the Snark as a unitary entity. To this end, we used two main software infrastructures - Equip (12) and Elvin (21) – that were designed to map device interaction to the adjustment of personal attributes of the Snark. The two are similar in many ways, but there are important differences which we wished to explore. On the one hand, Equip provides scope for supporting more services, which allows for more flexibility for integrating a range of devices. On the other, Elvin is faster and the client code is small enough to fit onto devices, like wearables, enabling a more efficient coupling between them and the real-time software visualizations we wished to run when they were in active use.

Equip: The infrastructure was designed to scale to a number of devices, each of which would publish information to a central dataspace, which is part of the Equip platform. The dataspace is a Java and C++ compatible object repository. Once running, clients can publish objects to the dataspace and/or listen for events that occur (and the corresponding data) as objects are added, updated or deleted. The dataspace was monitored by the 'Snark Engine'. This is a system component that maintained the attributes of the Snark and adjusted them according to each interaction. For example, if the first food item given to the Snark in the well is a vegetable, then the dietary attribute of the Snark is set to vegetarian. The setting of the dietary attribute formed part of a series of events that were recorded as feedback triggers. Such triggers resulted in an update to the dataspace that would be detected by a proxy running local to the client. This acts as a bridge between the dataspace and the device specific platform, such as Director. Figure 1 illustrates this set-up with the Magic Well shown in detail.

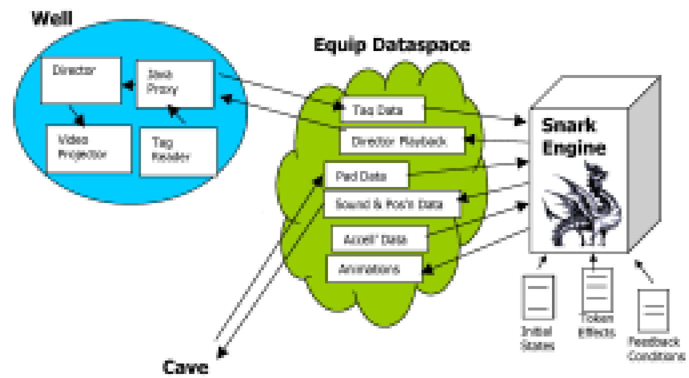

Figure 1 Outline of the Software Infrastructure. For the Magic Well, a Java proxy would publish details of the RFID tokens that have been added. The Snark Engine detects this and produces feedback (in the form of a Director movie name) when appropriate which is in turn detected by the Well's Java Proxy. This is then communicated to Director via a TCP/IP data connection, and the movie is played.

The Snark Engine was designed as a state machine in which initial states are modified according to input, which at certain points would trigger feedback. For high flexibility, the details of states, interactions and feedback were recorded separately in three XML files. These are summarised as follows:

Initial States. A list of all attributes and initial values e.g. diet unset, hunger 5, happiness 5.

Token Effects. A list of possible values that may be produced by each device (such as RFID tags) and their effect on the states e.g. tag ID 5 is a meat food token, if diet is vegetarian then subtract 1 from happiness but also subtract 1 from hunger.

Feedback Conditions. A list of states and corresponding feedback data e.g. if hunger is 4 and happiness is 6 then publish Director movie name 'Happy Eater'.

The separation of these details from the logic of the Snark Engine meant the we were free to experiment with different scenarios for input and feedback without need for redesign of software. Instead, simple modifications could be made to XML files and the system could then be restarted.

Elvin: Decoupling the production and consumption of information in software systems facilitates extensibility by removing explicit dependencies between components. So called "publish/subscribe" notification architectures are comprised of undirected production, and subscription to events by their characteristics rather than their source. Elvin is such a notification service, being developed at DSTC. It was adapted for the Hunting of the Snark as a middleware platform, particularly for interfacing the jacket to the personal attributes of the Snark.

The use of Elvin as a middleware platform increased the ease with which separate components (e.g. Extra jackets) could be added to the system. Each wearable jacket acted as an Elvin publisher, pushing data to the Elvin server. A unique identifier was given to each jacket as the software was started, allowing the server to distinguish between the streams of messages. This allowed specific jackets to key relevant parts of the visualisation. This was important to make sure that the representations of the arms could be displayed on the correct side of the screen to match the placement of the children, and that they were colour coded to the right jacket.

Unlike other message notification middleware (e.g. CORBA) the overhead of using Elvin as a transport mechanism is minimal, the client library is small and efficient enough to run directly on the embedded system used in the jacket. This means that external server-based proxies to translate from the low-level raw stream of information into higher level messages for the rest of the system were unnecessary. This greatly increased the ease with which the system could be reconfigured for different numbers and types of jacket, and made it feasible to switch configurations during the experience to mask component failures from the children.

The jacket clients publish two types of message into the Elvin server, arm positions are transmitted about 10 times a second to maintain a real-time representation of the children. The gesture recognition system on the jacket publishes messages as gestures which are recognised to trigger changes in the Snark's behaviour. We also experimented briefly with a server-based gesture recognition system that interpreted gestures made up of combinations of arm positions on different jackets. This allowed us to recognise gestures made up of actions of three or four arms which were collaborative in nature as well as when both jackets were performing the same gesture. This was implemented as an Elvin consumer / publisher that registered interest for the real-time arm positions and then published gesture recognition messages back into the server.

THE CHILDREN'S EXPERIENCE OF THE INTEGRATED SNARK ADVENTURE

In this section we describe the children's experience with the Snark adventure game. Two sessions were held, one at Sussex and a second at Nottingham, where 10 pairs of children, aged between 7 and 10, took part. Each session lasted between 30 and 40 minutes. Various changes were made to the game for the showing at Nottingham, based on reflections about the technical and practical problems, together with the experiences the children had in the first session.

Stage 1: The initial briefing

To begin, pairs of children were told that the purpose of the game was to find the Snark. They were told that the Snark is a strange creature that appears in all sorts of places in different shapes and forms. Their goal was to discover as much as they could about the Snark – its appearance, its likes and dislikes – by exploring various spaces and interacting with it in different ways. They were also told that they should try to capture what they had experienced (seen or heard) using a special 'Snark camera' (see figure 2). This was an adapted toy which had a (false) lens, providing orientation and a capture button, which gave tactile feedback for each shot by vibrating the camera. The children were told that they would be able to 'download' what they had captured (as a multimedia record) at the end of the game. During the game itself one of the children acted as camera person in each of the spaces.

Figure 2 Child holding Snark camera

Stage 2: Collecting virtual/physical clues

The children are told that the Snark never appears in its entirety but only as partial glimpses in different places. To elicit these the children have to do things in the mixed reality environment. The first of these activities involved discovering a number of invisible 'virtual' objects and tokens. Once these have been located they can be transformed into visible counterpart physical tokens. These then can be used to enter the spaces where the Snark might be and/or to interact with the Snark itself.

To find the tokens the children entered a space called 'the snooper room'. They were given a 'snooper tool' to enable them to discover the clues. The snooper tool was designed as a physical/virtual interface, that used ultrasonic sensing and a handheld computer (HP Jornada 548 PDA with Windows CE) to provide the experience of making invisible objects become visible. The ceiling was wired with ultrasonic beacons readable by the handheld, allowing the coordinates of the user to be read. The snooper tool was also set up to provide various representational views of the room in relation to the children's location (see figure 3a). Hence, when they approached a hidden object, it appeared on the screen of the snooper tool (see figure 3b). Their task was to move towards the hidden objects as indicated on the display. This required them walking around the room, with the snooper tool in front of them, trying to align the virtual tokens that appeared on their screen with where they were hidden in the actual room. When they found one, the snooper tool would emit a sound, indicating that the hidden object had been found. Simultaneously a picture of what the object looked like would appear on the screen. The children could then discover its physical counterpart in the immediate vicinity by looking under a cardboard square (the room was covered in such squares, some of which had objects under them). This process was repeated until all the physical tokens were discovered.

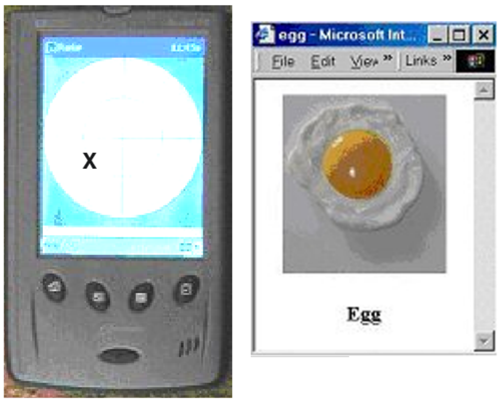

Figure 3a and 3b: The snooper tool display: (a) with representation of hidden object as an X on visualisation of the room in radar mode and (b) the discovery of a hidden food token in the room

The children easily understood the purpose of this part of the game and moved around the room in search of the items. They had no problem understanding that the invisible, as represented as pictures on the screen, could then be realised as physical tokens. They also readily understood the floor map used and their position in relation to it on the snooper tool. Once the children had collected all the available tokens they moved to the first discovery base, which was designed as a well.

Stage 3: Transforming physical food tokens into virtual food to feed the Snark

The well was designed to provide the children with an experience of the Snark's feeding habits. For this, the children had 'snooped' six physical food tokens. These were small plastic facsimiles of food, e.g. chicken, tomato, onion, with RFID tags concealed inside them(see figure 4), which they took to the well. At the heart of this was a horizontal, back-projected display screen with a concealed data projector to provide visualisations. The screen was embellished with grass and stones to mimic the appearance of a real well. On the side of the well was a 'feeding chute' with a concealed RFID Tag Reader (Texas Instruments Reader 600) which identified any RFID-tagged object dropped into it.

As the children entered the space the sound of something splashing could be heard. This was to attract them to the well itself and suggest the Snark's presence inside it. Once there they could see (a Director visualisation of) water rippling on the well's surface. They were asked what they could do to attract the Snark to the surface, to which 'feed it!' was the immediately apparent answer. The children, sometimes with a little direction, posted a food token into the chute. As it disappeared from sight in the chute there was a splashing noise (food enters the water) and the object appeared virtually, diminishing in size. The reader identified the token and triggered a visualisation on the screen (well surface) to show the Snark's response. These visualisations were deliberately fairly abstract (figure 5) showing the form of a mouth, with appropriate noises, to convey disgust or appreciation of the food the Snark had been given. Colour coding was used for the expressions, red for dislike, green for like. Thus the Snark could be vegetarian, liking tomato and disliking chicken, or sweet-toothed, liking cookies but not other things and so on. Posting all six tokens gives the children information about what the Snark liked to eat. The various conditions were based on output from the Snark engine and could be changed for each visit to the well. Since the preferences could be dynamically changed, no two visits to the well were the same.

The well uses continuity of perception to achieve a high permeability for objects across the physical/virtual interface. The novel experience for the children is that of making physical objects continuous with virtual ones – the tokens in their hand become ones sinking in the well and eaten by the Snark. In terms of the game, the well provided the first experience of the Snark and an indication that it has a volatile personality! The children were very taken by the appearance of the Snark's satisfaction or dissatisfaction with what it had been given and instantly knew what it meant. The contrasting green and red images used to indicate these opposing states worked well. The children were sometimes taken by surprise, however, when the Snark showed a dislike for a food they thought it would like. The different responses made them think: they found it puzzling to work out why the Snark might like certain foods and why it might dislike others. For example, why did the Snark like a cookie but not an egg? Why did it like everything except the onion?

Figure 4 Examples of the RFID tagged food

Figure 5a and b: The facial expressions of the Snark at the well when fed food (unhappy red turned down lips and green happy smile)

Stage 4: Creating sounds for the Snark to respond to through embodied movement

Once the Snark had been fed all the tokens it would swim away, either satiated or hungry and happy or sad, depending on whether it had been fed food it liked or disliked. The children would then have to look elsewhere for it. They were told they may find it again in a cave, another space in the environment. To be able to enter the cave, though, they needed to use some more of the tokens they had collected, and understand the transform that would allow them to do this.

To enter the cave they used one of a set of special music tokens, that had previously been collected in the snooper room. Outside the cave was a tag reader disguised as a 'sound box' which could identify a token as it was placed on it and trigger a linked file, playing a single sound, at which point the cave opened allowing the children to enter. The cave was designed as a darkened enclosure, three metre cube. On entering the cave the children had to find out what sounds the Snark liked and disliked. The idea of this was to suggest to the children that it was the Snark's responses to the sounds they created that was important here, just as the appearance of the well tokens suggested the relevance of feeding.

Inside the cave the floor was covered with a 3 x 3 array of pressure-sensitive pads. The cave was programmed so that the children's movements on the pads triggered a particular kind of environmental sound: a stream, a jungle or the wind. Depending on where they moved in the space, the volume of the current sound would change. The children had to collaborate in order to find out which two pads gave maximum volume, at which point there was a flash of light (for dramatic effect and to indicate that a Snark picture should be taken) and the Snark cried out. The Snark's possible vocalisations were excited, scared and nonchalant, indicating its likes/dislikes for the noises the children had triggered by their movements. The children repeated the cycle of token-entry-experiment for all three tokens.

The cave uses a mapping between actions/effects (movements creating sounds) and the Snark's responses to create the illusion of physical-virtual continuity. In terms of the goals of the game it was fairly successful in that the children did form strong views about what the Snark liked/disliked. In terms of creating an illusion of physical/virtual continuity, it was less so. Part of the reason for this may lie in the nature of the contingencies for the traversal designed for the cave. The mapping between collaborating in physical location (what pads are stepped on) and volume of sound was somewhat arbitrary and sometimes got in the way of a perception of seamless continuity.

Stage 5: Flying with the Snark through collaborative gesturing

The goal of this part of the adventure was to allow the children to interact with the Snark, seen flying through the air, in order to find out something about its personality through the way it moved. Here the children enter the 'flying space' with one token left, a large key, which allows them to open a box. Inside the box were two 'magic flying jackets', which are anoraks enhanced for wearable computing, based on the Bristol CyberJacket model (see design exhibit for details). The jackets contained no visible hardware or wiring, with components stitched into the lining and powered by long-life batteries. The hardware was based upon using two ADS-Bitsy boards each with a StrongArm1100 processor with 32 Mb of memory and 32Mb of flash storage. These were interfaced to accelerometer sensors embedded in the sleeves of the jacket which gave real-time data on gestures, as arm angles relative to the body and other movements. The jackets were also linked via a wireless network system to a visualisation server, providing feedback on a large screen, via a data projector. The feedback was both visual and 3D audio. The infrastructure configuration that ran the flying jackets used a Linux server. A separate Windows machine was used to run the Director movies for the visualisations and control the video projector. The jackets produced both a real-time stream of arm positions and a stream of gesture codes as, and when gestures were recognised in the system. These were transmitted to Elvin, which collected the information from both the jackets and sent the information to the Director movie which used it to control animations and sound effects.

The two children's arms were represented on the screen along with the Snark. The Snark has three positions (far away, middle and close), and the arms of the children were represented at the bottom of the screen. The animation of the Snark changed depending on what the children's arms were doing, as follows:

- If neither jacket is registering arm movement then the Snark is sad and a slowly moving, dark blue square in the distance.
- If either one of the jackets is banking in either direction then the Snark comes to the middle of the screen and registers interest. It is shown as a green square with faster movements.
- If either jacket is flapping then the Snark comes to the middle and registers interest and slight confusion because the two aren't both together.
- If both jackets are banking the same way then the Snark comes close and laughs.
- If both are flapping together then the Snark comes close and is very happy, soaring and swinging and gliding.

After donning the jackets the children faced the screen and were encouraged to move their arms as though they were flying. Two versions of linking the Snark with the children's combined movements were tried (see figure 6). In one, the Snark movements mimicked what the children did. In the other, the Snark responded with different noises and movements of its own, to the gestures that the children made. The interactivity was constrained by having some, but not all, of the possible children's gestures (arm movements) cause a response. For example synchronous 'banking' – both tilting the body in conjunction with a flapping arm - was an effective gesture but asynchronous banking movements were not. As the children experimented, they could learn which gestures the Snark would respond to favourably. A further refinement was that the children needed to collaborate on their gestures in order to succeed: they had to perform the same actions.

The flying space uses a direct mapping between actions and the Snark's responses to create the illusion of physical-virtual continuity. The children really enjoyed moving their arms and watching the effect of doing this on the screen, but simply having the Snark mimic what they did (with a time lag) was not very interesting nor did they learn much about the Snark. The second version worked much better and the children were able to understand what was going on and make more inferences about the Snark's behaviour (e.g. "it liked it when I flapped my arms").

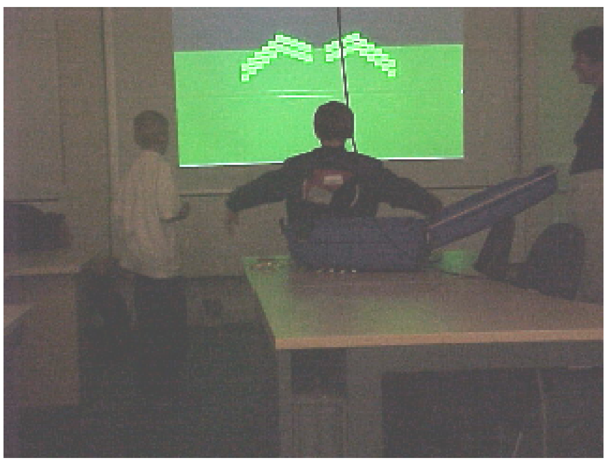

Figure 6a Version 1 of the flying jacket in action, with the Snark mimicking the children's arm movements

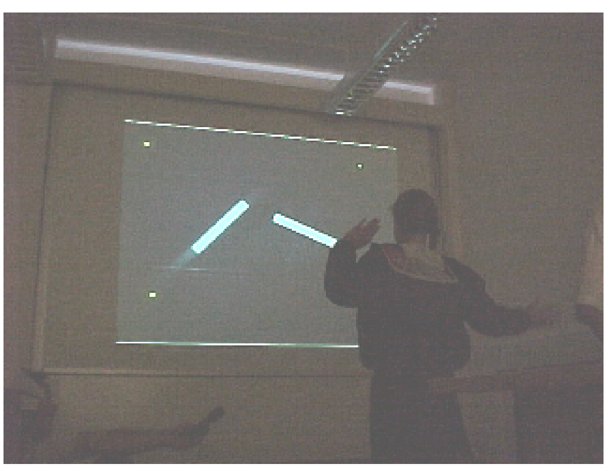

Figure 6b Version 2 of the flying jacket in action, with the Snark responding (small green squares) to the child's arm movements on the screen (represented as moving blue bars)

Stage 6. Reflection on the children's experiences of the Snark adventure game

The final stage in the game was for the children to take their Snark camera and 'download' what they had 'captured'. They did this by taking the Snark camera to a laptop, where the Equip Snark engine allowed them to play back the events that had been recorded. This was to allow the children to reflect on their experiences of the Snark. The children captured all aspects of the Snark throughout their adventure and frequently used the 'Snark camera'. The tactile feedback when the button was pressed on the camera added to the excitement and made them believe they were really capturing the events.

When the images, animations and sounds were subsequently 'downloaded' at the end of the game onto the computer, they were instantly reminded of their experiences with the Snark, enabling them to reflect what the Snark was like and what it was doing. The download procedure worked very smoothly and the children had no trouble recognising the snapshots and what they meant in terms of the Snark's appearance or personality.

As well as downloading the children were taken back to the various discovery bases to tell us what they thought had been going on. The reason for revisiting them was that it is well-known finding that situated memory is better for remembering and reflecting on things than recalling them out of context.

OUR REFLECTIONS ON THE FINDINGS

The sessions with the pairs of children were recorded, using a number of video and cam-recorders discreetly positioned in the Snark spaces. The children also wore wireless microphones to enable us to track what they were saying. Both proved to be effective at capturing the children's experiences as they moved around the interactive environment. Our preliminary analysis of what the children said and did during the adventure game and afterwards when they downloaded the images collected and revisited the interaction spaces indicate that overall the children were engrossed by the whole adventure game. They were also able to collaboratively discover aspects about the Snark and talk about these at length.

In relation to their understanding of the transforms and traversals, we found that the children had few problems with them. There were also several instances where the children tried different things and actions to try to elicit Snark responses, which we had not anticipated and which were prompted by particular situations. For example, in the cave one pair of children elicited the initial Snark's responses reasonably quickly, but found it harder to know what to do when interacting with the pressure pads for the last one. During this session they began to try different things e.g. jumping, straddling more than one square at a time. It appeared that once they had understood and achieved the initial task, and then had difficulty in achieving the task again, that this difficulty triggered them to explore different ways of doing it. They were in effect forced to think about how they had previously elicited a response. Thus, the unexpected caused them to question their understanding and try something different. This could also facilitate questions about their understanding, such as why do you think 'x' worked and 'y' didn't.

We also found there was a trade-off between the amount of direction given to the children as to what they should do in the interaction spaces and the amount of exploration that took place. It seemed that the more direction given the less exploration that took place, but if too little direction was given then the children sometimes got confused, resulting in less spontaneous involvement. For example, explicit direction in the cave enabled children to elicit the digital response, but without having to explore or think about how they might achieve this. Intertwined with this, the amount of exploration taking place also seemed dependent on the ease at which the feedback was received. Thus, in the cave when the digital feedback was fairly immediate, the children were highly motivated and carried out the activities in a straightforward and essentially 'reactive' mode. It was when they were given the opportunity to repeat a similar experience in a modified form that provided them with the challenge to explore the space in more diverse ways.

DISCUSSION AND CONCLUSIONS

In this paper we have described an approach to the design of novel experiences. How successful were we in terms of what happened with the Snark game?

Firstly let us consider the user experience. As we have already mentioned the children uniformly found the game to be engrossing, to the point of insisting on making return visits. On the level of understanding specific events and mappings between action and effect, the children seemed to understand the transforms we implemented. Examples include (i) the transformation of appearance, such as of virtual snooper objects to physical tokens and of physical food tokens to virtual eating in the well and (ii) transforms of action resulting from physical action causing Snark responses such as the sounds in the cave and flying with the magic jackets. There were also indications from the children's expressions and comments during the adventure that they did on occasion, stop and wonder, about these. Moreover, the various experiences provoked many of the children to form models of what was going on. They came up with a number of explanations of what they thought was happening in the download session. For example they said: "putting food in the chute makes the Snark come into the pond" (for the well) and "If you make a loud sound - it likes a loud sound so it shows up on here (the screen)". (for the cave).

However, not all the children were so articulate and some found it difficult to explain the models of causality they had for our designed transforms. This may point to an inherent tension in our design goals since having things run very smoothly (seamlessly) is, paradoxically here, not ideally suited for reflection. However we also observed interesting experimentation on the part of some children, particularly with the physical artefacts. For example, in one case children who didn't hold the Snooper tool (PDA) level, tended to tip it forwards or sideways as if trying to get the dot on the display to move to the middle by their actions. In another case children tried experimenting with the RFID-tagged tokens outside the cave by seeing how many could be played at once. This suggests that we could design more unpredictability into the artefacts themselves in order to increase further playful exploration.

Of all the discovery bases, the well proved to be the most successful insofar as the transform appeared seamless to the children, while at the same time the effects of their interactions with the Snark, provoked them into thinking about the motivations behind its likes and dislikes. Interestingly, though, a common initial intuition was to put food directly onto the water surface (the embedded monitor) and not use the feeding chute. The familiar activity of 'feeding the ducks' was what was behind this expectation. Another case was the expectation that the Snark would appear where the children placed the food (i.e. in the chute), rather than at a more 'remote' location (i.e. in the well). For example, some children peered intently down the chute as they posted the food. This raises issues about how we implemented the conceptual framework of transforms and traversals that we derived and used to inform the design of our novel user experiences. In general these designs were both effective and evocative. However, the kind of observations detailed above also revealed to us that more thought needs to go into how to weave real world-based affordances with novel transformations. In particular, if we want to promote seamless continuity between the physical and the virtual, while at the same provoking wonder, then we may need to design an interactive environment where novelty is appropriately embedded in familiarity.

Finally, we should comment on the value of what we called our research aesthetics, technology inspiration and promoting playful technology. Did we succeed with these? The process of technology inspiration has worked remarkably well but it does require the kind of multidisciplinary brainstorming and hard multi-site workshops that we described. The back and forth between wild imagination and harsh technical realities is familiar to many software development projects. Such interactions are even more likely when thinking about cutting-edge technologies, where the dreams and the reality can be much further apart. In sum, our aim of promoting playful technology was, we believe, innovative as witnessed by the spirit in which the children interacted with and commented on the game we developed. Some of this 'success' was a consequence of the sheer novelty of the experiences provided. But it is also fair to say that without our own playful excursion into the technology we would not have been able to design creatively, doing so as much for the joy of travelling as in the hope of arriving.

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REFERENCES

1. Philips Vision of the Future: www.design.philips.com/vof/vofsite3/vof3main.htm

2. HP Cooltown: www.cooltown.hp.com

3. IBM User Sciences and Experience Research (USER) lab, IBM's Almaden Research Center (San José, CA). www.almaden.ibm.com/cs/user.html

4. MIT Media Lab: www.media.mit.edu/

5. RED, Xerox PARC: www.parc.xerox.com/red/

6. The Equator Project www.equator.ac.uk

7. Back, M., Cohen, J., Gold, R., Harrison, S. and Minneman, S. (2001) Listen Reader: An electronically augmented paper-based book. In *CHI'2001 proc.* 23-29.

8. Bruner, J.S. (1979) On knowing Cambridge, Mass. : Belknap Press of Harvard University Press

9. Cassell, J. and Ryokai, K. (2001). "Making Space for Voice: Technologies to Support Children's Fantasy and Storytelling." Personal Technologies 5(3): 203-224.

10. Colella V., Borovoy R. & Resnick M. (1998). Participatory Simulations: Using Computational Objects to Learn about Dynamic Systems. Proceedings of the CHI98, Los Angeles, CA, 18-23 April 98, 9-10.

11. Drascic, D. & Milgram, P. (1996) Perceptual Issues in Augmented Reality. In Bolas, M.T., Fisher S.S. and Merritt, J.O. (Eds.) SPIE Volume 2653: Stereoscopic Displays and Virtual Reality Systems III. San Jose, California, USA, 123-134.

12. Greenhalgh, C. Izadi, S., Rodden, T. and Benford, S. (2001) The EQUIP Platform: Bringing Together Physical and Virtual Worlds Submitted. www.dcs.gla.ac.uk/~matthew/lectures/HCI4/greenhalghEquip.pdf

13. Koleva, B. N., Schnadelbach, H. M., Benford, S. D. and Greenhalgh, C. M., Traversable interfaces between real and virtual worlds, in Proc. ACM Conference on Human Factors in Computing Systems (CHI 2000), Hague, Netherlands, April 2000, pp.233-240, ACM Press

14. Koleva, B., Taylor, I., Benford, S., Fraser, M., Greeenhalgh, C., Schnadelbach, vom Lehn, D., Heath, C., Row-Fatt, J., Adams, M. (2001) Orchestrating a mixed reality performance. CHI'2001 Proc, 38-45

15. Kolomyjec B., Cassell J., Kafai B.Y. & Williamson M. (1997). The implications of a theory of play for the design of computer toys. Proceedings of the 24th annual conference on Computer graphics & interactive techniques, 431-433.

16. Leont'ev, A.N. (1981) Problems of the development of mind. Progress Press, Moscow

17. Monk, A.F. (2000) User-centred design: the home use challenge. In Sloane, A. and van Rijn, F. Home informatics and telematics: information technology and society. Boston: Kluwer Academic Publishers, pp. 181-190.

18. Randell, C & Muller, H. 2001 Low Cost Indoor Positioning System. In Gregory D. Abowd, editor, Ubicomp 2001: Ubiquitous Computing, pages 42--48. Springer-Verlag

19. Resnick M., Martin F., Berg R., Borovoy R., Colella V., Kramer K. & Silverman B. (1998) Digital Manipulatives: New Toys to Think with. Proc. of the CHI 98, Los Angeles, CA, 281-287

20. Scaife, M. & Rogers, Y. (2001) Informing the design of a virtual environment to support learning in children. International Journal of Human-Computer Studies ,55, 115-143

21. Segall, B. and Arnold, D. Elvin has left the building: A publish/subscribe notification service with quenching. Proceedings AUUG Technical Conference (AUUG'97), pp. 243-255 (September 1997)

22. Stanton, D., Bayon, V., Neale, H., Ghali, A., Benford, S., Cobb, S., Ingram, R., Wilson, J., Pridmore, T. and O'Malley, C., Classroom Collaboration in the Design of Tangible Interfaces for Storytelling, in *Proc. CHI 2001*, pp. 482-489, ACM Press

23. Thackara, J. (2000) Advance abstract for Opening Plenary DIS200 http://www.acm.org/sigs/sigchi/chi2000/advance-program/main.cgi?function=view_session&session=ple_101 (full paper is: Edge Effects: The Design Challenge of Pervasive Computing interactions Vol. 8, No. 3 (May 2001), Pages 46-52.

24. Vygotsky,L.S. (1978) Mind in Society. MIT Press, Cambridge MA.