Making Magic:
Designing for Open Interactions in Museum Settings

Robyn Taylor[1], John Bowers[1], Bettina Nissen[1], Gavin Wood[1], Qasim Chaudhry[1],
Peter Wright[1], Lindsey Bruce[2], Sarah Glynn[2], Helen Mallinson[2], Roy Bearpark[2]

[1]Culture Lab, Newcastle University,
Newcastle upon Tyne, UK
initial.surname@ncl.ac.uk

[2]Great North Museum: Hancock,
Tyne and Wear Museums, Newcastle upon Tyne, UK
initial.surname@twmuseums.co.uk

ABSTRACT
This paper describes three interactive artefacts created for a children's exhibition intended to encourage creativity and allow educational opportunities to emerge naturally through playful exploration. We describe five sensibilities that were used to inform our designs: considering artefacts as resources and scaffolds for imaginative engagement, rewarding extended investment, facilitating requisite unpredictability, encouraging an imaginative orientation to participation, and permitting multiple loci for interaction. Based on observation of how our interactives were used by the public, we discuss how our approach facilitated 'open interactions' in a manner that was sensitive to the museum context, favoured a mix of materialities, and manifested a subtle mix of participation and designer autonomy.

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INTRODUCTION
The Victoria and Albert Museum's *Magic Worlds* was a child-oriented exhibition that invited visitors to explore fairy tales, fantasy literature, and the origins of magic and illusion. Drawing from the museum's national childhood collection, a touring version of V&A's Magic Worlds was presented in several British museums in 2013 to 2014. Each host museum was able to make local design enhancements to complement and augment the touring exhibition.

In 2014, our research team designed and crafted bespoke interactive digital content that was used as part of a three-month installation of Magic Worlds at the Great North Museum:Hancock (GNM), located in Newcastle upon Tyne. Working together with the exhibition designer, educational director, and the museum manager over a period of several months, we created three digital artefacts for the exhibition: an interactive witch's cauldron that responded with audio-visual feedback when children cast spells by throwing ingredients into the cauldron, and two magic mirrors that displayed fantastical reflections and optical effects. These artefacts were carefully placed within the overall spatial design of the exhibition so as to create possibilities for story-telling and dramatic play within the setting. The GNM's presentation of the Magic Worlds exhibition was extremely popular, receiving 154,655 visitors during the three months it was open to the public – making it the museum's most well-attended exhibition since its reopening in 2009.

Figure 1. Helen, the Gallery Interpreter, plays with the Magic Cauldron alongside a child visiting the exhibition

In this paper we explore how the Magic Worlds exhibition provided us with an opportunity to design interactive pieces intended to support a children's museum in facilitating open-ended enquiry and creative exploration. We built our approach upon current research surrounding the use of digital interactives in museum settings [14], the exploration of playful design [13] strategies in HCI and how the experience of interactive technology is shaped by and shapes the overall design of the setting [10]. We define a

series of *design sensibilities* that helped inform the making of three compelling digital interactives that were congruent with the stylistic and educational goals of the exhibition, and discuss several interesting phenomena we observed arising from their use. We follow an orientation to Research through Design which recognizes that there is a mutual refining of the designed artefacts and the detailed sense we give to our sensibilities as the design process unfolds (c.f. [3,12]) Overall, we characterize our work as situated, favouring a mix of materialities, and manifesting a mix of participation and designer autonomy. Taken together this makes a contribution to how museum design can be reimagined as a resource for designing open interaction.

THE MUSEUM AND EXHIBITION CONTEXT
There exists a substantial and varied body of literature in human computer interaction (HCI) and computer supported cooperative work (CSCW) addressing the complexity of designing for modern museum and related cultural spaces. [11] and [10] describe some early explorations of the use of ubiquitous computing and mixed reality technologies in, respectively, a castle and a personal collection, giving particular attention to the design of trajectories through multiple interactive 'loci' – an emphasis given further analysis by [2]. [8] has been particularly concerned to draw upon 'place geography' in design work in museum and heritage sites to create characterful and meaningful hybrid digital artefacts within them. Heath, Hindmarsh, vom Lehn and colleagues in an extensive body of work [e.g. 14, 15] have analysed the details of social interaction within museum and related settings, drawing out a number of implications for design and research agendas in HCI and CSCW more broadly. To give a final example of work in such settings, Nissen and colleagues [19] explore how fabrication technologies can be used to create bespoke souvenirs based on individuals' experience of an exhibition.

This research literature is an essential context for our work. So, equally, are the specific contingencies associated with the opportunities we had. As a touring exhibition, Magic Worlds was already organized around the V&A's own design commitments but these left much undetermined. Local museums hosting the exhibition could not only add items from their own collections but also give the overall architecture of the exhibition space a specific character. Equally, our digital artefacts were not produced 'to brief'. We had creative licence with them under the overall aegis of relevance to the Magic Worlds theme. Indeed, the local design of the exhibition space was developed mindful of the fact that digital artefacts were under development and, as their form began to emerge, particular locations in the exhibition were selected for them and the local context in which these artefacts would appear was shaped to maximize visitors' potential appreciation of them. As such, Magic Worlds presented a fascinating occasion to explore the complex 'entanglements' and 'meshwork' involved in

making [1,17] and the different constraints and enablements which configure design spaces.

The Layout and Visit Trajectory of Magic Worlds
Magic Worlds was installed in a 500m^2 gallery space in the GNM that was divided into three major rooms, each themed in accordance with the V&A's selection of artefacts around a different aspect of magic and folklore: fantasy, illusion, and enchantment. The 'Fantasy' room featured materials relating to fairy tales and fantasy literature, 'Illusion' showcased the history of magicians and magic-as-spectacle, as well as examples of classic optical devices and trickery. The third room, 'Enchantment' focused on magical creatures and beings such as dragons, fairies and elves. In each of the exhibition's rooms, familiar scenes and settings from literature and folklore were staged in child-size miniature. Visitors to the 'Fantasy' room, for example, encountered a variety of themed play areas such as a child-sized gingerbread house from Hansel and Gretel, and a walk-in wardrobe space from The Lion, the Witch and the Wardrobe, while the 'Enchantment' area was styled as a magical meadow populated by fairies and dragons. Each area and referenced story corresponded to artefacts and educational materials situated nearby.

Much emphasis was placed on the importance of crafting visitors' trajectories of experience through the exhibition [cf. 2]. As the gallery was divided into several spaces, each themed space was made visually and sonically distinct with the goal that visitors would thoroughly explore and engage with one space before progressing through to the next. To encourage a flow of movement throughout the exhibition, transitions between the major themed areas were carefully crafted, stimulating the senses through appealing staging and set design (notable transitions included a tree-lined canopy leading into 'Fantasy' and a vintage-styled hall of mirrors welcoming visitors into the world of 'Illusion') in order to tempt visitors onward to find out what came next. It was intended that this journey – a winding path of exploration and discovery – would add to visitors' enjoyment of and engagement with the exhibition.

The Exhibition 'Interactives'
The GNM wanted the experience of visiting Magic Worlds to differ from a traditional museum visit, in order to challenge any lingering perception of museums as stilted, inaccessible places where visitors are only permitted to look but not touch. As the museum manager put it in a recorded group discussion: "we want people to care about the venue, to care about the objects. If you constantly put barriers between them and the stories and the objects, it becomes very difficult for them to [care]". To encourage visitors to engage with the exhibition content through hands-on activity, many pieces were physically accessible to the patrons. The designers of Magic Worlds provided an extensive array of costumes and props, and encouraged the

children to touch, wear and use them as they visited, explored, and play-acted inside the exhibition space.

We created three digital interactives for the exhibition – two 'magic mirrors' (one residing in the 'Fantasy' room, and one in the 'Illusion' room) and a 'magic cauldron' situated in a small room of its own next to the 'Enchantment' space, and styled in the theme of literary witches and witchcraft. The digital interactives as well as the expanded collection of costumes and props were intended to encourage children to play-act and engage with the story-based spaces. It was hoped that, by providing numerous opportunities for hands-on, interactive play, the exhibition content would inspire social exchange and provide creative stimulation for further discovery. Later in this paper we will explore how successful our strategies were.

Enquiry-Based Learning Through Hands-On Activity

Magic Worlds did not present curriculum-based educational content in a traditional manner, but rather exhibited an open-ended collection of materials intended to support and stimulate children's creativity and curiosity by presenting classic literature and folklore in an accessible fashion. The museum's educational goal was to encourage 'enquiry-based learning' [18] whereby educational opportunities were allowed to grow naturally out of playful visitor experiences. The GNM's learning officer elaborated on the museum's belief that open ended enquiry and exploration would lead to learning, citing the work of Piaget, Vygotsky and Bruner [e.g. 23] on cognitive and social constructivism. The learning officer explained that their vision for Magic Worlds was to enable visitors to craft their own individual journey through the experience. Educational opportunities or avenues for discovery would arise as visitors constructed their own knowledge through firsthand explorations with artefacts – encounters mediated by parents or Gallery Interpreters or through peer-to-peer interaction and play.

Anticipated Visitors

While many school groups toured and visited the exhibition, the GNM also wanted to target family groups comprising individuals from different age groups, and provide avenues for family members to interact with and alongside one another. The design of the interactives – both the traditional (such as costume pieces and cozy family reading spaces) as well as the digital – intended to challenge and stimulate older children while simultaneously engaging younger family members as well. The GNM also wanted to make sure that the exhibition would encourage families to make repeat visits, with the intention being that the exhibition should be enjoyable on multiple levels. Entry to the museum was free, and it was hoped that children whose first visit consisted primarily of discovering and playing in the space might engage more thoughtfully with specific artefacts or interactives on subsequent visits. These concerns of the museum relate very strongly to the

contributions of Heath and his colleagues [e.g.14, 15] which emphasize how visits are typically made within small groups who manifest quite characteristic patterns of interaction – for example, animating exhibits for each other, comparing perceptions, adults facilitating the engagement of children, and so forth – and all of this done in the presence of other such groupings.

The Role of the Gallery Interpreter

To facilitate and support social interaction in the exhibition, the GNM brought in Helen, a specially trained Gallery Interpreter. While also being responsible for ensuring museum safety and performing daily routine operational tasks, Helen's function as a Gallery Interpreter differed from that of a traditional 'invigilator' or 'docent'. While she was available to protect and provide knowledge about the exhibition artefacts if needed, her primary role was to scaffold social interactions amongst the families visiting the space. She was encouraged to mediate the visitor experience by stimulating and even modeling role-play and creative, educational interaction, functioning in a manner similar to the role of 'orchestrator' described by Benford and Giannachi [2]. Joining alongside visitors to take part in creative play (see Fig. 1) allowed Helen to function as what Heath et al. term a co-participant [14], able to influence visitors' experience simply by visibly engaging with the exhibition herself. Helen worked on-site six days a week during the entirety of Magic Worlds' run. Later in this discussion we will explore how her situated understanding of the experience was helpful when evaluating and making sense of the way our interactives were used by the public.

DESIGNING THE DIGITAL INTERACTIVES

We began exploratory design work on potential digital interactives several months before the GNM exhibition's launch. Through collaborative discussion with museum stakeholders (including the exhibition designer, the educational director and the museum manager) the digital designers in our team explored how interactive digital content could enrich the visitor experience.

Design Sensibilities

Alongside engaging in a variety of design activities, we began to formulate design sensibilities on the basis of some of the above concerns of the museum, our own past work and creative practices, and other relevant contributions within HCI and CSCW, such as the works of Heath, Hindmarsh and vom Lem (e.g. [14] [15].) In addition, we consider the work of Humphrey and Gutwill, whose discussion of 'Active Prolonged Engagement' (APE) [16] extensively explores how educational value is obtained through deepening visitors' interactions and personal processes of meaning-making rather than simply by measurably increasing their canonical knowledge. Humphrey and Gutwill further distinguish APE from what they term 'planned discovery' [16] in which encounters with museum content are carefully orchestrated to

maximize the discoverability of educational content. Accordingly, rather than deterministically directing exactly what it would be that visitors were intended to learn from their own participation, we identified five design sensibilities to create a design space in which play and discovery were emphasized in a manner consistent with the GNM's goals for the exhibition. These provided initial orientations for our design activity that were subsequently refined as our design work unfolded.

1) Resourcing and scaffolding. In contrast to firmly enshrining a story or meaning into the technology, whatever is designed should instead enable and inspire creative storytelling and acting out, allowing children to imagine and discover the content of their play. In this way, technologies serve as a resource for interaction, rather than mandate what should occur [cf. 17, 20]. This approach allows the Gallery Interpreter to appropriate the interactives rather than merely enact what their 'rules' require. Where constraint is designed into the artefact, it should be for the purposes of configuring participation rather than restricting visitors' creative choices and/or forcing them down a path of 'planned discovery' [16]. In this way, adults might be able to 'scaffold' the activities of children, to use Bruner's term [6], rather than tell them what to do.

 2) Rewarding extended investment. Artefacts should be designed such that prolonged or repeated exposure should yield deepening engagement, whether through revealed complexities, or by encountering a greater breadth of creative stimuli [13]. While extended engagement should uncover more of interest, we did not want casual encounters to somehow feel incomplete. Accordingly, we concerned ourselves with artefacts which manifested a variety of behaviours, any one of which might offer some intrigue, but where extended curiosity uncovered more of the picture, without there being a sense that there was a hidden goal, which might frustrate if not discovered [see also 3].

3) Robustness yet requisite unpredictability. Artefacts should maintain an acceptable level of (physical and interactive) robustness, while introducing a requisite level of unpredictability in order to stimulate engagement through mystery. Dalsgaard terms this as designing for 'inquisitive use' [9]. Bowers [3] in his analysis of the work of designs such as the drift table [13], argues that they are appealing because they have interactivity which combines the right kind of unpredictability (so users 'steer' the pieces, rather than control them) with known states that are easy to get (back) to or recognise if troubles occur.

4) Encouraging imaginative orientation to participation. To design technology that exists at the intersection of multiple potential users and permits a multiplicity of footings from which it can be encountered, design should be mindful that participation with the artefact could take many forms [14,16,21,22]. So exactly *how* one should participate with the technology should be a matter for flexible, imaginative appropriation too.

5) Multiple loci for interaction, trajectories and placements. As we have described, any digital interactive we were to build would need to coexist with many other things. It would not be appropriate for digital pieces to overshadow the other exhibition content, nor require ways of engaging with them which were out of keeping. Thus we avoided artefacts that were recognisably interactives favouring an embedded computing and sensor-based approach. Also, by carefully placing a number of devices through the exhibition, we aimed for each piece to afford a 'locus for interaction' [10] within the visit trajectory [2].

The Design Process
Identifying and finalizing the particular digital interactives was done through a collaborative process that saw our digital interaction researchers meet several times with the museum manager, exhibition designer, and the educational director. In between these meetings, our digital designers met independently to brainstorm and generate ideas. This allowed us to address the museum's needs and desires, while still maintaining some autonomy over our own design practice and digital research goals. Correspondingly, as design ideas emerged, the museum designers were able to anticipate the best locations for the pieces and to ensure that their surrounding contexts promoted the intended experience of them.

The initial meeting with the whole team allowed us to share the museum's vision for the exhibition, identifying several aspects of the Magic Worlds national content that could benefit from digital enhancement. In a half-day workshop, our digital design team began by discussing, exploring and elaborating the design sensibilities we hoped to embody in our interactive artefacts. With these design sensibilities in mind, we held a freeform brainstorming session whereby we suggested and debated numerous ideas for artefacts we hoped would fit well with the museum's interests while remaining aligned with our creative vision for interaction design. Some twenty proposals were offered. We then critically evaluated this array of initial ideas, in terms of their clarity, feasibility, relevance to the exhibition, the degree of collective enthusiasm shown for them amongst the digital designers, and a general anticipation of their research value. A long short-list of six proposals was discussed together with the museum stakeholders. We further examined the practicalities and logistics of realising each proposal, as well as the educational potential and thematic congruence each idea would contribute to the Magic Worlds exhibition as a whole. Three interactive digital artefacts were mutually agreed upon as particularly suitable.

CRAFTING THE INTERACTIVE ARTEFACTS
The first two artefacts we built were *magic mirrors*. The first one would be situated in the 'Fantasy' area, where children were encouraged to try on an array of playful fairytale costumes and examine their reflections in a magic

mirror augmented with digital technology. The second magic mirror was to be placed in the 'Illusion' area, which had previously been identified as an aspect of the exhibition that would benefit from the inclusion of interactive reference points for young children to engage with. The third digital artefact would be a *magic cauldron*, with digital technologies used to make children's interactions generate audio-visual response and provide a scaffolding resource for stories and play-acting around casting spells.

Magic Mirrors

The mirrors were implemented using 42-inch flatscreen monitors that were mounted in portrait orientation on the walls of the exhibition space. To disguise the monitors and make them coherent with the exhibition's physical aesthetic, we fashioned elegant antiqued-gold picture frames (made from lightweight wood and firmly attached to each monitor's casing) that concealed the plastic monitor bezels. Mounted in the top of each picture frame was a digital camera whose field of view was trained upon the space in which a visitor would stand if looking at the framed monitor. Displaying a horizontally flipped stream of the live camera feed on the monitor display allowed the visitor to see him/herself as if in a mirror (see Fig. 2.) While both mirrors were physically identical, they functioned in two distinctly different ways, with one 'magic' mirror transforming time, and the other manipulating space.

Delay Mirror

The Delay Mirror's 'magic' trickery was based upon manipulating the temporality of how a visitor saw his/her mirrored reflection. At times the Delay Mirror behaved like a normal mirror, showing a live feed of the visitor's reflection. However, after several seconds the visitor might observe a subtle surreality as the video image gradually time-shifted or reversed the camera feed.

Figure 2. Costumed girls dance in front of the Delay Mirror

Layering and overlaying time-delayed image feeds, and varying the playback speed and playback direction of the video in an unpredictable fashion produced complex visual effects. A visitor might catch sight of his/her own reflection in the mirror, seconds later only to notice a time-delayed video recording of his/her original entrance into the frame, accelerating through time to catch up seamlessly and merge back into the live feed, leaving him/her to observe a simple 'mirror image' once more. This gave the impression of a

ghost of one's past-self occasionally being visible alongside one's current self, from time to time entering and leaving one's current body. Visitors were unable to predict exactly what would happen next, or even verify what in fact they had just indeed seen – the time-shifted overlays replaying the visitor's previous behaviours were intentionally bewildering. Just when a visitor thought s/he had figured out what the mirror was doing, the mirror's behaviour would change. In keeping with our previously identified design sensibility valuing *requisite unpredictability*, we hoped that this type of ephemeral, unrepeatable interaction would engender enchantment and engagement through its very mystery, and in addition, that the mirror would *reward extended investment* with deepening knowledge. Visitors who persisted in exploring the mirror's functionality could learn to react to and exploit the layering algorithms to produce pleasing visual effects.

Kaleidoscope Mirror

As the second mirror was located in the 'illusion' space, the intention was to tie its functionality to the other artefacts in that part of the exhibition – optical illusions and classic magical trickeries. To do this, the mirror's 'magic' was enacted by manipulating the spatial orientation of the visitor's mirrored reflection. Visitors looking into the mirror could see their images dissected into shards reflected like the spirals of a traditional kaleidoscope, or bisected and reflected, making them appear a one eyed Cyclops, or in possession of two heads. Thus the Kaleidoscope Mirror referenced vintage Hall of Mirrors experiences, alongside other exhibits exploring classic magic tricks and illusions.

Placing, Encountering and Playing with the Magic Mirrors

When designing the mirrors, we were mindful of their placement within the exhibition's trajectory of discovery. The Delay Mirror was situated in the 'fantasy' room, which included a large array of fairytale costumes for dressing up so that the wearing of costumes would naturally prompt the children to seek out the mirror and discover it's functionality. Being located in the 'illusion' room, the Kaleidoscope Mirror's constantly moving and eye-catching imagery would attract the attention of children in the space. As both of the mirrors had narrow fields of view, and their 'reflections' were partially obscured when people stood in front of them, the experience of using the mirror was relatively private. As in [22], our design allowed the visitor some control over what aspects of the interaction s/he chose to reveal.

Magic Cauldron

The Magic Cauldron resided in its own witchcraft-themed small room adjoining the 'Enchantment' space dedicated to magical creatures. While most of Magic Worlds had a charming, friendly feel, the cauldron chamber had a darker, spookier atmosphere. The Magic Worlds national collection had originally contained a simple cauldron, associated with several two-dimensional painted wooden objects (such as

spiders and toads) that children could throw into it in order to play at casting magic spells. When one of our design team observed the Magic Worlds exhibition in Liverpool, it was apparent that even this very basic prop appealed to children's imaginations – although it did nothing in response, small children were enthusiastic in their willingness to don witch's robes and play around it.

We were eager to explore how we could encourage even greater engagement by augmenting the cauldron's functionality with responsive audible and visual behaviours. As children threw each item or combination of items into the cauldron, we wanted to reward them with interesting audio-visual effects, in the hopes that by exploring the feedback their actions could trigger, they would be motivated to develop ever more complex play-acting 'spells' – ideally by drawing upon the age-appropriate examples of literary and cultural witches and witchcraft that were presented as part of the Magic Worlds content. In keeping with our previously identified design sensibilites, we wanted the cauldron to be a *resource that would scaffold* creative, theatrical, 'acting out' behaviour. We needed to design an interaction system that could support *multiple orientations to participation*, as a successful feedback mapping would need to respond satisfyingly to children old enough to role-play more elaborate, nuanced games with the cauldron artefact, as well as engage and entertain younger, less sophisticated children at a simpler level. In addition, we had to anticipate that the cauldron would be used in a very challenging environment – the system we created would have to be *robust* enough to accommodate rough handling, accepting of the inevitability that the toys and objects thrown into in the cauldron would vary over the exhibition's lifespan as items went missing or were broken and replaced.

Designing a Weight-Responsive Self-Calibration Algorithm
For these reasons we had to think very carefully when designing the algorithm which mapped the children's actions to audio-visual responses. We had initially considered working with a fixed set of 'ingredients' that could be combined to produce a finite number of predefined 'spells'. This idea was rejected for reasons both practical and pedagogical. Logistically, we acknowledged the likelihood that items would routinely go missing, and that it might be difficult to find exact matches for their identical replacement. Equally, from a pedagogical perspective, we were aware that this form of interaction could overly constrain children's natural creativity.

Instead, we devised a weight-responsive, self-calibrating, self-mapping algorithm that would respond to any number of items, thrown in in any order. The cauldron was outfitted with a weight-sensing mechanism by situating 6 Phidget load sensors under a platform that sat inside the cauldron to catch the items as they were thrown in. Significant changes in the mean weight picked up by the sensors were recorded and a histogram of their distribution was computed,

normalized and used as a transfer function to map any given input to an output state in a manner inspired by techniques of histogram-based normalization in computer graphics.

Overall, the algorithm had the effect of ensuring that any given set of inputs would be remapped automatically to fill the available range of outputs approximately evenly. Although this meant that processing could take a little time and produce some 'false positives' and 'misses', as we shall argue further, this is consistent with our overall philosophy of *requisite unpredictability*.

Aesthetics of the Cauldron Interaction
We needed the cauldron's visual feedback to be striking in order to make its presence visibly impressive. We hid flat LED light panels under the translucent acrylic panel that registered the weights of the items thrown in, making it appear that a ghostly glow was emanating from the surface of the cauldron itself. The bubbling and burbling lighting evoked an eerie roiling cauldron whose flickering glow immediately drew visitors' attention upon entering the chamber. The lighting effects intensified as children threw objects into the cauldron while play-acting at spell-casting. We wanted to imbue the cauldron with a 'witchy' personality, making it seem as if it was 'hungry', wanting to 'eat' the objects thrown inside. To convey this, the audio soundscape we created for the cauldron consisted entirely of 'mouth' sounds – chewing, swallowing, gulping and groaning – increasing in volume and intensity as more items were 'fed' to the cauldron.

The items provided as 'ingredients' for the spells were carefully chosen for their sensory as well as conceptual qualities – including furry rats and scaly snakes and a giant friendly rubber toad. Children so inclined could revel in what the exhibition designer referred to as "the ick factor" of the grosser items, while younger or more tentative ones could enjoy the soft squidgy textures of the cuter creatures.

Facilitating Educational Play with the Magic Cauldron
A number of design choices made to help shape encounters with the cauldron were intentionally done to stimulate learning through creative play. Firstly, the cauldron room featured a large glass display case that contained a curated collection of taxidermy animals and fossils drawn from the GNM holdings and archives. This macabre collection evoked traditional witchcraft, and while the items contained were too delicate to actually touch, their presence in the space was intentionally situated to provide material to stimulate children's imaginations when play-acting at spell casting. Secondly, one wall of the chamber was decorated with a variation upon the Macbeth text, *"Hubble bubble, toil and trouble…"* the intention being that this reference might encourage children to incorporate literary concepts or references into their creative play. Additionally, several of the items that could be thrown into the witch's cauldron specifically related to thematic material featured in other exhibitions found throughout the museum in order to spark

children's recollections and encourage self-driven reflection and creativity. Finally, as previously mentioned, Helen, the Gallery Interpreter was on hand to assist children in using and exploring the piece.

OBSERVATIONS

During the exhibition's three-month run, our research team was able to observe our artefacts being used in-situ, taking detailed notes of the encounters that took place, and discussing the experiences with the public. In addition, we had ample opportunity to share experiences and work alongside the museum staff, most notably with Helen. Her long-term, situated exposure to the daily goings-on of Magic Worlds proved an invaluable resource when trying to make sense of how our interactive content was experienced by the public. 'Living with' the exhibition for an extended duration and incorporating the artefacts into her creative practice availed her a unique vantage point from which to understand the experience [cf. 21].

Inspired by Ciolfi's walkthrough methods in which she encouraged docents to share their knowledge while physically traversing an exhibition space [7], we conducted three 45-minute walkthroughs with the staff: one with Helen, one with a front-of-house staff member, and one with the museum's exhibition designer. In addition, we were able to conduct a debriefing session that brought the entire team together to discuss our experiences. Upon examination of the data, several high-level themes emerged that helped us characterize the nature of the public's experience with the digital interactives. These were prominent throughout our data but for space reasons we can only illustrate each with a few clear examples.

Telling Stories and Acting Things Out

In our interviews with parents and families, the vast majority of the parents we approached indicated that the interactive content was the primary reason for their repeat visits to Magic Worlds. Our cauldron provided a key opportunity for children to dress up and 'act out', and it was hoped that by providing children with the spooky cauldron room – effectively a theatrical set – and themed costume pieces and props, creative, educational play would naturally take a theatrical turn.

Let us give a characteristic example of this type of play. A school group of nine year old girls put on the witches' costumes, and began experimenting with throwing items into the cauldron and remarking upon the increased audio-visual feedback in return. They spent some time investigating how the cauldron worked, remarking upon the various effects they could trigger by throwing large items in versus small ones, or multiple items at once. Eventually the girls ceased their play, and began conferring with one another, with much emphasis being placed on discussing the text painted on the wall, *"Hubble bubble, toil and trouble…"* The girls called their teacher over to confer with her as to what they should do next. We asked the teacher

what had been discussed, and she told us that the girls had been asking her for additional lines of text from Macbeth that they could use to create a small performance for the parents who had accompanied them on their trip. After some rehearsal time during which they assigned each other lines and decided upon an order of items to be thrown into the cauldron for maximum effect, the parents were summoned and assembled. The girls presented a brief excerpt from Macbeth, using the audio-visual functionality of the cauldron to punctuate their dialogue as they took turns throwing objects into the cauldron (see Fig. 3.)

Figure 3. Schoolchildren use the Magic Cauldron to act out a scene from Shakespeare's Macbeth

This type of behaviour exemplifies the creative learning our digital interactives were intended to provoke. Interviewing the exhibition designer, she told us she loved "the fact that it was their idea, before they called [their teacher] over to say '*Look what we've been doing!*' …I was really pleased with that." The children observed in this incident used the cauldron as a *resource for acting out* – and a true stimulus for child-led educational creativity. The digital content, experienced cohesively situated within the exhibition context, had sparked a learning opportunity – the girls took initiative in researching and engaging with the story of Macbeth.

Scaffolding the Skilled Storyteller

We were pleased to see how our cauldron interactive facilitated the activities of the Gallery Interpreter, and helped scaffold the storytelling and play-acting activities she used to encourage children to engage with the exhibition. We spent a substantial amount of time with Helen, watching her interact with the children. It was intriguing to observe how she made use of the cauldron artefact in her practice, because rather than directly instructing the children with regards to how the cauldron worked, her manner of encouraging and helping children often took the form of inviting them to join her in improvisational play. She would invite them to help her cast a magic spell, and as part of the process of doing so would

exaggeratedly pause to observe and remark upon what kinds of magic effects were triggered after each item was thrown in – intentionally drawing their attentions to the audio-visual feedback programmed into the cauldron artefact. All the while she maintained the children's focus on the experience of play-acting at casting a spell. In this way, rather than directly instructing them on how to use the cauldron, she could model for the children how to best explore its responsivity in a creative, playful way. Her willingness to play-act alongside the children (see Fig. 1) modeled the type of creative play the exhibition designers hoped to encourage. In addition, Helen's storytelling and play-acting skills helped her to encourage younger or more timid children to experiment with the cauldron. Helen would try to coax shyer children into joining her, and if they still found the skulls and brains too frightening, she could engage them in discussion about the rubber toad – sometimes convincing them to play-act as toads themselves, hopping and jumping with her around the space.

Helen found the very mouth-like, human vocal sounds we had designed for the cauldron helped support an anthropomorphic approach to explaining any technical vagaries that might crop up when engaging with it in view of the public. For example, if too many objects were thrown in at once, or the weighing platform became misaligned or dislodged, causing the weight-sensing algorithm to behave erratically, she could explain that the cauldron "wasn't behaving itself properly today." She could then remove the objects and firmly settle the weighing platform, patting it into place "so it could calm down" – an easily accessible 'return-to-start' that we had designed for and our algorithms support. The conceit that it was an entity capable of obstinacy or misbehavior helped Helen reduce the need to break character, allowing her to maintain the play-acting scene being developed. Her ability to use the nuances of the cauldron's *functionality as a scaffold* upon which to build a creative context allowed her to seamlessly accommodate 'glitches' in her method of practice or even be usefully inspired by them

Experience Sharing amongst Families
The Magic Cauldron often provided opportunities to observe family groups playing together, as its interface clearly facilitated multiple users. The two magic mirrors also provided us with opportunities to watch how families and groups shared their playful experiences. The Delay Mirror was designed to both delight and teasingly frustrate visitors due to its ever-changing method of layering real-time and time-delayed video streams. Its behaviour would unpredictably switch from displaying a 'normal' mirror image, to suddenly displaying surreal time-lapsed footage. We had ample opportunity to observe how this functionality stimulated interesting social interactions amongst family groups. Typically, one member of a family would notice the Delay Mirror's weird, time-lapsed imagery, and would then try to draw another family member's attention so that they

could share the experience. As the mirror's behaviour shifted between augmented imagery and 'normal' mirror functionality, it was quite often that by the time the summoned family member arrived to see the supposedly 'magic' mirror, s/he was greeted by nothing more interesting than his/her own reflection, to the consternation of the family member who had been insisting that something interesting had been going on. This often resulted in animated discussions amongst the family groups. In addition, children playing and dancing in front of the mirror often attracted the attention of their parents, spurring the children to engage in even more performative behaviour knowing they had an attentive audience.

The Kaleidoscope Mirror also produced opportunities for parents and children to interact with one another – particularly parents with smaller children that could be lifted and held. The repetitive, pattern based imagery of the Kaleidoscope was able to hold small children's attentions, and both ourselves and Helen regularly witnessed parents lifting their little toddlers to eye level with the Kaleidoscope, pointing out and identifying the child's own image as it was fragmented and replicated in geometric patterns in the moving display.

Connecting to the Wider Museum
The Magic Cauldron provided an interesting stimulus for visitors to make connections between the Magic Worlds exhibition and the rest of the museum. Some of the toy items used as spell ingredients opened up an opportunity space to establish connections with other exhibitions concurrently running in the GNM. We often noticed children showing a particular fascination with a large rubber skull and a pink rubber brain of corresponding size. Children could regularly be seen trying to compress the rubber skull to push the brain into the appropriate place inside the cranium. When we asked Helen about this behaviour, she laughed, and asked the nearby child to tell me why she was trying to press the brain into the skull. The child explained that she knew "from the Egypt [exhibition]" (held downstairs as part of the museum's permanent collection) that brains were pulled out of the noses of bodies as part of the mummification process. Helen told us that that she often used this discussion as an opportunity to educate children about how bodies were prepared as part of traditional Egyptian mummification practices. Helen also told us that a large rubber toad used as a prop for the cauldron often found its way to various other places in Magic Worlds, sometimes being treated as a potential prince to be kissed in the 'Fantasy' room's fairytale settings, or taken as a guest to the Mad Hatter's Tea Party. On multiple occasions, children snuck the toad out of Magic Worlds altogether, whereupon staff would eventually find him – often having been returned to his natural habitat in the area of the museum's permanent collection exhibiting reptiles and amphibians.

DISCUSSION

In this paper we have described our work on Magic Worlds, a touring exhibition of the UK's Victoria and Albert Museum, to which we added playful, interactive digital artefacts. Our work was informed by research on interaction in museum and related cultural settings in HCI and CSCW and involved extensive consultation between museum stakeholders and digital designers. As our exploratory design work developed, we formulated a number of design sensibilities to configure the design space we were working in and created three digital artefacts which were carefully placed within the exhibition environment. We have discussed how those artefacts were engaged with and, in particular, how they could be used playfully and casually, yet also in a manner which supported concerted activities of potential pedagogical value, including curiosity into their own technical operation. Through this, wider connections to the exhibition and the museum context could be made. Let us now draw out some more general contributions.

Resources For Open Interactions

The richness and nuanced complexity of behaviours around interactives in cultural settings have been noted by many authors [e.g. 2,10,11,14,15,19,21,22]. The interactions we have observed around our pieces are radically *open* in at least two senses. First, they are *open to variable participation*: it is not defined in advance exactly who the users might be in any particular encounter with an exhibit. Second, they are *open-ended*: it is not defined in advance when exactly their encounter should start and when it should stop – people can carry on indefinitely if what they are acting out continues to amuse. This makes it highly problematic to define interaction around a sense of the 'session' or of given 'user-identities'. It is more appropriate to design technologies which are open to the (rest of their) world, yet offer enough to be appropriable for a variety of purposes, many of which might be unknown in advance to designers – technologies which serve as *resources* for action and interaction. While these arguments might be familiar from students of Suchman [20] onwards, we feel that we have outlined some design sensibilities and given some specific examples of this approach in concrete design action. We have taken the idea of creating resources for open interactions 'down' to the level of computational algorithms for calibrating and mapping sensor data.

While the idea of supporting interactivity in this way is often called upon, digital interactives in museum environments – including some of the most impressive design work in HCI – often still require considerable buy-in to make them work. For example, much of the research reviewed by Benford and Giannachi [2] still involves conspicuous technologies even if they are embedded or ubiquitous (e.g. an RFID tagged object which has to be held just so for a tag reader to detect it, a handheld device needing network coverage) – often with a cover story to help participants suspend disbelief. In our case, we feel we have gone some way to reverse this picture. Our pieces do not require anything other than ordinary action (stand and watch, put a toy in a pot) to come alive, thereby enabling participants to develop their own stories, with any accounts of the behavior of the artefacts being easy to incorporate within ongoing play rather than something that requires a suspension of disbelief or detailed instructions at the outset.

Interaction Far Beyond The 'Interface'

It is important to realize, though, that this is achieved only through the concerted influence of the overall context of the exhibition. The design of the various rooms in Magic Worlds, the positioning of our interactives in them and in relation to other exhibits, the overall design quality of the whole exhibition, their presence in a museum which has an amphibian section (even), all – in various ways – contribute to what success we have in designing for open interactions.

Important also is the role of the Gallery Interpreter in further scaffolding playful engagement. In a more general sense, participants to our setting can be regarded as *performing technologies,* incorporating them into some performed activity but also giving sense to them through that. For some time, critical thinkers in HCI have been arguing that "the interface reaches out" and that it is perhaps better to speak of the activity of *interfacing* than the idea that an interface is a fixed object [5]. Our work convinces us that these points need to be pushed to quite a radical extreme. Human computer interaction exists in a heterogenous context, with a mix of materialities in play. In making up a story around the cauldron, children equally avail themselves of the writing on the wall, their teacher's knowledge of Shakespeare, the skillful performance of Helen, the costumes and props, and put it all together to make their own coherence. Clearly, one cannot anticipate all possible such ad hoc 'assemblages'. However, we feel our sensibilities for the design of open interactions go someway to giving a hint of where to start in making things which are open to these possibilities and so give participants a desirable *creative latitude*.

An Entangled Design Process

The approach we took also enabled us to organize a design process that did justice to the complex entanglements that can be involved in engaging with cultural settings. As we have noted, Magic Worlds lay at *the intersection of multiple constraints and enablements*. The Museum worked within what had been curated by another institution, yet enhanced it with local design work and contributions from local collections. The digital designers in our team were not making things 'to brief' but were concerned to explore configurations of human-computer interfaces through their work. It was important to develop a *reciprocal accommodation* of the interactives which were made to the setting in the exhibition and of aspects of that setting to the interactives. This required design work that entangled different expertises (the digital, exhibition building,

performance). We feel that our patterned mix of design autonomy and wider organizational consultation suggests a *'third way' in HCI between design research and participatory and co-design tendencies*. Building multiple pieces that could resource open interactions with a requisite unpredictability and robustness facilitated this. At the other extreme, proposals for a unitary work requiring considerable organizational and end-user buy-in or asserting an independent aesthetic would have been badly suited to such an entangled context.

Making Magic: Ludic Design For Real
Design research in HCI commonly advocates a principle of 'ludic design'. In a number of papers, Gaver and colleagues [13] have counterposed playful, ludic design with functional design where particular purposes are designed for. However, the context of Magic Worlds puts this opposition in some crisis as here *the purpose is play*. However, the issue is perhaps not between what is playful and what is not, but rather where a commitment to purposes is made by designers. Designing to support a particular function, as much early HCI sought to, requires some definition or knowledge of purposes in advance of design that will then meet those 'requirements'. In contrast, we have sought to support open interactions (open to varied participation, open-ended in terms of activity and outcome) through design processes of a particular character and with artefacts which behave and intrigue in a particular kind of way, co-existing in settings with many other kinds of materiality. That, for us, is making magic.

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