Designing ubiquitous computing to enhance children’s learning in museums

T. Hall* & L. Bannon†
*Learning Sciences Research Institute, University of Nottingham, Nottingham, UK
†Interaction Design Centre, University of Limerick, Limerick, Ireland

Abstract

In recent years, novel paradigms of computing have emerged, which enable computational power to be embedded in artefacts and in environments in novel ways. These developments may create new possibilities for using computing to enhance learning. This paper presents the results of a design process that set out to explore interactive techniques, which utilized ubiquitous computer technology, to stimulate active participation, involvement and learning by children visiting a museum. Key stakeholders, such as museum curators and docents, were involved throughout the process of creating the exhibition, Re-Tracing the Past, in the Hunt Museum, Limerick, Ireland. The paper describes aspects of the evaluation of the exhibition, which involved 326 schoolchildren (ages 9–12-year-old), and which exemplifies important features of the design and use of the novel technology in the museum. The paper concludes by articulating a series of design guidelines for developing ubiquitous computing to enhance children’s learning in museums. These guidelines relate 12 experiential criteria to five supporting design informants and resources. The guidelines encompass important dimensions of children’s educational experience in museums, including collaboration, engagement, active interpretation, and materiality. While developed in a museum context, these guidelines could be applied to the development of novel computing to enhance children’s learning in other educational environments, both formal and informal.

Keywords

children’s informal learning, interaction design, museums, ubiquitous computing.

Introduction

Museums play a key role in children’s education. Through museums, children can come to a deeper appreciation and understanding of material culture and the history that this symbolizes (Hooper-Greenhill 1998). Museums can have a profound impact on children’s motivation and interest in learning, creating ‘the kind of present experience that lives fruitfully and creatively in subsequent experiences’ (Dewey 1963, pp. 27–28). In their discussion of intrinsic motivation in museums, Csikzentmihalyi and Hermanson (1995, p. 35) describe how ‘one often meets successful adults, professionals, or scientists who recall that their lifelong vocational interest was first sparked [as a child] by a museum’.

However, as Caulton (1998) notes, museums increasingly must compete with other cultural and ‘edutainment’ activities and centres. Furthermore, museums can be perceived by children as staid and boring places, austere environments where they passively view objects, or listen to historical accounts of the past (Csikzentmihalyi & Hermanson 1995).

To address these challenges, many museums are transforming their educational programmes for children, endeavouring to make children’s visits more
dynamic, engaging and enjoyable (Schauble et al. 2002). To help achieve this, museums are using computers to try to capture and maintain the interest of today’s children, the ‘Nintendo Generation’ (Soloway 1991; Guzdial & Soloway 2002).

However, rather than provide effective interactive solutions in museums, traditional or desktop PC technologies can be obtrusive and distract visitors from artefacts (Gammon 1999; Ciolfi et al. 2001; Gilkes 2001; Stille 2002; Stevens 2004).

Alternatively, novel computational paradigms, such as pervasive and ubiquitous computing, may create new possibilities for interactivity, enabling designers and technologists to create novel hybrid artefacts and environments, which combine digital and physical properties in novel ways. Consequently, this may allow new forms of learning to emerge. As Plowman and Luckin (2003, p. 160) note in a special edition of this journal, ‘New technologies may lead to new concepts of play and learning especially as new ways are found of conceptualising ICT so that the term does not simply denote standard computers.’

Notwithstanding, while innovative mobile technologies have been deployed in museums (e.g. Hsi 2003; Lonsdale et al. 2004) there is a dearth of research concerned with how novel ubiquitous computing can be developed and deployed to augment the museum educational experience for children (Caulton 1998; His 2004). There has, however, been considerable research concerning the design of ubiquitous computing and its impact on aspects of children’s education in other settings: in school (Lingnau et al. 2003); in the home, in after-school clubs (Plowman & Luckin 2004); and on a woodland science field trip (Rogers et al. 2002). The research reported in this paper aimed to help redress the lack of systematic design research in relation to how ubiquitous computing can be developed and deployed to enhance children’s learning experience in the important, informal learning domain of the museum.

The design process

Participants

In The Big Sink, a major report on the key factors for designing creative spaces in museums and other learning settings, Rogers and Edwards (2002, p. 8) identify lack of collaboration and consultation with educational and curatorial stakeholders as a major barrier impeding the design of successful exhibitions in museums, ‘The teachers, pupils, and gallery and museum education staff who use existing creative spaces have a wealth of knowledge and experience about what works and what does not. And yet they have been and are being rarely consulted’. A fundamental part of the investigation of the design of ubiquitous computing in the Hunt Museum was to involve key stakeholders. The stakeholders that were consulted included: visiting children and school groups; teachers; the curatorial, educational and managerial staff of the museum; the museum docents (specialist guides); and John Hunt’s biographer and personal friend, Professor Emeritus (University of Limerick) Patrick Doran. Overall, the design process encompassed six main elements, which included consulting the museum’s key stakeholders:

1. technical experimentation (six probes, where the interactive capabilities of a number of innovative computer technologies were tested, both in lab settings and in the museum);
2. consultation of children’s history and museum education policy (as outlined in the Irish Primary School History Curriculum and the International Council of Museums (ICOM) charter);
3. design, development and evaluation of a large-scale interactive museum exhibition at Nottingham Castle and Museum, which preceded and significantly informed the development work for the exhibition in the Hunt Museum;
4. observational studies (of schoolchildren’s interactions in two interactive museum workshops, a simulated archaeology dig and time machine; illustrated by Fig 1);
5. scan and evaluation of physical/spatial constraints of the museum;
6. consultation of museum and Hunt family experts (docents (the museum’s specialist guides), curators, museum education officers, Hunt family biographer).

In Fig 1, a girl uses a brush to clean sand off a shell she has unearthed during the Hunt Museum archaeology simulator. This workshop, organized for visiting school groups, was analysed as part of the design
process. Figure 1 also shows a group of schoolchildren, in costume, and led by a Hunt Museum docent, re-enacting an ancient chieftain burial. This workshop was also observed and analysed.

Several innovative computational technologies were explored during the design process, including: Polhemus™ Fastrak sensors and radio frequency identification (RFID) systems. To help ensure the design process was theoretically rigorous, a conceptual framework was developed. This framework was inspired by several major learning theories. These included the socio-cultural psychology of Vygotsky (1978), Bruner’s (2002) theories of narrative; Csikszentmihalyi’s (1990) notion of optimal experience or flow; and Norman’s (1998) ideas concerning Invisible Computing. In all, the theoretical frame comprised eight design concerns or themes:

(1) **Materiality**: handling and tactual interaction are central in children’s learning and meaning-making processes. Also, the physical learning environment must be conducive to learning.

(2) **Narrativity**: storytelling and narrative creation play a pivotal role in children’s educational development.

(3) **Sociality**: collaboration, between children and their significant others, is critically important in children’s intersubjective development.

(4) **Activity (active interpretation)**: children should be actively interpreting material culture for themselves, rather than passive and voiceless, as they often problematically are in museums (Caulton 1998).

(5) **Multimodality**: the exhibition should support somatic learning; children need to engage with exhibits through their many senses: for example: sound, touch, sight, smell (olfactory).

(6) **Engagement**: children should find the learning experience enjoyable and be motivated to participate.

(7) **Computer as augmentation tool**: the technology should be easy to use and unobtrusive, effectively supporting collaboration and interaction.

(8) **Pedagogical activity**: children should learn from the exhibition, evidence of learning will include correcting misunderstandings; asking questions; and interpreting and reflecting on material culture.

The aim of the authors and the Situating Hybrid Assemblies in Public Environment (SHAPE) consortium generally was to try to embody these themes in the final design of the exhibition. As will be presently discussed, these themes also formed the evaluative framework against which the exhibition data were interrogated.

**The design product: re-tracing the past in the Hunt Museum**

Many ideas and scenarios emerged during the design process, resulting from over 2 years of prototyping, scenario-based design, observational study, and consultation of museum stakeholders. Following a series of creative design sessions, which discussed how best to synthesize the design activities with the observational work, the final idea was to construct two interlinked spaces. The first space would be a reproduction study room, based on the secret study that John Hunt had at his home in Lough Gur, Co. Limerick. The Study Room contained four interactive fittings: an interactive trunk; the Virtual Touch Machine (using a Polhemus™ Fast-Trak device, children and other visitors could virtually strike or ‘touch’ a model of museum objects on a back-projected display, which was designed to look like a mirror in the Study Room); an interactive desk; and a radio, where users could hear opinions of fellow visitors that had been recorded in the Room of Opinion. In the second area, the Room of Opinion, children and other visitors could leave their opinion in a community memory through an interactive recording station. They were furthermore able to handle actual replicas of four mysterious objects in the Hunt Museum collection. For effect, and to facilitate group discussion and interaction, the replicas were placed under spotlights on four plinths in this space. While the Room of Opinion was darkened and made to appear mysterious, to help evoke visitor curiosity, the Study Room was dimly lit and fitted with
authentic furnishings; many were sourced from local antique shops. RFID-tagged keycards, representing each of the four mystery objects (the ‘subject matter’ of the exhibition) were used as the mechanism for visitors to interact with the trunk, desk, recording station (Room of Opinion) and the Virtual Touch Machine (interactive mirror).

Figure 2 shows the interactive desk and trunk. Through a combination of WebCam shape detection and RFID sensing technology, the desk could detect the location of keycards on the map and provide the visitor with information about the object on the card. For the interactive desk, an RFID reader was hidden inside the chest, which read the identity of the keycards and displayed an appropriate FLASH animation on the flat screen monitor, which was embedded within a two-way mirror frame.

Figure 3 shows the mysterious Stone Ball artefact: one of the four replica museum objects, which was created for the exhibition, and which children and other visitors could handle and touch in the Room of Opinion.

Children interacted with the interactive radio exhibit using the frequency dials on the front. Mouse parts were used to make the dials interactive. Other sensing equipment and devices, including a PICO adc 11, were concealed inside.

Results

Re-Tracing the Past was open to the public over a period of 10 days. In all over 900 people visited the exhibition. A total of 326 schoolchildren visited the exhibition. It is important to note that Re-Tracing the Past was designed to appeal not only to schoolchildren, but also to the museum’s other visitors. For details of the general impact of the exhibition in terms of different visitor groups, please see Ciolfi (2004), Ciolfi et al. (2004), Bannon et al. (2005), and Hedman (2004).

Over 60 h of digital video was recorded and analysed. Exemplary and interesting vignettes were subsequently marked, re-analysed and transcribed. Video analysis was supplemented by post-visits to schools where the research team met with the children and their teachers. Pre-visits were used principally to prime the children for the museum experience. Interesting replica objects were brought into the classroom and children were asked to create short enactments using the objects as props. During the post-visit ses-

Fig 2 The interactive desk (left) and trunk (right).

Fig 3 The interactive radio (left) and replica mysterious Stone Ball artefact (right).
sions, children were asked to create sketches and short essays describing what they thought of the exhibition. Some children also recorded short video testimonials reflecting on the exhibition and their experience of it. The research team also took field notes to assist the evaluation process. The community memory of the exhibition, stored on the interactive radio, also served as a data source for evaluation purposes. The accompanying teachers were informally interviewed and asked for their reflections and opinions. The visitor book also served as a point of triangulation for the evaluation, as did the docents and the museum curatorial and educational staff. The data from Re-Tracing the Past were interrogated against the design concerns and themes that guided the development of the exhibition. Both confirming and disconfirming data were sought. As will be presently discussed in greater detail, children’s experience of Re-Tracing the Past proved highly positive overall. However, on the negative side, the authors encountered one piece of disconfirming evidence in relation to the equity of children’s use of interactive exhibits in the exhibition. The following comment was written in the visitor book: ‘It was boring, the boys took over everything’. The entry was made on the first Friday of the exhibition. The authors did not know initially who had written this comment. However, only one class entered comments in the visitor book on this date so it was possible to deduce the school-group of the child or children who had made the entry. Apart from this comment, the children’s entries for this day were very positive about Re-Tracing the Past. Having identified the respective school-group, the authors were interested, if possible, to investigate the issue further. Four days following this group’s visit to the museum, members of the design team met the children in school. In a general discussion with the class, three girls complained that a number of the boys would not allow them to use some of the interactive installations. The girls understandably became disaffected when the boys would not let them use the interactives. Unfortunately, this discipline problem was not picked up by any of the teachers or exhibition assistants at the time. The girls’ experience in the exhibition serves to highlight the importance of intervention by teachers, exhibition assistants, etcetera, if required: to ensure that an exhibition’s resources are used equitably by all visiting children. Notwithstanding this problematic issue, children generally seemed to enjoy the exhibition and, as will now be discussed, the exhibition proved very successful in terms of the design themes. Because of the space constraints of a journal paper, and considering the large corpus of data that was collected for the evaluation of the exhibition, the authors will focus on four themes: materiality, sociality, activity/active interpretation and engagement. For discussion of the evaluation of data pertaining to the other themes within the theoretical frame, the reader is referred to the full thesis monograph on which this paper is based (Hall 2004).

Materiality

A key part of the design process, in addition to integrating novel computing effectively within the museum setting, was to create an exhibition space that children would find appealing, comfortable and engaging. Certainly, from the analysis of the exhibition data, children perceived the exhibition space as comfortable and welcoming. There was no evidence of the austerity that often inhibits children’s engagement in museums (Caulton 1998). On entering Re-Trracing the Past, children would frequently make comments like: ‘This is cool!’ and ‘Excellent!’ and they were obviously impressed by the appearance and layout of the Study Room.

Recognizing the space as an antique or old office was a key aspect of children’s appreciation of the material qualities of the exhibition. It was intended that the space would appear like a study room; the design team wanted children to feel like they were really in this type of environment, researching the museum objects. Figure 4 shows Brian, who has just arrived with his class from school, immediately recognizing the space as a study room.

Brian subsequently sees the oil lamp, one of the furnishings placed on the interactive desk in the Study Room to add authenticity to the exhibition. He has seen this type of lamp before in his grandmother’s house. This authentic material property of the Study Room evokes the memory for Brian of his grandmother’s house: ‘My gran [grandmother] has one of them in her house/Here [the Study Room] reminds me of my gran’s house’.

The comfortable and inviting qualities of the exhibition were also reflected in the way a number of
children relaxed in the space, for example: Darren, in the following image, who takes a break from exploring clues, reclining in the comfortable armchair while classmates continue interacting with the desk; and Rachel and Catherine (helped by exhibition assistant, Annette), who sit comfortably on the rug in front of the trunk as they interact with the device (Fig 5).

The physical design of the space had a significant impact on children’s engagement in the exhibition and evidence of their appreciation of the Study Room’s physical qualities was provided not only in their behaviour in the museum and the appreciative comments made verbally by them during their time in the exhibition, but also in their post-visit discussions with members of the design team, and in the sketches they were asked to produce in class. In their sketches and video testimonials, the children described the furnishings and style of the rooms, the Study Room and the Room of Opinion, and expressed their appreciation for them. In their drawings, as the following figure illustrates, the children also included not only the main interactive elements, but also detailed representations of the lamps, chairs and other decorative elements scattered around the Study Room.

Jessica’s drawing of the desk (left, Fig 6) includes not only the interactive elements (such as the book, the...

**Brian (with his hand raised):** “This is a place you would study in!”

**Lui (the exhibition assistant, standing to the left in the picture):** “Exactly, that’s very good. And we designed it like this because we thought this is the way John Hunt’s study would look . . . would look like.”

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**Fig 4** Recognizing the first exhibition space as a Study Room.

**Fig 5** Children relaxing in the exhibition space.

**Fig 6** Children’s classroom sketches of the exhibition.
map and projector), but also the books displayed on
the shelves. Antoin’s drawing of the radio (right,
Fig 6, circled) includes the picture that hung beside it
in the Study Room.

Among the most important material resources in the
exhibition were the reproduction or replica artefacts. The
data show how this material or physical aspect of the
exhibition enhanced children’s learning experience in
the museum, in a number of ways. Firstly, it engaged
the children in that they could actually handle the objects, or
at least a very good reproduction of the artefacts. For
example, in the following image, Jack has raced over to
the plinth with the Y-shaped object (Fig 7, left image),
one of the four mystery artefacts. He has just entered the
Room of Opinion with his class and is excited by the
opportunity to see and actually touch the object he has
been researching with his friends. Jack’s friends quickly
follow him over to the plinth and they begin a discussion
of the object (Fig 7, centre image). Handling the object
also helps Jack to formulate and verify his theory about
the object, that it is perhaps a stirrup.

Engagement

It was evident in the data for the exhibition that Re-
tracing the Past was very successful in engaging
children and capturing their interest. There were many
instances in the exhibition data to illustrate children’s
motivation to explore and interact in the Study Room
and Room of Opinion. The following vignette, how-
ever, is particularly significant because it highlights an
extended or prolonged engagement by children in the
exhibition. What also adds to the significance of this
vignette is that the boys chose to spend their time in
the exhibition. One of the boy’s mothers works in the
museum, and while they wait for her to finish work,
the boys are allowed to go into town, to the cinema,
shops, etcetera. The Hunt Museum is located just at
the edge of the centre of Limerick City, on Rutland
Street. However, instead of going into town, the boys
preferred to stay at Re-Tracing the Past and explore
clues and objects, and contribute their ideas to the
collection of visitors’ opinions. A ‘dwell time’ ana-
lysis of the duration of the boys’ stay in the museum
was conducted, to determine more specifically how
much time they spent in the exhibition. ‘Dwell time’,
when it is employed in a limited and deterministic
way, is problematic as a means of analysing museum
interaction, particularly educational activity in mu-
seums: ‘In traditional research in museum education,
learning outcomes have often been assessed through
structured interviews and visitor behaviour through
some kind of quantitative estimate of frequency of
visit to an exhibit and ‘dwell time’. However, if one
views learning as an inherently collaborative and so-
cial activity, particularly in informal settings, this
becomes inappropriate’ (Stanton et al. 2003, p. 296).
On the other hand, if visitors are interacting, as in-
tended, and they are continuously active then, Jones
(2003) argues, ‘dwell time’ can be useful as an in-
dication of the attractiveness of an exhibit or exhibi-
tion. The following time-stamped images show the
two boys, Mark and Tomas spending over 30 min in
the Re-tracing the Past exhibition.

Mark and Tomas are recording their first opinion
about the Y-Shaped Object, that it is a slingshot. The
timer on the Digital Video tape displays 0:00:04:06
(Fig 8, left). Just after the boys record their final opi-
nion before going home, the timer reads 0:30:28:24
(Fig 8, right). The boys have spent over 30 min in the
exhibition, and it seems they would spend more time
in the exhibition but they have to go home.

In all, Tomas and Mark contributed nine opinions
about the mysterious objects, ranging from theories
that the Y-shaped object was a slingshot to an idea that
the Stone Ball was a carved pottery artefact. There-
fore, taken in the context of the level of active en-
gagement the boys exhibited while in the exhibition,
the significant amount of time they spent in the ex-
hibition, (over 30 min), helps to demonstrate that they
were engaged and very much enjoyed the experience. Mark’s and Thomas’ experience was representative of visiting children generally, who really enjoyed and engaged with Re-Tracing the Past. Before they leave to go home, Mark and Tomas were asked by the first author whether they enjoyed themselves:

Exhibition assistant (first author): ‘Well done, you got loads of clues and some very good ideas guys. Did ye enjoy it?’
Mark: ‘That was cool!’
Tomás: ‘It was class’.

Sociality

One of the key themes to inform the design of the Hunt Museum exhibition was collaboration or sociality. The authors and the SHAPE consortium generally wanted to create an experience, supported by novel computing, which would facilitate children’s interaction with peers and significant others. The rationale in endeavouring to design the Hunt Museum exhibition as a social experience was not only to support children’s cognitive development (Vygotsky 1978) but also to address important aspects of their affective development. As Kolakowski (1990) notes, co-operation and collaboration with others are crucially important for one’s personal development and integration in one’s culture and social milieu: ‘Our inner integration is the result of consorting with others, of trust and friendship; it is not the result of the self-focused, monadically isolated void of the ego’ (1990, p. 258).

In the analysis of the exhibition data, in the context of children’s intersubjective activity or sociality in Re-Tracing the Past, it is noteworthy to consider that two different types of collaboration were observed, specifically at the interactive trunk and the Virtual Touch Machine (interactive mirror). In analysing the virtual touch machine from the perspective of children’s collaboration, children’s interaction with this device involved turn-taking or sharing the resource, rather than them working through the technology to achieve mutual tasks. In Fig 9, children are seen ‘competing’ to use the interactive.

At the trunk, on the other hand, children acted more cooperatively: they placed cards together, helping each other to find out more about the objects, and their interaction tended to be more discursive, as the following images and related dialogue illustrate (Fig 10).

Children realized that by working together they could ascertain additional information about objects at the trunk. The trunk would display extra information about an object or objects if children placed their respective cards together simultaneously. There was ‘collaborative added value’ to children’s interaction. This ‘reward’ for their collaboration helped significantly to encourage co-operation among children using this interactive.

Active interpretation

One of the principal aims for the exhibition was to support children as active interpreters of museum

Fig 8 Images at the start (left) and conclusion (right) of the boys’ interaction.

Fig 9 Children competing to use the Virtual Touch Machine.
objects. The design team, museum docents and curators were interested in supporting the ‘shifted vision of museums, towards one that regards visitors as something other than awaiting receptacles of culture’. Stevens (2004) Thus, rather than have children listen passively to a catechism of ‘historical facts’ about objects, the aim was to design the exhibition to encourage them to explore clues and information related to objects, and ultimately develop – in an active, constructivist way – their own, well-informed opinions of the artefacts. The data for the exhibition showed that children accomplished this successfully.

In Fig 11, one of the visiting schoolchildren, Niall, is seen synthesizing clues; others’ opinions and ideas; comparing objects; and linking to his personal experience in generating his own theory about the mysterious Oxford Disc object.

Niall’s class visited the exhibition around 10:00 hours on Thursday 12 June, the morning after the official opening of Re-tracing the Past. A faculty member at the University of Limerick recorded this opinion of the Oxford Disc on the Radio at the official opening: ‘I believe it’s a personal ornament, worn ‘round the neck, probably on a string, although it’s a little large for that . . . ahhh . . . it’s so well-worked that it must have been for ornamentation and not just for function. And, I believe, because of the hole at the top of it, that it was a medallion that was worn around the neck’. Before recording his idea, Niall heard this opinion. This was the first time Niall’s class had visited the Hunt Museum and after their visit to Re-tracing the Past, they visited the museum’s permanent galleries upstairs. On the way from the interactive exhibition upstairs to the main galleries, the first author was talking to Pat, Stephen, and Niall from this group, and took the opportunity to ask Niall how he came up with his idea.

FA: ‘Where did you get your idea for the status symbol from . . . for the Disc object, Niall?’

In Fig 10, children’s collaboration at the interactive trunk.
Niall: ‘I heard the opinions that is was an ornament and a medallion on the Radio ... ahhh ... I liked those ideas. Also, looking at it in the dark room and in the magic mirror [virtual touch machine] it looked like someone spent lots of time making it, and it was really expensive looking with the patterns on it, not like the Stone Ball object, which looks just like a stone. That’s where I got my idea from’.  
FA: ‘Very good, so it would only be worn by someone with a lot of money or someone with influence’.  
Niall: ‘Yeah ... like the mayor’s chain. The mayor visited our school last year’.

Clearly Niall was an active interpreter in the exhibition, synthesizing other visitors’ opinions and ideas; comparing objects; using clues; and linking to personal knowledge in creating his theory, which he contributed to the corpus through the interactive recording station. Having interpreted the objects for themselves, it was furthermore enjoyable for children to leave and hear their trace in the exhibition.

Emerging design guidelines

The analysis of children’s experience of the Re-tracing the Past exhibition led to the development of a series of guidelines for designing novel computing to enhance children’s learning experience in museums. While developed in a museum context, these guidelines could be applied to the development of novel computing to enhance children’s learning in other educational environments. The guidelines identify 12 principal criteria and five main design informants and resources. They do not constitute a complete or exhaustive; rather, they are intended as a ‘working framework’ or evolving ‘theory of practice’. For a more detailed account of how the authors arrived at these guidelines the authors refer the reader to the research monograph on which this paper is based (Hall 2004).

The guidelines are summarized as follows:

1. Provides a narrative structure: it is important that the experience has clear learning objectives or a readily comprehensible learning narrative. A compelling narrative structure can engage children while also lending an overall coherence and intelligibility to their activities in the museum.
2. The exhibition space is an inviting place: this aspect is closely related to the narrative design of the experience but it is integral that the physical environment and layout of the exhibition is both comfortable and appealing to children, inviting them to explore and investigate.
3. Incorporates children’s contributions: children should not be voiceless in the experience, they should be viewed as capable constructors of their own knowledge, and encouraged to contribute, share, and discuss their interpretations.
4. Experience integrates computing: computing must sensitively support the overall narrative structure of the experience. In general, computing must be unobtrusive in the experience with the focus on artefacts or the particular aspect of the museum that curators and other educational stakeholders want children to focus on.
5. Sustains children’s curiosity: the experience should capture children’s curiosity. Where appropriate, novel computing can be deployed to contribute something ‘magical’ to the experience, as in the Hunt Museum exhibition where the fittings of the Study Room were bestowed with ‘special’ capabilities through the integration of novel computing components and devices.
6. Complements ‘formal’ history pedagogy: the experience should link to and complement...
children’s curriculum study of history; for example, questioning objects and the past.

7. **Supports somatic learning**: there should be opportunities for children to learn through all their senses – sound, vision, tactile (handling), including their olfactory sense.

8. **Facilitates both individual and group interaction**: there should be support both for individual and collaborative endeavour – children on their own, or in pairs, with their parents, in school-groups, etcetera. And, the computing must be designed to facilitate this.

9. **Encourages discovery learning**: the pedagogical framing of the experience should be exploratory, not expository. The museum is an ‘informal’ or ‘free-choice’ learning environment. Thus, the designed experience should support children’s exploration of artefacts in an open-ended, nondirective way.

10. **Supports different types of visits**: the experience should support multiple levels of engagement, from a short transitory visit to a complete and extensive exploration of artefacts.

11. **Incorporates a variety of activities**: to maintain children’s interest, there should be variety in the tasks they can perform. Children might lose interest if engaged in the same interactive activity for the duration of their visit. In the Hunt Museum exhibition, there were six different interactive activities in all so children were kept active and their interest sustained throughout the visit.

12. **Timely and relevant intervention is provided**: it is imperative that there is expert help present to assist children.

It is furthermore important that the design process incorporates the following five elements.

1. **Children’s perspective**: the design process should address key aspects of children’s experience and learning, including their familiarity with technology; usability; children’s interests and motivation; their developmental stage: optimal ZoPD, and prerequisite knowledge.

2. **Curricular/educational perspective**: the process must be sensitive to educators’ aims: parents, teachers, ICOM, History Curriculum.

3. **Museum perspective**: the museum’s point of view is also crucially important. The process should encompass the museum’s ethos; vision/mission statement; considerations of curatorial and educational personnel; the history of the museum; and, if applicable, the perspectives of expert affiliates (e.g. Prof. Patrick Doran in the context of the Hunt Museum).

4. **Physical-spatial requirements**: the design should address logistical limitations, architecture, aesthetics, gallery layout, location of shops, exhibition spaces.

5. **Technical exploration**: this should be conducted in situ (in the museum), and in the lab, where appropriate. It must be iterative and a technology should only be selected if it fits effectively with the overall narrative design of the experience. In other words, aspects one to four determine the technology that is utilized and how it is used.

**Discussion: open issues**

In addition to the emerging design guidelines, there were three important open issues, which arose in this research. The first concerned the relationship between children’s learning experience in museums and their ‘everyday learning’. Although pre- and post-visit sessions were designed and conducted with children in schools, these sessions focused on collecting evaluation data, which it was not possible to gather while children were in the museum. Furthermore, the pre-visit sessions were designed to promote the exhibition, and just to get the children used to handling and interpreting objects for themselves. However, it would be interesting in future research, to explore how novel computing might be designed, not just for inside the museum, but to connect children’s learning in the museum with their ‘everyday cognition’ in relation to history and material culture.

Scaffolding also emerged as a key issue. The analysis of children’s interactions in *Re-Tracing the Past* underscored the importance of timely and relevant intervention, in ensuring children used the interactive resources in the space effectively and equitably. Also, the exhibition encouraged children to question objects, which is a key objective of museum pedagogy. The ‘interpretational openness’ of the exhibition resulted in multiple perspectives and diverse opinions about the mystery objects. *Re-tracing the Past* certainly supported children’s questioning of objects, but this
generally remained unorganized. It would be insightful if future research investigated how scaffolding might be designed to explicitly support the development of children’s multiple ideas and initial questions into a systematic series of questions relating to artefacts and historical interpretation. This research would almost certainly look at developing conceptual structures appropriate to guide children’s questioning in museums; and, the role that computing could play in this process.

‘Invisibility’ of technology also arose as an important issue. The analysis of the exhibition revealed children sometimes focused on the ‘magic’, the concealed technology, rather than on the task-at-hand, the interpretation of the objects. Most of the children that visited Re-tracing the Past took some interest in the technical functioning of the exhibition. It would be instructive if future research could investigate how the ‘disappearance’ of the computing should be accounted for in the learning experience. Furthermore, it might be pedagogically and educationally important that children discuss and explore the technology, and the rationale for its design.

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Supplementary Material
The following supplementary material is available for this article online:

Video Clip S1. Interactive desk: children exploring clues and hidden technology at the interactive desk.

Video Clip S2. Interactive radio: girl and classmates browsing opinions on the interactive radio.

Video Clip S3. Interactive trunk: children exploring clues and discussing at the interactive trunk.

Video Clip S4. Recording Station: boy adding opinion at the Recording Station in the Room of Opinion.


Figure S1. Classroom lexicon: classroom blackboard showing words used by children to describe the exhibition during a post-visit session in school.

Figure S2. Classroom sketch: a child’s classroom sketch of the Re-Tracing the Past exhibition.

This material is available as part of the online article from http://www.blackwellsynergy.com

References


