Engaging Augmented Reality in Public Places

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ABSTRACT

Augmented Reality (AR) systems are moving beyond the laboratory and into the public domain. Such a shift presents new challenges for AR design. In this paper, we study a public artistic exhibition which includes a bespoke AR system. Our design reflects social and physical constraints of the public space in which the device is placed. We investigate the effect of AR on the engagement of visitors with the exhibition. Through our analysis, we provide evidence to illustrate the differing 'augmented' and 'disaugmented' levels of engagement users experience with the AR device in addition to typical engagement observed in social scientific studies of the exhibit face. We discuss the importance of separating target and display, and how levels of engagement with public AR can be explicitly supported.

Author Keywords

Augmented reality, public exhibitions, engagement.

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous; J.5 Computer Applications: Arts and Humanities

INTRODUCTION

In this paper, we explore the challenge of publicly deploying an Augmented Reality (AR) system. AR has, in recent times, become a prominent strategy for overlaying digital content on physical environments. The development of AR across research laboratories has provided increasing speeds [12], improved registration [16], better quality graphics [3,7,23], devices to support multiple users [6,1] and broadening domains of projected use [5,25,28]. Numerous frameworks exist which place AR into a particular relationship with other mixed reality systems [10,20,22] and tangible interfaces [18]. Nevertheless, there have been few attempts to date at placing AR systems in everyday settings, and none that systematically reflect on the constraints that are imposed on development strategies.

As HCI studies move from traditional laboratories to investigate users' everyday experiences, we find new challenges in making technologies work in the real world. Novel technologies that emerge from early research have often co-existed uneasily when faced with the practical settings of public places, and numerous studies describe challenges in deploying systems as varied as kiosks in shops and bars [9], interactive displays in museums [13], and tourist touch-screens around city streets [8].

In exposing such systems to everyday use, public exhibitions have become increasingly important settings for studies of human-computer interaction [15, 14]. The exhibition presents an ideal domain in which to study AR systems in a public setting. Curators are often seeking new ways to engage the public, recognising that collections which are problematic to exhibit often include absences and assumptions, such as fragments of complete artefacts or incomplete collections of these artefacts. In these cases demonstration through, for example, digitally recreating artefacts [21], or augmenting existing objects [26], could improve access to the material. It has previously been noted that there is a close correspondence between such exhibition goals and the goals of AR [13]. Furthermore, the technical requirements associated with inserting digital content to augment exhibition spaces closely compare to the aims of AR research on registration of environments [2,3,4,12]. In various ways, then, AR systems have begun to display reconstructions of events and objects in context with the physical world [24,14,11]. Nonetheless, AR systems development currently prevails as an enterprise primarily driven by the improvement and demonstration of the technological achievements, rather than being equally balanced with detailed reflection on such developments.

Several key issues are prominent in the design of public experiences which are available within social scientific studies of exhibition settings. For example, studies have

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shown that both companions and passers-by can often shape each others' experiences [19]. Furthermore, visitors often draw on the activities of others to learn how to use and appreciate interactive exhibits [15]. In line with this corpus of research and other discussions of sensing visitor types (such being characterised as 'busy,' 'greedy' or 'selective') [26], we expected visitors to occupy a particular level of engagement in the exhibition space. There are those directly engaged with the exhibit; co-visitors that form a local (collaborative) grouping with interactors; and co-visitors that are bystanders, often being implicated in the proceedings. We therefore begin from the standpoint that AR design should not just refer to one or more people using a device, but rather adapt to the many ways in which the public engage with each other with and around displays.

ONE ROCK

One Rock was a two-month public installation developed by Welfare State International, an arts company located in Ulverston, Cumbria. The focus of the exhibition was a large rock in Morecambe Bay, on the north-west coast of England. The aim was to use the various geological, microbiological, historical and social aspects of the rock to engender and renew fascination with the surrounding locality and its features. The installation was created inside an exhibition space a short distance away.

An Overview of the Exhibition

The exhibition attracted varying numbers of people, both in terms of group sizes and daily throughput (from individuals through to groups of forty). Automated progression between stages of the installation precluded any latecomers (who would be asked to wait until the next run), so once a performance had started, the group inside stayed until the end without any additional visitors entering the space. A single performance lasted for twenty minutes in total. A docent was usually on hand during the performance, providing different levels of intervention for the visitors. When visitors entered the space, for example, some docents described briefly the experience, where others said nothing.

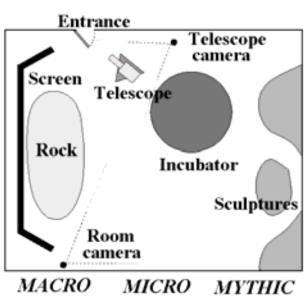

Figure 1. Exhibition space floor plan

The exhibition itself was structured specifically around three ways of viewing the rock: macro, micro and mythic; the space was divided up into three parts to reflect these three aspects. All the sections involved dramatic changes in lighting and a loud accompanying soundtrack.

The first section was deliberately passive and meditative with coordinated visuals and sound showing the rock and its surroundings (Figure 1, left). The entrance area contained a model of the rock which matched the dimensions of the real rock, which is approximately the size of a small car. The macro section provided a physical representation of the rock to give visitors a sense of its place within the local ecology of the Bay.

Once the initial sequence on the large screen ended, lights underneath the gratings in the floor directed visitors towards the second, more interactive section (Figure 1, centre). This area of the exhibition contained the bespoke AR device called the Telescope, which was placed approximately two metres from a feature of the exhibition called the Incubator. The Incubator was a metal structure lit from below that supported hundreds of bottles containing microbes, sea life and other residue collected from around the rock. It also held concealed speakers for associated sounds. During this part of the exhibition, views of microscopic sea-life were projected onto the opposing wall. The micro section allowed visitors to experience the 'unseen' world of the rock, studying its microscopic life and substance.

The final section adjacent to the area where the Telescope and Incubator were located was primarily sculptural, using traditional materials including those collected from the Bay. These forms illustrated various social and historical legends that the rock might tell if it could speak (Figure 1, right).

Telescope Design and Constraints

The Telescope (Figure 2) could be rotated to examine the bottles in detail. The device provided visitors with a way of conjuring video sequences out of the bottles on the Incubator. We hoped to create the illusion that prefabricated microscopic images and videos from the rock could emerge from the glass bottles by 'zooming' into them. We wanted to register which bottles the Telescope was pointing at to create connections between them and the digital content. Figure 3 illustrates the view that visitors would see when using the Telescope. In the centre, we can see video content emerging from a bottle that is behind it. This bottle is enclosed by the green region polygon. Just to the edge of the display, we can see another region, indicating another video associated with the bottle over which that region sits.

Figure 2. The Telescope and Incubator (left) in use (right)

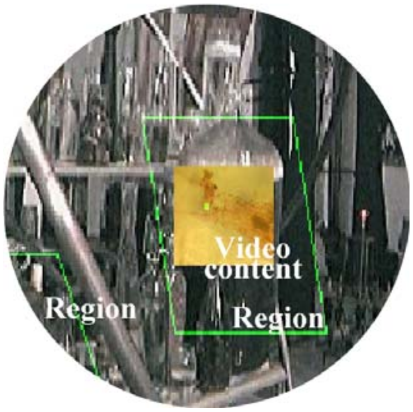

Figure 3. View experienced looking through the Telescope

As an element of the overall installation, the Telescope needed to fit within the artistic thematic of the piece. Indeed, the 'telescope' metaphor emerged through discussions on the various ways in which the public could currently view the physical Bay at a distance. Real pay-per-view telescopes are available in waterfront towns around the Bay, and provide ways of inspecting it in more detail. In addition, the Telescope metaphor was relevant to conveying some sense of the dangers of viewing the Bay too closely. The display inside the Telescope was also informed by this metaphor, and was intended to emulate the sense of distance experienced when using a real telescope.

Challenging some of these aesthetics, however, were more practical considerations. For example, the Telescope needed to be robust enough to last through the two-month exhibition, yet not supersede the impact of the digital content (the microscopic images) and physical target (the Incubator). The sturdy casing of the Telescope was therefore covered in black paint and cloth so as to reduce its physical impact.

We were faced with the issue of registration. AR devices often rely on a registration scheme embedded in the environment. The significant and constant changes in lighting would have seriously challenged an image processing algorithm. More importantly, however, the aesthetics of the Incubator, and indeed the surrounding space, meant that we could not make concessions over the inclusion of fiducial markers (for example, placed on the bottles to be examined). We therefore had to depend only on sensor data obtained from the compass.

We also had to calibrate the device for the exhibition space in ways that impacted both physical and digital components. For example, increasing the Telescope's distance from the Incubator obtained a more realistic telescope effect but led to a poorer display resolution.

We had to decide whether to explicitly display media-tagged regions. During initial testing, the speed of update in electronic compass readings made it hard to simply explore to find tagged regions. Furthermore, compass readings were often subject to unexplained magnetic disturbances, despite internal smoothing and thresholding in the software. Taking into account the impact on the aesthetic of the view, polygonal plotting of tagged regions was agreed upon to reduce the brief time in which visitors were going to be able to learn how to use the Telescope.

Finally, the lighting changes that featured in the exhibition meant that the Incubator was not illuminated at all times. Therefore, visitors using the Telescope outside of the 'micro' section were unable to see the Incubator well. For this reason a halogen lamp was placed inside the Telescope in order to provide temporary illumination of the jars. The light switch was intended for users studying the Incubator when the lights were low. The background light level was accounted for when drawing both the regions and video file overlay; in low light, neither regions nor media were visible, whereas when the Incubator's internal lights were on, the regions and media appeared (as seen in Figure 3).

Telescope Hardware

The Telescope construction is shown in Figure 4. Looking into the viewing tube (1) reveals the contents of the screen (2), which displays a processed video feed from a webcam located at the front of the body (3). The Telescope can be moved using the handles (4) which rotate the entire body section about the pivot of the tripod (5). The light switch on the right handle triggers a halogen lamp attached next to the webcam. A digital compass[1] (6) is attached to the underside of the viewing tube, and detects changes in the heading and pitch of the Telescope's upper section. Rotation of the tube is calculated from the roll of the compass as it is rotated by the viewing tube. The compass heading readings allowed a 360-degree range, whereas both pitch and roll were limited to ±40 degrees.

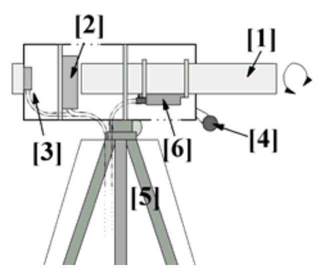

Figure 4. The Telescope

Telescope Software

The software that was developed combined code for the electronic compass (accessed through the Java Communications API) and provided a video handling and display service using the Java Media Framework API and OpenPTC graphics library. The Z-axis roll of the compass was mapped to increment or decrement the level of zoom. Video data from the webcam was enlarged in proportion to this level of zoom so that rotating the viewing tube showed the video content emerging from the Incubator bottles.

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[1] A Honeywell HMR3000

Our software was devised so that multiple arbitrarily shaped regions could be defined. Each region could be associated with a video file, which would then be played when the Telescope was pointed within the bounds of a region. The success of the Telescope's augmentation relied on it ensuring two distinct spaces were kept in correspondence – 'compass space' and 'video space.' Compass space, shown in Figure 5, is the 2D, cylindrical compass view of the environment. Video space, on the other hand, is the 2D image of the 3D world received from the webcam that moved in accordance with the motions of the Telescope (Figure 5 shows real world objects as cylinders). Once the video feed from the webcam was captured, the software superimposed the compass space view – i.e., of regions and video files – on top of the video space view to produce what is seen in Figure 3.

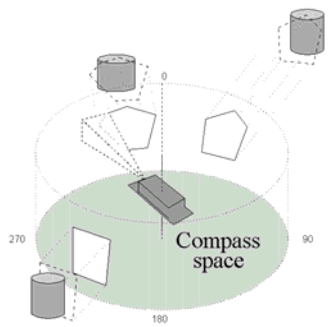

Figure 5. Mapping flat compass space to 3D video space

The size of the video image was tied to the size of the region, which in turn was linked directly to the current level of zoom. The size of both the video file and the webcam image grew in proportion to the amount of zoom applied. Zoom varied from the standard resolution of the camera to an enlarged portion of an overlaid video. In this way, the video image could be increased in resolution as the webcam feed was gradually occluded, giving the impression that the media emerged from inside the bottle.

ANALYSIS

The reaction to the exhibition was positive. Comments recorded in the visitors book continually made reference to the beauty and audiovisual impact of the "shifting light images" and sound effects. One visitor reflected many comments when they stated "I'll see the bay in a different way." Our interest, however, was directed particularly towards the details of the Telescope in use, and the interaction taking place around it.

Over the course of the two-month exhibition, we collected data at various intervals to study the Telescope in use. Our analytic data corpus consisted of many hours of video data shot from two positions in the exhibition space (marked in Figure 1), and log files of the electronic compass sensor readings taken at corresponding times. Video cameras were placed to give an overview of the exhibition space and a close-up of the Telescope. The camera recording the Telescope obtained audio from a plate microphone attached to the front of the device, allowing conversations to be heard above the ambient music and sounds of the exhibition.

Alongside the video data, we developed a tool to reconstruct the Telescope's movement from the sensor logs and provide a view of what visitors would have seen (simulated view shown in Figure 6). The reconstruction of this view was a necessary feature of our analysis, as there were a significant number of cases in which visitors reacted to or commented on what could be seen on the display inside the Telescope. Due to the time constraints, we were unable to link the tool with existing video players, and so a reconstructed 3D graphical simulation of the Telescope and its movement (3D model shown in Figure 6) was implemented, allowing us to manually synchronisation between the reconstructed view and the video data by visually comparing our video recording of the Telescope in use and the motions of the 3D simulation. The bottom window in Figure 6 shows one camera view, but note that typically we viewed the recordings from both cameras concurrently. Video segments needed to be repeatedly viewed in tandem with the simulated view in order to better understand the often subtle interactions we found occurring. We were able to perform such repeated viewings by skipping to certain points in the log data using the controls shown in the centre of Figure 6.

Figure 6. The analysis tool

In the following three sections we describe various facets of the Telescope's use by visitors. Examples shown are typical of cases we have studied throughout the data. Given our interest in making the telescope fit appropriately within the public exhibition, we were particularly interested in how visitors engaged both with the Telescope and one another around it. Our first examples illustrate how visitors swapped over and collaborated around the device.

Lighting and Turn

We found that the use of the light provided on the Telescope had an unexpected impact on co-visitors in the space. In our first example an exhibition docent, Tom, is using the Telescope. The exhibition space is relatively dark at this point in the performance, and the Incubator in particular is not illuminated. Tom presses the button to turn the Telescope light on.

Figure 7[2]. The Telescope's light illuminates the Incubator and many visitors move or look towards it; Jenny (circled) moves towards the Telescope

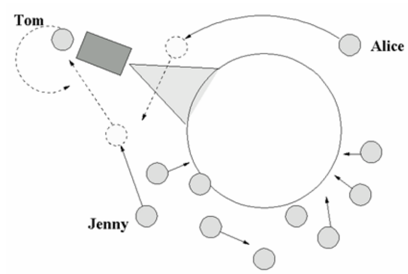

Figure 8. Movement of co-visitors

As Tom switches the Telescope light on, visitors situated near the Incubator turn and move towards the newly lit glass bottles (Figures 7 and 8). Such attention or distraction caused by lighting effects is a well-known phenomenon [27,17], and here highlights the ability of the Telescope to provoke interest in the Incubator. It also shows how the use of the Telescope can impact on co-visitors not using the Telescope or otherwise locally engaged with a Telescope user.

The Telescope's light in this example not only affects the behaviour of both the current user and the bystanders, but also causes a visitor (Jenny) to move towards the Telescope. As with others of the group, Jenny's gaze is intermittently cast on the Incubator, but her movement is directed towards the Telescope. She stops a short distance away from the device. Tom finishes using the Telescope, lets go of the light switch and, at this very instant, Jenny turns her head from the Incubator towards Tom. Tom disengages from the Telescope, and arcs around Jenny, creating space so she can use it.

The light cast upon the Incubator brings about Jenny's initial movement towards the Telescope. However, when she adopts a position of proximity, it is the light turning off which brings her gaze away from the Incubator and towards the device. Tom's use of the Telescope light on the Incubator may at first appear to have a 'moth effect' on the gathering visitors, but Jenny's movements highlight a more subtle point. There is a relationship between using the device and the effect that has on the trajectory and transitions of other visitors' engagement.

[2] This and some subsequent images have been artificially enhanced to improve visibility for the reader. The real exhibition space is substantially darker than it appears here.

In our next example, the Incubator lights have just come on and the same exhibition docent, Tom is explaining the contents of the glass bottles to the group. A woman, Mary, leaves a crowd of visitors across the room walks across to the Telescope. She grabs the handles and looks through the eyepiece. She spends approximately six seconds in this position as another woman, Pauline, approaches. Pauline arrives at the Telescope. She makes a comment (undecipherable) to Mary after which they share a laugh. A few seconds later, they swap turns and Pauline peers into the eyepiece. She spends some time examining the image inside (about eight seconds), and then pulls away from the Telescope, making a distasteful expression and saying "wriggling" (Figure 9, left). She then moves away to examine the Incubator. Her view prior to pulling away can be seen in Figure 9 (right). A few seconds after Pauline's disengagement, a man, Freddy begins to use the Telescope. Freddy approaches directly towards the device following Pauline, but does not talk to her.

Figure 9. Pauline's reaction (left) to what she sees (right)

We must attend to the relatively rapid 'handover' speed with which several visitors are able to use the Telescope and move on. Mary, Pauline and Freddy all move from positions as bystanders to being engaged with the device and accessing augmented content directly. Symmetrically, Pauline, after her encounter, swiftly moves from this direct engagement with the device to engaging with the target, the Incubator. Amongst the handovers, Pauline and Mary briefly take part in a humorous exchange regardless of the fact that Pauline is not engaged with the device, and has (at this point in time) no direct experience with the augmentation. Beyond these person-to-person encounters, however, visitors are able to collaboratively share experiences of the Telescope itself, by collaboratively varying their engagement with the device.

Later on, at the end of the same show, Pauline, David and Eric are standing nearby. The house lights have come on and they appear to be discussing the structure of the room. Bob begins using the Telescope by placing his left eye to the viewing tube and moving it around (Figure 10, left). He then turns the Telescope light on using the button on the handlebars. Previous examples have shown how bystanding groups are attracted by the Telescope's light cast on the Incubator. In this example, however, Eric and Pauline turn their gaze and subsequently bodies directly towards the Telescope (Figure 10, centre). After a few seconds Eric moves towards the Telescope, followed by Pauline. Bob moves up from the Telescope eyepiece, his right hand releasing the light switch (Figure 10, right) and then the handlebar. As he pulls up, Bob looks in the approaching visitors' direction and then moves away, creating space as Eric and Pauline move in.

Figure 10. Bob uses the Telescope with Eric, Pauline and David standing nearby (left). He presses the light and Eric orients towards the Telescope via the Incubator (center). Bob disengages from the Telescope as David, Eric and Pauline approach (right)

Eric and Pauline take over, with Eric grabbing the handlebars (Figure 11). Pauline here uses the same word, "wriggling," to describe the function of the Telescope to her co-visitor. Bob also overhears, as shown in the following dialogue:

P: There's the ((mumble)) thing there
((Pauline points to the Telescope))
E: Mmm (.) does that help?
P: Hhh if you wanna see something
wriggling down there ((Bob laughs))
P: ((Pauline laughs and looks up at Bob))
E: ((looking through Telescope))
How weird (.) huh

Figure 11. Eric (right) looks through the Telescope whilst Pauline stands next to him

The interaction between Bob, Pauline and Eric forms part of handing over the Telescope between Bob and Eric, a process where the physical features of the Telescope enable the swift traversal of visitors between being part of the local milieu and becoming engaged users of the device. Earlier, we saw how a rapid succession of visitors came to view augmented content in a matter of seconds. By 'physical features' we mean the simple access to the augmentation afforded by the eyepiece style that, when configured by a docent or previous visitor, provides a relatively stable experience that is less sensitive to 'handover' instabilities, namely, jumps of alignment between users.

In cases such as these we see the impact of both lighting and body movement inform and affect visitors' engagement with the device. The impact of the Telescope's light appears to be contingent upon the ambient lighting of the surroundings and here we note how the aesthetic impact of the Telescope changes with the lighting aesthetic of the space. Bob's movement away from the Telescope is occasioned by Eric and Pauline approaching, which in turn is occasioned by Bob's use of the Telescope light. Here, however, we are interested in how Pauline and Eric share content across different levels of engagement with the Telescope. They have both used the Telescope before, and are able to interact during, and as part of Eric's first encounter with the augmented videos. Pauline draws on her previous characterisation, "wriggling," to frame Eric's direct engagement with the device. Similarly, Bob and Pauline's interchange of laughing in response to Pauline's description weaves a fabric of sense for Eric's use of the Telescope. Thus, we see co-visitors providing a context in which direct users directly engage with the augmentation.

Interestingly, the reconstruction from our sensor log files indicates that there is no augmented video being played out while during Eric's characterisation "how weird." He can only see a direct (pass-through) view of the Incubator and never manages to locate any green regions, in contrast to Pauline's previous experience of seeing some video content overlaid on this pass-through view (Figure 9, right). Nevertheless, he orients to that content as "weird" to Pauline before disengaging from the device. The view in the Telescope is experienced both in the context of what can be seen and in what ways co-visitors are collaborating with the user. The exclusive access the Telescope provides for a 'augmented' user can therefore create problematic discrepancies in views between users and co-visitors.

Sharing and Stability

Our next example takes place when the Incubator lights are on. Tom is talking to two women, Sally and Fay, about the Telescope. He approaches the device with them, and begins to adjust the viewpoint. Tom lines up the view through the Telescope at the edge of a video, and provides a brief description of its operation. Just as he disengages, however, the Telescope moves slightly, shifting the focus to outside the video region. Tom then makes space for Sally as she grabs the Telescope with both hands and places her left eye to the viewing tube (Figure 12). As she grabs the device, the view through the Telescope jumps again, moving the focus to between two regions. After approximately three seconds, Sally looks over the Telescope, still holding the handlebars, and says:

S: What am I looking at? (4.0) Can't see what I'm
looking at

Just before Sally looks up (on her first "what"), the Telescope focus moves inside a region and a video starts to play. Sally hands over Telescope to Tom who then very briefly checks the view. When Tom checks the view, he sees that there is a video on screen, the same video Sally unwittingly lined up just as she asked her question.

T: Right oh there you go you've got something y-
you've on screen ((points at eyepiece)) now
you've act- you've picked something up you've
picked a beastie up there you've picked a blob
a live microbe

Tom disengages from the Telescope at "got something" and Sally then reengages. Unfortunately, an anomalous movement (possibly due to magnetic field jitter) shifts the focus of the Telescope again to the other side of the region such that the focus is now too far to the left of the region and again no video is playing.

```
S: Have I?
T: Yes can you see what it is?
S: Nooooh!
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Tom laughs and moves in on Sally's "Nooooh!" as Sally backs away from the Telescope. He grasps the eyepiece and places his right eye on it. The view he sees is the same as Sally's when she says "Have I?"

Figure 12. Sally requests help (top left, circled), Tom adjusts (top right, circled), Sally still has problems (bottom left), Tom adjusts again (bottom centre), Sally sees the augmentation (bottom right)

```
T: Oh it's gone now ummm
S:                  What that blue there was a
   blue ((Tom pushes the Telescope's view to the
   right in order to get the focus inside the
   region))
T: Try and line it up with the green squares ahh
   there you go yeah yeah those are living ((Tom
   hands over the Telescope to Sally)) living
   microbes in the inside the jars
S: Oooh my lord
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When Sally first uses the Telescope, Tom frames her use of with a description of its operation. Sally's grab of the Telescope's handlebars, however, disrupts the viewpoint that Tom has configured. Due to the 'single-user' properties of the Telescope (i.e. a private view), Tom is unable to monitor the display during the handover. Thereafter follows a further problem – albeit one not caused by accidental movement of the Telescope's body, but an anomalous jump in viewpoint – which also follows a similar pattern: Sally says "Have I?" and "Nooooh!" after which Tom moves in to perform another correction. Tom, building on his previous description, now provides a more detailed account of how to locate the content, "Try and line it up with the green squares."

There are therefore three attempts at configuring the viewpoint for a handover before any success. The interface does not allow a shared perspective on the content and so the docent is unable to reconstruct or correlate a user's difficulties in using the interface without drawing from second hand information, namely accounts of the problems occurring, or by taking over himself. For this reason, the two causes of breakdown in this sequence, the accidental bumping of the Telescope and the anomalous jump of viewpoint, indicate that attempts at repairing the problem may be required repeatedly until the set up view just happens to survive during the handover. As a result, the docent is unable to craft the experience for the visitor.

The key issue here, then, is how those using the Telescope and those standing alongside identify and repair disparities in content during handovers. The problematic handovers between Tom and Sally show how the Telescope's design limits co-visitors' ability to see what others are seeing. That the Telescope is a 'private' device means repair of these discrepancies is problematic. Nonetheless, the amount of time taken to perform several iterations of the configure-handover-view cycle is a matter of seconds. Repair is eventually possible, enabled by the rapidity with which users and co-visitors can move between looking through the eyepiece, holding the handlebars but talking to co-visitors, and handing over to become a co-visitor themselves.

Viewing and Vicinity

In this example, Freddy approaches the Telescope for the first time. The Incubator lights are on. After getting into a comfortable position with the handlebars, he begins to move the Telescope around. He zooms in to watch a video emerging from a bottle. A few seconds later, Pauline walks directly between the Telescope and the Incubator. Freddy stops and briefly glances up and over the Telescope at Pauline (Figure 13, left). Freddy's movement is noticed by Pauline who looks to her left, and then crouches down (Figure 13, right). In response to this ducking movement, Freddy jerks his head back to the Telescope slightly. He then moves back up again and grins at Pauline while she laughs. Finally, Freddy moves his head back down to look through the Telescope, still smiling.

Figure 13. Freddy looks up (left) from his view through the Telescope and Pauline ducks (right, circled)

This sequence illustrates how Freddy and Pauline seamlessly traverse and collaborate across different levels of engagement, both with the Telescope and with one another. Freddy initially engages with the Telescope. He notices a disruption of his view, and pulls up from the Telescope in order to work out what is happening. He maintains physical engagement with the device by holding on to the handlebars, and checks the real world view against what he has just experienced in the augmented view. Pauline indicates an understanding of his movement by belatedly making an attempt to avoid blocking his augmented view, and Freddy is able to both recognise this fact, and share a moment with Pauline that shows his recognition. There are a series of resources that are drawn upon to retain a view of the Incubator: the ability to 'disaugment' yet maintain engagement on Freddy's part; the ability to recognise and orient to such an activity on Pauline's part; and their ability to acknowledge and complete such a process quickly (in this case, approximately two seconds between Freddy moving his view away from the Telescope and returning to it). In this example, the Telescope's physical form allowed Freddy to assess a discrepancy and subsequently resolve it.

The Incubator is an interesting artefact in its own right without using the Telescope to view it, so we encounter frequent obstructions of the Telescope view by co-visitors passing between the two. Pauline has used the Telescope before and it is possible that she realises to some extent the effect her movement may have on Freddy's view.

In our next example, Tom has set up the Telescope's orientation for Jenny to see a video of diatoms in the centre of the view. He begins to speak to Jenny as she approaches the Telescope.

```
T: Press the light
J: Yes
T: And twiddle round until umm line it up with the
   (.) line the image up in here with some of the
   little green squares ((Jenny moves to place her
   eye to the Telescope))
T: You can see some of the microbes inside ohh
   look there's a big microbe there
```

As Tom starts to say "the microbes inside," Jenny presses the light switch. Alice happens to be walking in front of the Incubator at this moment, and the light illuminates her movement across the Telescope's view. Tom points at Alice and says "ohh look," just as Jenny presses the light. As she is illuminated, Alice glances towards the Telescope and quickly moves past. However, Jenny does not disengage from the Telescope despite Tom's statement to "look," and she continues to view through the eyepiece. Tom then goes on to account for Jenny's potentially occluded view of the Incubator. He has no direct access to what Jenny is seeing on the Telescope display, but he describes Alice's movement in terms of Jenny's potential experience by saying "there's a big microbe there" (referring to Alice).

In the first section, we saw how Pauline provided an account for Eric to show what he might see and similarly in the second section, we saw how Tom's accounts to Sally assisted the identification of the discrepancies in their views. In this case we see how Tom is able to share an account of how the Incubator may (dis)appear even though he is not using with the Telescope. In this case, Tom draws on his view as a co-visitor's and his experience of having used the Telescope in order to provide some sense to Jenny's augmented view. Whether by a user looking up or having a co-visitor explicate the situation, a 'disaugmented' viewpoint is important to understanding how the Incubator appears.

DESIGN IMPLICATIONS

We now generalise from our observations, reflecting on the specific strengths and weaknesses of the Telescope design and drawing out broader issues for the design of public AR experiences.

Telescope Design Features

The form of the Telescope fundamentally shapes the way in which social interaction plays out in One Rock.

Despite our use of black paint and fabric, the sheer physical size and visibility of the Telescope attracts attention. We have derived unexpected benefits from this attention, most prominently that its size requires large gestural usage, so that bystanders and co-visitors are aware when and how it is being used. Furthermore, the Telescope light amplifies its visibility and also the visibility of the target, making a connection between them; we see that some visitors' attention is drawn to the target and then back to the display, attracting them to become involved. The Telescope's projection of presence into the environment caused by this light is, however, contingent upon the lighting aesthetics of the environment; changes in lighting featured centrally in the show and thus the Telescope's light was most meaningful in that aesthetic context.

Due to the Telescope's handles and mounting being separate to the viewfinder, it is easy to make room around the device while still holding on to it, as a way of sharing, handing over and inviting others to use it. It also facilitates rapid handover to others and rapid disengagement/ reengagement by an individual, which is useful for negotiating social interactions such as repairing breakdowns in communication due to instability or interference.

The peephole style display is especially interesting. The privacy of the view causes problems for co-visiting, especially when it comes to lining up and maintaining views for others during handover and when sharing and discussing content within a group. In contrast, however, the physical form of the viewing tube permits swift handovers since the action involved in engaging and disengaging with the augmented view is simple and takes little time. The design therefore does at times permit quick, seamless and even humorous negotiations between the AR user and others in the exhibition space. Nevertheless, there are some important benefits to such a display, even in a social situation. A concealed display can certainly engender both immediate surprise and ongoing fascination with digital content. Additionally, it is clear when someone is looking through a peephole display. This can enable others to infer both what that person is doing with the display and in what directions they might be doing it.

Separation of Target and Display

AR interfaces are characteristically distinguished from other forms of interface by their combination of a physical artefact, a target, and a computer display, a device, and that these are very often separate from one another. Both the target and the device in One Rock are legitimate objects of interest for the visitor. While we expect visitors to use the device, we should anticipate that others will attend directly to the target in its own right as a painting, sculpture or a part of a building, or similar.

This separation of device from target has an important consequence for design in that we typically need to consider a shared environment in which some participants have an augmented view while others have a un-augmented, or 'plain,' view. This will be especially true in public environments such as exhibitions, where there are many visitors flowing through the experience and it is infeasible to ensure they are all equipped with a display.

Target and device are also often separated in space; that is, the device is some way from the target and has to be pointed at it in order to view the target. This raises the possibility of interference, as we saw when visitors physically moved into the space between the Telescope and the Incubator. In our case, this interference is distracting, but in other cases, especially if tracking is used to identify targets using video cameras on the device, it might also affect the operation of marker tracking. Either way, interference requires resolution, typically involving collaboration between the people involved. In our case, this involved the Telescope user temporarily and rapidly disengaging, an action that was then noticed by the passing visitor, enabling the pair to quickly and fluidly resolve the problem without the need for explicit discussion.

In cases where the sensing technology is separate from both the display and the target, for example where we are using wall- or ceiling-mounted video cameras to track targets, there are further possibilities. Visitors may cause visual interference by passing between the device and target or may interfere with the sensing system by passing between the external sensor and the target and/or device depending on which is being tracked. In situations in which multiple displays, targets, visitors and even sensors can change locations, designers need to be aware that the possibilities of interference become far more complex. Fortunately in One Rock only the visitors move.

Levels of Engagement and Transitions

Previous studies of interactive exhibits in museums and galleries have introduced the idea of varying levels of engagement. The subtle interplay between various movements made by bystanders, co-visitors and users around the Telescope might be compared to the observations reported by vom Lehn et al. [19] who describe the coordinated conduct of groups and strangers around museum exhibits. Our observations confirm these observations, in that we see substantial coordination of conduct between both strangers and friends, groups and individuals, roles and responsibilities. However, we also suggest some refinements. We propose that the use of the Telescope in One Rock, especially the separation of plain from augmented views and the use of a peephole-style display, results in several distinct levels of engagement:

- *Augmented User*. Visitors who are looking through the peephole.
- *Disaugmented User*. Visitors who are controlling (holding) the telescope but not looking through it.
- *Co-Visitor*. Visitors who are part of the local group around the telescope.
- *Observer*. Other visitors who are grouped around (or in the way of) the Incubator.
- *Bystander*. Those currently not engaged with the device or target.

As we have seen, collaboration across and transitions between these levels are an important part of the experience. We have seen collaboration across augmented and disaugmented perspectives (such as the humorous exchange between Tom and Jenny), and, specifically, how a 'disaugmented' perspective might inform an augmented one. We note that such collaboration might be problematic in more permanently worn displays, such as HMDs (Head Mounted Displays). We have also observed a variety of transitions, such as Jenny moving from bystander to co-visitor to augmented user, Sally and Tom swapping between co-visitor and user, and Freddy moving from augmented user to disaugmented user. These transitions relied on a variety of collaborative activities, such as: drawing attention to the target and or device; communication (verbal, gestural) between engaged visitors and those nearby; engaging/disengaging from the display; inviting and making room for others; and, as we shall now discuss in closing, handing over the display to others.

Handovers are particularly important moments, with the current visitor going to considerable lengths to set up the experience for the next visitor, both in terms of verbally framing their experience but also in carefully positioning the display to provide them with an appropriate view when they engage. The need to position the display for others is clearly important, but is also difficult, and handovers are dangerous moments for social interaction. We have seen that a combination of physical instability, sensor instability and an inability to see the other's view when disengaged from the display can cause problems here. Fortunately, in the case of the Telescope these issues can often be resolved by quickly disengaging and reengaging with the device.

In contrast, aligning an HMD's viewpoint for a handover to a subsequent user is almost impossible, whereas due to the Telescope's construction, handovers become less problematic when crafting an experience for others. Tracked opera-glass or handheld displays will be faster to handover but by default will provide a different perspective making it difficult to set up a particular view for a co-visitor. Such transitions will therefore be more or less rapid and seamless depending on the design and type of AR display used, which will in turn fundamentally shape the ways users engage with, and collaborate around, the augmentation.

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