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Designing Mixed Media Artefacts for Public Settings

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Abstract. This paper describes how principles which are emerging from social scientific studies of people's interaction with mixed media artefacts in public places have been used to support the development of two installations, the second of which is a long term museum exhibit. Our principles highlight the design of 'emergent collaborative value', 'layers of noticeability' and 'structures of motivation' to create an 'ecology of participation' in installations. We describe how our first installation was used as a 'research vehicle' that guided and shaped the design of the museum installation. We also provide an account of how people interact with our installations and how this analysis has shaped their design. The paper closes with some general remarks about the challenges there are for the design of collaborative installations and the extent to which we have met them.

1. Introduction

In recent years, research in Computer Supported Cooperative Work (CSCW) has begun to include topics and settings which add to its traditional concern for the world of work and the information technologies to be found there. For example, Craven et al. [8] describe applications of collaborative virtual environments which have clear leisure and entertainment uses. While these authors speculate that the methods they have used for organising participation in game-like or story-telling environments might have applications in more traditional areas of CSCW (e.g. the coordination of contributions to a shared work task), this is not their primary concern. Mynatt et al. [19] discuss a community computing initiative called SeniorNet in which people who are or who are about to become retired from employment are supported in their use of networked computing technologies. Brown et al. [5] describe a system for music sharing (Music Buddy) which embeds this activity in social interaction and collaborative exchange. Again, the concern is to examine a phenomenon not normally associated with activity at the workplace to "learn lessons for more conventional CSCW applications" (p.180). All three of these examples demonstrate a growing tendency to broaden the remit of CSCW beyond workplace settings, systems and applications, even if an ultimate reference back to them is intended.

Another tendency in recent CSCW contributions is to examine the use of technology by a broad population of users. The Craven et al. research just mentioned is concerned to enable members of the public to participate in 'on-line experiences' of an entertaining kind. SeniorNet and Music Buddy are similarly broad in their conception as to who count as users of them (the over 50s, music fans). This stands in contrast to much traditional CSCW which trades on a strong conception of users or workers as engaged with particular work tasks and, through analysis of that work, offers design ideas or systems intended to mesh with those work settings. Rather, we see CSCW coming to engage with notions of 'the citizen' or 'the public'.

Indeed, some researchers have begun to examine people's encounters with technologies in public places such as museums and art galleries. Büscher et al. [6] describe a media art exhibition space and characterise the ways in which people move between the pieces contained therein, learn about them and cooperate with each other in making sense of them. On the basis of these observations, the authors make proposals for organising of large scale, interconnected multi-user virtual environments and enhancing their intelligibility. In recent work, Heath et al. [12] describe how people engaged, largely within small groups of friends, with an interactive visual installation so as to draw each others' attention to interesting features while cooperating on the joint operation of the piece. In particular, these authors are concerned with how co-participants shape each others' perception and appreciation of the installation, and how passers-by maintain a peripheral awareness of the activities of those directly engaged with it, perhaps learning from them when they in turn initiate interaction.

1.1 Social Scientific Design Sensitivities

The work we report in this paper is an extension of this emerging concern for engagement and collaborative interaction with technologies in public places in general and museums in particular. The paper centres on the design of two installations. The first, ToneTable, acted as a prototype and 'research vehicle' where we explored a number of interaction principles derived from social scientific design sensitivities. This research was then used to shape the design of a long-term installation, The Well of Inventions, at the Museum of Science and Technology in Stockholm, Sweden. Our work, in many respects, instantiates a design response to the social scientific precepts we gain from the work of Heath et al. and Büscher et al. and their studies of behaviour in public places with respect to artistic and museum pieces. In particular, we itemise two areas of concern we wish to be sensitive to in design.

- *Multiple forms of participation.* People manifest many different orientations towards artefacts, installations and exhibitions. There is a range of forms of engagement–central or peripheral, active or passive, overhearer/overseer etc.–which need to be taken account of. Visitors who are alone, and those who come with others, need equally to be accounted for. If possible, one should design so as to support the simultaneous coexistence of these multiple forms of participation in an 'ecology of participation' (Heath et al. [12]).
- *Interaction and co-participation.* Interaction should not refer to just the interaction of a single 'user' with an exhibit but should address the multiple ways in which people engage with each other in, around and through the artefact. This may involve providing "enhanced or variable functionality when participants interact with each other in and through the exhibit" (Heath, et al. [12]).

2. ToneTable

ToneTable is a multi-participatory, mixed media installation which embodies a number of systematic strategies for combining sonic and computer graphical materials in ways which support multi-participant interaction. The installation consists of a table-top graphical projection situated in the middle of a multi-speaker sound environment. We publicly exhibited ToneTable a number of times and continually refined its design in the light of

experience, which allowed us to illustrate a number of interesting design principles in action in real practical settings. As we shall see, we have worked with some specific design concepts to respond to the social scientific sensitivities outlined above. As such, we hope our work shows how social scientific work in CSCW can be responded to methodically yet creatively.

2.1 Related Technologies

A number of table-top interaction devices with an embedded graphical display have been reported in the CSCW, HCI (human computer interaction) and allied literatures. For example, the InteracTable developed at GMD (http://www.darmstadt.gmd.de/ambiente/activities/interactable.html) uses a large projection onto a table top with information manipulation being supported by pen and finger-touch based interaction at a touch sensitive surface. Local infra-red networking allows other devices to be brought to the table for interaction purposes. Interactive sound has been incorporated into InteracTable to provide feedback to user gesture, in some cases through the physical modeling of dragging and writing sounds.

A further development of this concept is to combine the manipulation of specially designed physical objects on the surface with a projection of a computer graphical world onto the surface. For example, DigitalDesk [22] and phicons [16] are both concerned with the combination of computational media with a physical device or display surface.

Hoch et al. [14] describe The RoundTable in which a visualisation is projected up onto a table surface. On the table surface, a small number of phicons can be placed, which can have a variety of effects on the visualisation. The phicon positions, orientations and identities are extracted from video which is captured by a camera positioned above the table. Hoch et al. describe an application in which movements of the phicons control, amongst other things, the deployment and movements of virtual cameras in an on-line collaborative virtual environment, the table top visualisation providing a map-view of the overall environment. In an extension of this work, Bowers et al. [3] describe an application of The RoundTable in which the positioning of objects on the table surface mixes sound sources, a kind of ‘mixed reality mixer desk’. The position, orientation and identity of objects in the visualisation denote sound sources, while the position et cetera of phicons placed on the surface denote virtual microphones with the mix at a selected virtual microphone being computed and rendered on a stereo loudspeaker system.

In our current work with ToneTable and The Well of Inventions, we decided to simplify the interaction methods to concentrate on design principles for supporting multiple participants working with sound and graphics. Accordingly, we chose to work with simple trackball based interaction (rather than the phicons and video processing of The RoundTable). This simplification enabled us to explore more satisfying inter-media relations than our earlier mixed reality mixer desk. Our installations support multi-user interaction with real-time sound synthesis, as well as sound file playback and processing, both in relation to the behaviour of a computer graphical animation.

2.2 Introducing ToneTable

ToneTable is a sound and computer graphics installation which enables up to four people to collaborate to explore a set of dynamical relationships between different forms of media [4]. We envisioned a scenario in which visitors would encounter a table within a room-sized environment which also contained a multi-speaker sound system. A visualisation of a real-time updated physical model of a fluid surface would be projected onto the table from above (Figure 1). The 'virtual fluid' would have its own autonomous flowing behaviour, as well as being influenced by the activity of the visitors. A small number of virtual objects would be floating on the surface, and these would move around the display in response to the dynamics of the modeled fluid surface. By using the trackballs, our visitors would be able to move sources of virtual 'wavefronts' around the display, which in turn would enable the visitors to 'push' the floating objects. If the local force upon a floating object exceeded a certain threshold, the object would suddenly exhibit a radically different behaviour. In our realisation of ToneTable, we chose to let this new behaviour consist of an orbiting motion around the display, which would gradually come to rest and resume the more gentle meandering behaviour characteristic of the objects moving as a result of the flowing surface alone.

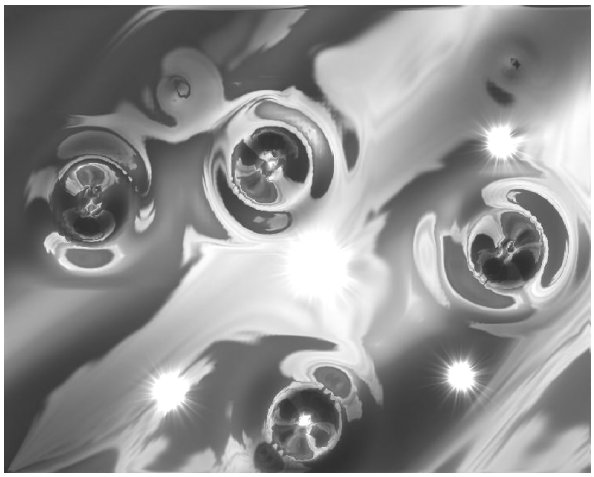

Figure 1. The graphical projection of ToneTable. Each of the four 'wavefronts' is associated with the motion of a trackball. The 'stars' are the visual representation of the spatialised sound textures.

To achieve a mixed media installation, our scenario involved a number of correlations between the interactive computer graphics and the sound. Each floating object would have a specific sound texture associated with it. By carefully arranging a set of four speakers in the vicinity of the table, we would create a soundfield within which these sound textures could be heard. Furthermore, the sounds would be spatialised so that their visual representation on the table was spatially consistent with their heard-location in the soundfield.

2.3 Design Principles and Scenarios

ToneTable can be seen as an exploration of a number of principles for the design of interaction in mixed media artefacts, principles that are responsive to the design sensitivities emerging from the social scientific work touched on above. These principles include (from [4]):

Layers of Noticeability, Varieties of Behaviour, and Structures of Motivation. Our ToneTable scenario involved a variety of sonic and graphical behaviours which would be progressively revealed through visitor interaction (both individually and collectively) with the trackballs. This would give a 'structure of motivation' to the installation. That is, we intended to provide an 'in-built' incentive to explore the table and its varied behaviours and image-sound relations. Indeed, the dynamical behaviours of ToneTable were defined and calibrated with various non-linearities. Our intention here was to make the exploration of ToneTable an open-ended affair with some of the behaviours it is capable of being 'emergent' and not necessarily known to the designers in advance. As such, we were hoping that ToneTable would make for a contrast with interactive installations where there is a 'key' or hidden, underlying principle that needs discovery and, once discovered, exhausts the interest of the piece. Finally, by 'layering noticeability and interaction' in the manner we have described, we wanted to create an artefact which could be explored over various timescales. While there would be an immediate responsivity to its use, additional behaviours would be revealed with more extended engagement. In this way, ToneTable is intended to give value no matter how long visitors engage with it.

Interaction Through a Shared Virtual Medium and Emergent Collaborative Value. Our ToneTable scenario was developed to support interaction between visitors through a shared virtual medium. By coordinating their activity in that medium, visitors can engender 'added values'; behaviours of ToneTable which a person acting alone can not so easily obtain. However, the resting state of ToneTable would not be without interest and variety: it would have a variety of behaviours available to visitors acting alone. The intention here was to design an artefact which permits variable forms of engagement, both individual and collaborative, both 'hands-on' and spectating. In addition, by coordinating activity through a common virtual medium, we hoped that participants could gracefully move between one form of engagement and another. They could work individually or in close coordination with others through the use of the same devices and repertoire of gestures. Thus, collaboration would not require a switch of 'interface mode' over individual activity (cf. the proposals for 'encouraging collaboration' in [1]).

Variable Image-Sound-Activity Associations. ToneTable relates image, sound and participant-activity in a variety of ways. Sound is associated with individual graphic objects. Sound is also associated with individual device-usage. This variety of strategies was intended to enable an approach to the mixing of media which is rich and more satisfying for participants than if just one technique had been employed. It has the consequence that a single gesture may well produce multiple sonic effects.

Abstract, Yet Suggestive Content. ToneTable was developed in cooperation with the Museum of Science and Technology in Stockholm, a cooperation which carried over into the development The Well of Inventions. The museum allowed us autonomy in the design of content for The Well of Inventions, which enabled us to regard ToneTable as a 'research vehicle' for exploring various inter-media design strategies and approaches to collaborative interaction. These strategies and approaches then became the foundation from which the design of The Well of Inventions was built. The content of both installations is 'abstract, yet suggestive'. That is, neither installation attempts to compete with any of the museum's substantive exhibits. They both suggest the domain of fluid dynamics and could be related to other interactive exhibits whose treatment of physics is more 'correct' than our approximations. They do not directly attempt to teach fluid dynamics but could provide an occasion for a teacher or the museum staff to do so. By dealing with content in this way, we hoped to produce exhibits of a playful sort that could be incorporated alongside more pedagogical exhibits or be treated as just fun.

2.4 Observations of ToneTable in Use

ToneTable has been presented to the public on a number of occasions, and feedback from the public enabled us to refine its design (cf. [4] for details). In addition, we also collected video-based material at one of the public events where ToneTable was displayed. Although this material was not optimal for detailed interaction analysis (sound quality was poor, for example), we were able to use it to draw a number of conclusions that assisted in shaping the design of The Well of Inventions.

Our treatment of the data collected (video-recordings and field notes) draws upon principles of ethnographic research as established in CSCW by authors such as Hughes and his colleagues (e.g., [2]) while being sensitive to interactional phenomena of the sort documented by Heath et al. [12]. This social scientific tradition of research emphasises detailed descriptions of the data (here concerning interaction and gesture in relationship to a mixed media artefact) rather than a hypothesis testing approach.

In general, most of our visitors appeared to endorse the quality of sound and graphics in ToneTable, together with the existence of different behaviours which could be progressively uncovered. Some visitors, however, were less tolerant of something 'abstract, yet suggestive' and found ToneTable lacking in real content (an issue which we shall return to in section 4). However, amongst those who were willing to enter in a more playful spirit, we were able to see many examples of careful collaborative interaction between participants at the table as, on a number of occasions, people coordinated their gestures to jointly elicit the orbiting behaviour and other effects.

Gestural Variety. Although ToneTable used conventional trackball input devices, it should not be thought that there is necessarily anything lacking in them with respect to their usefulness in this setting. Indeed, we observed a great variety of different gesture types being performed on the trackballs, with correspondingly a variety of different behaviours being achievable in the virtual environment projected on the table and in the soundfield.

Some of the gesture types we have noted include the following.

- *Tickles.* By gently and in turn moving the fingers over the trackball a slow, continual, yet interruptible, trajectory of the wavefront across the table can be sustained.
- *Tremors.* By quickly moving a finger or the palm backwards and forwards or from side to side, the wavefront can 'shudder' on the display.
- *Rubbings.* By rolling the palm across the trackball, a large displacement of the wavefront on the table can be achieved. Such gestures have a characteristic acceleration and deceleration and a start-move-stop 'envelope'. They are often followed by a rubbing in the reverse direction as large oscillations across the display and the soundfield are accomplished.
- *Circular rubbings.* By rolling the palm around the trackball, a large continuous circular path can be inscribed on the display, perhaps pushing sound objects around the soundfield along the way.
- *Single finger rub.* A single finger, commonly the index, might be used to accurately and delicately position the wavefront at a particular locus in the display so as to interact with, for example, a single object/sound.
- *Flickings.* A single finger, again commonly the index, is withdrawn under the base of the thumb and out of contact with the trackball, it is then suddenly released, hitting the ball which turns freely and then decelerates while the flicking finger follows through. This produces a trajectory on the table with sudden onset and rapid movement, and a corresponding sudden change in the soundfield.

Coordinating Gestures. Our video recordings revealed a number of examples of co-participants closely coordinating the kinds of gestures they perform and their temporal patterning. For example, at one moment, Y initiates a rubbing gesture to perturb one 'corner' of the graphical display. Immediately following this, M moves his wavefront to the same corner and performs the same gesture type. After a couple of seconds of this joint activity, they both simultaneously 'expand' the rubbing behaviour so as to take in more of the display in their wavefront movements with a highly noticeable increase in intensity of the activity sonification accompanying their gestural expansion.

Figure 2. Coordinated gestures at the table.

Figure 2 shows three people at ToneTable. The two to the right of the picture are both jointly engaged in rubbing gestures, one with the middle and ring fingers in contact with the ball, one with the thumb. They are jointly achieving an extensive perturbation of the virtual surface at the corner between them. For her part, H with her back to the camera and to the left of the picture is rubbing the trackball vigorously with the palm of her hand, producing large movements of her wavefront over the rest of the display. At this moment, then, a pair of participants are coordinating their gestures with each other in close interaction, while a third person employs a gestural type which will enable her to make a big effect but without disturbing them. Importantly, then, the table is able to support the coexistence of a variety of gestural types and activities. It does not enforce all participants to collaborate with one another and is tolerant of variable groupings and foci for activity.

Gestures in Physical Space. So far we have discussed some of the different gestures which we have observed being made with respect to the trackballs and the different effects in the graphical and sonic environment they produce. We have also noted how participants coordinate their different gestures with each other. We will now consider some other kinds of gestures, in particular, those not made on or with the trackball. For example, at one moment, K points to a region of the display just adjacent to where L and M are making their wavefront movements, and he is using the shadow of his hand in the projection to precisely pick out a graphical object he would like his co-participants to try to perturb.

Gestures of this sort are often precisely timed so as to accomplish a kind of 'commentary' or 'suggestion' with respect to what is going on within the display, without disrupting it. Equally, activity on the table often accommodates such gestural commentaries and suggestions as they are being offered.

In Figure 3, H is making a large circular gesture with her right hand to draw attention to the orbiting of a sound around the room's soundfield. In this way, she picks out

a particular consequence of her activity at the table and draws attention to the relationship between sound and graphics. This occurs just after the moment depicted in Figure 2 where H was dramatising the effect of large gestures. The table and her gestural activity with respect to it is enabling H to 'instruct' visitors to the installation in the graphical-sonic relationships it contains for her. Throughout all this, two other participants continue to explore the table with smaller gestures.

Figure 3. Gesturally 'animating' the moving sounds.

Coming and Going. Throughout our work on ToneTable, we have been designing not just for hands-on use of the devices at the table but for a participant's trajectory through the installation. Our design is very flexible in how it allows for 'comings and goings'. A single person can explore the table, as can a pair both working together or separately. While up to four people can be accommodated hands-on, they can pattern their activity very flexibly. Equally, there is space allowed for others to peripherally participate, perhaps waiting their turn while watching, or allowing a friend to have their turn.

The simplicity of the trackball as an interaction device and the fact that it requires no special 'tooling up' or instruction allows comings and goings at the table to be elegantly managed. A visitor can peripherally monitor the action at the table standing close to one of the participants. When that participant gives way, the new person can take over probably having already worked out the associations of particular trackballs to particular wavefronts and having observed a variety of behaviours and gestural types. Our design makes it easy for a newcomer to 'pick things up' where an earlier participant 'left off' and either extend the earlier person's explorations or try something new.

Collaboration and Emergent Effects. In several groups of participants we were able to observe a repeatable pattern of coordination which tended to elicit the orbiting behaviour of the graphical objects and their associated sounds. If two or more participants approach one of the floating objects together following approximately the same trajectory with their wavefronts passing over the object at approximately the same time, then the object is highly likely to start orbiting. By jointly pursuing the orbiting object, the participants are likely to get the object to orbit again once it stops. This strategy of 'co-chasing' one or more objects is likely to systematically elicit the orbiting behaviour and maintain it, if not continuously, then at least prominently. A number of groups of participants realised this and organised themselves to achieve this outcome. In particular, one pair of participants returned to ToneTable on a further occasion with an extra friend so as to more effectively chase the computer graphical objects around the projected display, and make the sounds move around the room.

3. The Well of Inventions

At the initiative of the Museum of Science and Technology in Stockholm, we evolved the design of ToneTable into a long-term, unattended museum installation–The Well of Inventions–which opened in May 2002 and is currently still on display. Let us now describe how the design sensitivities upon which ToneTable was developed have been carried over into the new installation.

Layers of Noticeability, Varieties of Behaviour, and Structures of Motivation. It is well established within museum research that visitors' prior motivation and expectations together with their current knowledge, beliefs and interests shape and influence the outcome of their visit (e.g., [7], [13], [15], [11]). Choice and control, and whether such choice is governed by intrinsic or extrinsic factors have also been shown to be important factors. For specific interactive activities, characteristics like clear goals, immediate unambiguous feedback, and levels of difficulty that are in balance with the visitor's abilities have been shown to be important features of successful exhibit designs [9].

With ToneTable and The Well of Inventions, we have attempted to be sensitive to this research by providing visitors with artefacts that can be used in multiple ways, and where new features are progressively revealed through extended use. At the same time, uncovering all of these layered features is not essential to the quality of the visitors' experience. Furthermore, our ToneTable observations suggested that the use of trackballs might be particularly suitable for The Well of Inventions; while they were straightforward to use for most visitors, they also afforded a large range of expressive and creative types of interaction. Indeed, many museum installations make use of trackballs, albeit more often as a replacement for on-screen cursor positioning devices like mice than as an integrated part of an exhibit.

Interaction Through a Shared Virtual Medium and Emergent Collaborative Value. Recent museum learning research suggests that the social circumstances and how people interact with each other at exhibits directly influence the success of their museum visit [11]. Thus, many museums are now showing an increasing sensitivity towards designing exhibitions that encourage discussion and collaboration between visitors and between visitors and staff. However, the physical design of many interactive exhibits still neglects to explicitly support multiple co-present visitors, and this is especially true for computer-based exhibits (e.g., [11], p. 191, [10], [18]).

The interaction principles embodied in ToneTable thus seemed particularly suitable for the museum setting. By supporting simultaneous input from multiple co-present users, ToneTable enabled–and indeed seemed to encourage–collaborative behaviour. By projecting onto a table, other forms of participation were made possible, ranging from passive observation to pointing and gesturing. The physical design of ToneTable also allowed for graceful turn taking.

Variable Image-Sound-Activity Associations. Different forms of multimedia have been used in museum exhibitions for a long time. Such technologies are typically straightforward in their use of inter-media connections, e.g., CD-ROM-based catalogues, kiosks and listening booths. At the same time, museums are currently facing fierce competition from other entertainment providers such as theme parks and movie complexes, which has resulted in an increasing interest in state-of-the-art technologies (ranging from IMAX-like theatres with interactive elements to personal, portable digital assistants). However, non-trivial forms of associations between image, sound and visitor activity in interactive museum exhibits are still relatively rare. Thus, in addition to acting as a

'research vehicle' for the exploration of a number of interaction principles as described above, ToneTable also embodied a number of design principles that have previously received limited attention within the museum domain – principles we sought to extend in The Well of Inventions.

3.1 The Design of The Well of Inventions

From our observations of ToneTable, we concluded that while its basic design supports and extends important features of the modern museum experience, its content, aesthetics and physical features would have to be further developed before it was suitable as a unsupervised long-term exhibition. Furthermore, the number of visitors to the Museum of Science and Technology can be very large at times. Therefore, our new installation had to support larger groups of co-present users than ToneTable. As a result, we envisioned a configuration of the architectural space that would make it possible to walk through the installation area without interrupting the activities at the table. The space would also contain a spectator platform from which it would be possible to overlook the installation, and a number of movable stools would allow visitors to sit down at the table. Figure 4 shows the ensuing layout of the installation.

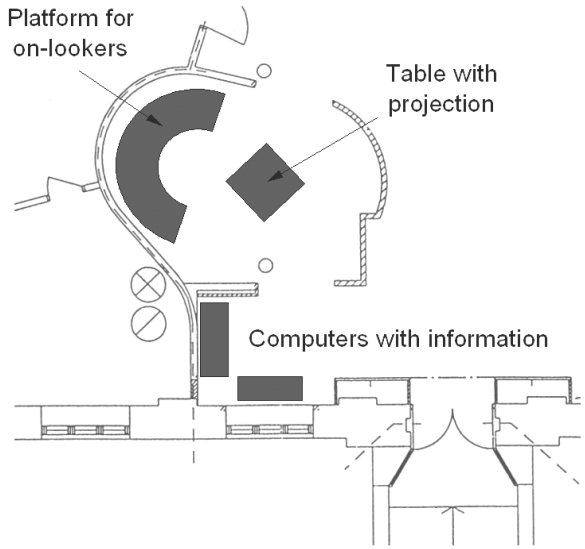

Figure 4. The layout of The Well of Inventions.

The Well of Inventions would be situated in the museum's Science Centre gallery where most exhibits are of a concrete, pedagogically oriented, experimental nature. Thus, we felt that a more explicit content for our installation would be less disruptive and fit better with the general theme of the gallery. At the same time, we wanted to retain the overall 'abstract, yet suggestive' feel of ToneTable. The Museum of Science and Technology contains many artefacts that are associated with machinery and dynamics in different ways, and this provided us with a suitable theme for the installation. Thus, our scenario for The Well of Inventions involved replacing the abstract star-like floating objects of ToneTable with depictions of museum artefacts like propellers and turbines. The object sound textures were also modified to be suggestive of these depictions.

Our scenario also allowed the objects to be situated both above and beneath the fluid surface, and replaced the empirically developed equations that governed their motion in ToneTable with rigid body mechanics (Figure 5). We also extended the range of motion behaviours by replacing the original fluid-like animation of ToneTable with a two-dimensional fluid flow simulation beneath the water surface and an airflow simulation above the surface. As a result, trackball motion would 'stir' the water by injecting virtual

forces into the simulation. Such ‘stirring’ would move the objects along the local velocity of the fluid flow. In addition, by correlating the buoyancy of the objects to their velocity, it would be possible to ‘push’ the objects through the water surface. Above the surface, the motion of the objects would be governed by the airflow simulation, which would allow them to move in a radically different manner. This feature would replace the original ‘orbiting’ behaviour in ToneTable. In our scenario, the trackball positions would also act as wind vortices that create turbulence in their vicinity. Thus, by coordinating their activities at the table, visitors would be able to collaborate to more readily push the objects through the water surface or cause the objects to ‘hover’ above the surface.

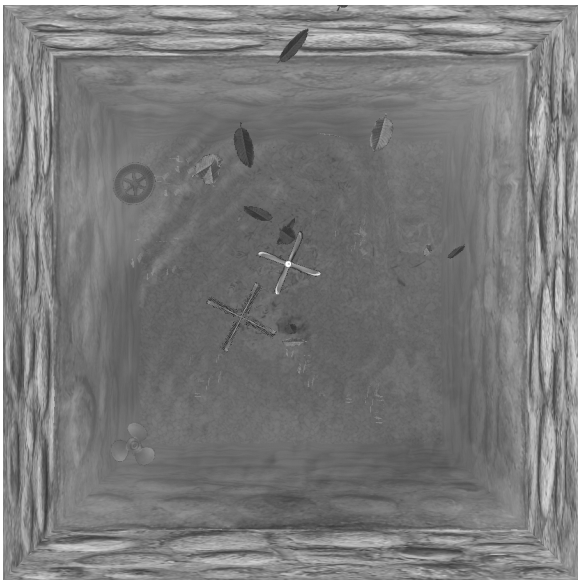

Figure 5. The graphical projection of The Well of Inventions.

While we acknowledged the need to provide visitors with background information concerning the purpose and goals of the exhibition, we did not want to introduce such texts into the main installation area. Thus, the installation was to be accompanied by an ‘antechamber’ that would contain a number of computer monitors. These monitors would display a set of different slideshows containing the background information.

Our scenario also introduced additional layers of noticeability, including ghostly reflections in the water and ‘sticky’ water. The reflections are images of machinery in which propellers and turbines are used, and constitute the inventions referred to by the title of the installation. ‘Sticky’ water is achieved by successively increasing the apparent viscosity of the fluid locally around two or more cursors when they are in close proximity for an extended period of time. When the cursors are brought apart, the viscosity gently relaxes back to its default value. In this way, the behaviour of the installation can subtly change depending on how visitors coordinate their movements and positions in the shared virtual medium. Further details concerning The Well of Inventions can be found in [20] and [21].

3.2 Observations of The Well of Inventions in Use

We have observed visitors interacting with The Well of Inventions for a total of approximately twelve hours, spread across multiple days. As with ToneTable, most of our visitors appeared to endorse the quality of sound and graphics present in the installation. Although our data indicate that visitors interacted with The Well of Inventions in ways that

were similar to how visitors interacted with ToneTable, a number of interesting differences are also present.

Larger Variations in Dwell Times. Typical dwell times at The Well of Inventions varied from a few seconds to roughly ten minutes. The longest dwell time we observed was close to thirty minutes. Often, visitors would stay for at least a minute if they 'got hooked', which is considerably longer than with ToneTable.

Opportunities for Rest and Relaxation. The Well of Inventions appears to provide many visitors with an opportunity for relaxation and rest. On many occasions, we have observed visitors who approach the installation at a high pace and initiate their interaction with it through quick and aggressive trackball gestures, and then successively relax down into a slower pace and more intricate and careful trackball movements. Our observations also include other types of visitor body postures that are typical of restful environments, such as relaxation and lowering of shoulders, sighs, leaning forward towards the table, and using the table to support arms and body weight. The environment also seems to afford a more quiet verbal intercourse than other parts of the Science Centre.

Layers of Noticeability Were Challenging to Discover. Of those that interacted with the exhibition, about one in five discovered that it is possible to push the underwater objects through the water surface, while almost all ToneTable visitors were able to produce the orbiting behaviour. Most visitors that interacted with the exhibition were able to discover the association between trackballs and cursors (and reliably produce the splashing sound associated with high trackball activity). Those visitors that did manage to push objects through the surface frequently co-operated with others to keep them in the air. Only a small number of visitor groups discovered that the water surface has the ability to become 'sticky'.

Age Group Differences. As with ToneTable, it was common for one visitor to discover a feature and demonstrate to other visitors how to use it. However, our ToneTable visitors were almost exclusively adults, while visitors to the Museum of Science and Technology are a substantially less homogenous group, both with respect to age and demographic background. With ToneTable, visitors would sometimes leave to bring back friends, and this behaviour occurred at The Well of Inventions as well, especially among children. Young children were often fascinated by the graphical animation of the water surface and would put their fingers onto the display to 'feel' the water. Children in the approximate age-range of ten to thirteen seemed to be more interested in the exhibition than other age groups. These children typically viewed the exhibition as a game: they often (quite enthusiastically) referred to the transformation of objects moving through the water surface as 'a kill'. However, adults expressed less interest in the installation, and would often encourage their children to leave while they were still engaged at the table.

Interaction with Other Visitors. Many of the visitors that entered the space as a group discussed the purpose of the installation and the nature of the interaction. They also verbally negotiated the meaning and underlying rules of the motion of the objects. The issue of legibility was of limited concern with ToneTable since a member of the design team was always present within the installation to explain its background and purpose. With The Well of Inventions, the computer screens in the antechamber provide this information. During our observations, however, very few visitors read the text on the screens. Many adult visitors also expressed puzzlement with respect to the educational goals of the installation, which may account for the fact that many adults encouraged their children to turn to other exhibits in the Science Centre.

Figure 6. Interaction at The Well of Inventions, as seen from the antechamber. Note the person quietly observing the activities at the table from the platform in the background.

The Design of the Environment. Apart from the fact that a few visitors found it difficult to spot the trackballs that are built into the table, the environmental design of The Well of Inventions appears to be largely successful. Most visitors that enter the Science Centre gallery approach or walk through the installation, and it is able to support both observation and active participation simultaneously (Figure 6). Larger groups of visitors also make use of the platform for on-lookers (when space runs out at the table) and older children often spend extended amounts of time exploring the physical features of the room, such as determining the source of the graphical projection or searching for a hidden 'control room'.

4. Conclusions: Designing Mixed Media for Public Settings

In this paper, we have presented two installations which combine, in a number of different ways, high quality computer graphical and sonic materials in room-sized environments. We have exhibited these installations on numerous occasions, ranging from short demonstrations to long-term unsupervised display. We have adopted a design strategy of incremental improvement in the light of experience, while being guided by some substantive design principles and concepts. These have been proposed as responses to social scientific sensitivities emerging from studies of interaction with and around artefacts within public places. Overall, we believe that we have developed artefacts which support collaboration and which are tolerant of multiple coexisting forms of participation. This enables people to explore a variety of gestures and concomitant behaviours of graphical and sonic objects. The installations have been exhibited with systematic regard for the trajectories people follow as they participate in relation to the artefacts at different times and in varied relationship to other people. Furthermore, we believe that we have produced two engaging mixed media installations which are sensorially rich without being overwhelming, and which repay repeated visits.

However a number of challenges endure.

- *Educational issues.* Neither ToneTable nor The Well of Inventions has any elaborate high-level educational goals in themselves (although, as we have pointed out, they could be used by museum staff or teachers as tools in an educational context). However, our observations of The Well of Inventions indicate that some adult visitors encourage their children to leave the installation. We believe that one important reason for this is that the installation is situated in a Science Centre, where adult visitors can expect exhibits to feature a straightforward pedagogical

'opening' from which educational interactions with their children could be built. Because few visitors make use of the information available in the antechamber, this 'opening' is not readily apparent in The Well of Inventions. Thus, we are currently experimenting with different ways of subtly suggesting such 'openings' within the main installation area itself.

- *'True' collaborative emergence.* While we have referred to 'emergent collaborative value' as a strategy for giving motivation to collaboration, it is questionable whether our installations truly manifests 'emergence' in the stricter senses one often encounters in the literature on complexity and non-linear dynamics. To obtain a greater likelihood of novel and unexpected behaviour as participants interrelate their conduct, we simply introduced thresholds in the underlying dynamics. This has the virtue of the dynamics being manually 'tuneable': the threshold can be set to taste with ease. A more thought-through non-linear dynamics could allow for a greater variety of behaviours emerging with different constellations of participants. In addition, a time-varying dynamics (e.g. possibly through the mutation of the underlying dynamical equations or a drift in their parameterisation) would allow for yet further behaviours to be encountered on re-visiting. Such dynamical systems would require a kind of 'in-line' calibration of their equations to user-input. This is a difficult, yet fascinating challenge.
- *Object-sound associations.* Some of the sounds in play in ToneTable and The Well of Inventions stand in a one-to-one relationship with particular graphical objects. However, even with a small number of sound-object pairings (currently four), we do not have evidence of participants commonly 'decoding' the relationships so that they can, say, 'map' the rattling sound to the brown aircraft propeller. It has to be noted that participants were not set this as any kind of 'task' to perform but neither did these particular object-sound relations form part of their spontaneous discourse at the table. Other sound-image-interaction relations were clear as intended, however. For example, the sonification of activity at the table was clearly notable in both ToneTable and The Well of Inventions and, even, 'performable/playable'. A number of visitors have compared the installations to, or could imagine an extension of them, as collaborative musical instruments.

Let us finish this account by drawing out some lessons of general interest from our design work and our studies of people interacting with ToneTable and The Well of Inventions.

When interactive artefacts are deployed in public settings, it is noticeable that people take very varied orientations to interaction with them. An important challenge is to think how these multiple and varied participation formats can be designed for in an integrated fashion when developing an artefact (installation, exhibit or whatever) for a public setting. This is a much more complex question than those traditionally discussed in HCI research under the rubric of 'usability', and points beyond 'interface design' narrowly considered to the careful design of all environmental elements: computational, architectural and social. In our development of ToneTable and The Well of Inventions, we have tried a number of design strategies for addressing such settings. We have explored notions of 'collaboration through a virtual medium', 'emergent collaborative value', 'layers of noticeability', and 'structures of motivation'. Other important issues concern ergonomic aspects, social interaction, age group differences and affordances of the overall physical environment. These are all concepts and sensitivities intended to suggest ways for orienting the design of mixed media artefacts to support variable participation in public settings.

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References

[1] Benford, S. and 13 others. Designing Storytelling Technologies to Encourage Collaboration Between Young Children. Proceedings of CHI 2000. ACM Press, 556-563.

[2] Bentley, R., Hughes, J. A., Randall D., Rodden, T., Sawyer P., Shapiro, D. and Sommerville, I. Ethnographically-informed systems design for air traffic control. Proceedings of the 1992 ACM conference on Computer-supported cooperative work, Toronto, Canada, November 1992.

[3] Bowers, J., Jää-Aro, K.-M., Hellström, S.-O., Hoch, M. and Witfield, G. Production Support Tools for Electronic Arenas: Using Tangible Interfaces for Media Editing. In Bowers, J. M. (editor) Deliverable D4.5 of the ESPRIT eRENA project, KTH, Stockholm, 2000.

[4] Bowers, J. TONETABLE: A Multi-User, Mixed-Media, Interactive Installation. Proceedings of the COST G-6 Conference on Digital Audio Effects, Limerick, Ireland, December 2001.

[5] Brown, B., Sellen, A. and Geelhoed, E. Music sharing as a computer supported collaborative application. Proceedings of ECSCW2001, September 2001, Bonn, Germany.

[6] Büscher, M., Hughes, J., Trevor, J., Rodden, R., O'Brien, J. Supporting cooperation across shared virtual environments. Proceedings of the international ACM SIGGROUP conference on Supporting groupwork November 1999.

[7] Caulton, T. Hands-on Exhibitions. Managing Interactive Museums and Science Centres. London: Routledge, 1996.

[8] Craven, M., Benford, S., Greenhalgh, C., Wyver, J., Brazier, C., Oldroyd, A. and Regan, T. Ages of Avatar: Community building for inhabited television. ACM CVE2000, San Fransisco, September 2000.

[9] Csikszentmihalyi, M. and Hermanson, K. Intrinsic motivation in museums: why does one want to learn? In [14], pp. 146-160.

[10] Dean, D. Museum Exhibition. Theory and Practice. London: Routledge, 1994.

[11] Falk, J. H. and Dierking, L. D. Learning from Museums: Visitor Experiences and the Making of Meaning. Walnut Creek: AltaMira Press, 2000.

[12] Heath, C., Luff, P., vom Lehn, D., Hindmarsh, J. and J. Cleverly. Crafting Participation: Designing ecologies, configuring experience. Visual Communication, 1(1), 2002, 9-34.

[13] Hein, G. E. Learning in the Museum. London: Routledge, 1998.

[14] Hoch, M., Jää-Aro, K.-M. and Bowers, J. The Round Table: A Tangible Interface for Virtual Camera Control. In Bowers, J. M. et al. (editors) Deliverable D4.3/4.4 of the ESPRIT eRENA project, KTH, Stockholm, 1999.

[15] Hooper-Greenhill, E. (Ed.) The Educational Role of the Musuem. 2nd ed. London: Routledge, 1994.

[16] Ishii,H. and Ullmer, B. Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In Proceedings of CHI '97. ACM Press, 234-241.

[17] vom Lehn, D. and Heath, C. Displacing the object: mobile technologies and interpretive resources. Proceedings of the 7th International Cultural Heritage Informatics Meeting (ICHIM 2003), Paris, September 2003.

[18] Lord, B. and Lord, G. D. The Manual of Museum Exhibitions. Walnut Creek: AltaMira Press, 2002.

[19] Mynatt, E., Adler, A., Ito, M., Linde, C. and O'Day, V. The network communities of SeniorNet. Proceedings of ECSCW1999, September 1999, Copenhagen, Denmark.

[20] Taxén, G., Hellström, S.-O., Tobiasson, H., Back, M. and Bowers, J. The Well of Inventions - Learning, Interaction and Participatory Design in Museum Installations. Proceedings of the 7th International Cultural Heritage Informatics Meeting (ICHIM 2003), Paris, September 2003.

[21] Taxén, G. Towards Living Exhibitions. Licentiate thesis in human-computer interaction. TRITA-NA-0311, Department of Numerical Analysis and Computing Science, The Royal Institute of Technology, Stockholm, May 2003.
[22] Wellner, P. Interacting with Paper on the DigitalDesk. Communications of the ACM 36(7), 1993, 87-96.