Abstract.
Understanding how people behave in prototypical forms of ubiquitous computing systems can help determine future designs and technical requirements. In a theatrical puzzle game called “Last Will” we were able to observe two hundred participants over the course of a week immerse themselves in an instrumented environment and use a tangible interface to complete a series of tasks. Based on an analysis from interviews, questionnaires and observation we highlight priming, sense-making and context sensitive help as three perspectives that we think are highly relevant to pervasive computing.

Keywords: Tangible interface, pervasive computing, priming, artefacts, mental model, situation awareness.

1. Introduction.
Advances in technology can give rise to many new forms of interaction and system capabilities. Whilst these new capabilities may promise unprecedented access to information, services and communication they may also come at a cost in terms of cognitive overload and environmental simplicity. When everyday objects embed computing power and can interact with other objects and when environments can sense, retain and use information or history about us how will we know what is being sensed, what we need to do to access these new services and how we use objects in the environment?

An understanding of well established traits in human behaviour can provide insights into how ubiquitous computing systems could be developed to work in harmony with our basic human instincts and abilities and provide natural and powerful enrichment to everyday life. Tangible interfaces may provide a way for natural gestures to be used within smart environments to invoke powerful system functions that control elements in the environment or communicate across other remote system components. Key to the success of these forms of interface will be the ease at which the context for the gesture can be established and the scope of the actions that will be determined by the gesture can be made transparent to the user.

If computing disappears into the fabric of the environment the question remains as to what affordances or clues are visible in the environment to help us understand what is possible and how people will make sense of these advanced environments. To probe some of these question we engaged in a field trial called “Last Will”, a Multi-Platform Immersive Theatrical Experience (MITE) in which we instrumented a set of rooms as a theatrical puzzle game whereby a player in the physical space had to solve tasks through use of a tangible interface with the guidance of an online player who was interacting with a virtual space. Whilst theatrical experiences are extreme examples for the use of ubiquitous technologies they help to push the boundaries for technology frameworks and provide an enclosed and controlled world in which patterns of behaviour can be observed. Immersive gaming environments with a clearly defined purpose and goal also benefit from being effectively a single purpose environment in which lavishly creative spectacles and features may be created.

The development of the Last Will prototype was a collaborative research exercise undertaken with partners with expertise in pervasive games (Hide & Seek¹), immersive theatre (Punchdrunk²), and online worlds (seeper³). All partners were keen to test the feasibility for creating this new form of

¹ http://www.hideandseekfest.co.uk
² http://www.punchdrunk.org.uk
³ http://www.seeper.com
immersive theatre using ubiquitous computing technologies and to see if the end result could be as compelling as a live performance, installation art piece. The objectives of the collaboration were:

- To explore the theatrical possibilities of an instrumented physical space with a virtual counterpart.
- To explore how players in the physical space made sense of a world in which physical actions and presence had new and implicit consequences.
- To explore how an instrumented physical space could be represented through an application programming interface (API) facilitating the development of context-aware applications.

After a description of the experience and a summary of the feedback gathered we will look in more detail at three areas of interest which emerged from analysing user behaviour.

First we examine the role of cues, priming and affordances. Affordances are the relationship between an object and the organism that is acting on the object [1]. The perceived affordances of elements within an environment tell the user the actions that can be performed on an object and ideally how to do them. Perceived affordances are not necessarily the same as actual affordances in physical designs. They can establish conventions about how an object can be manipulated. For example a barcode image will be associated with scanning for people who have had experience with scanning items in retail stores but there is nothing intrinsic about the image which affords scanning. We reflect on the development of conventions for ubiquitous systems and how priming may be an important consideration for future system designs.

Second we examine how users represent knowledge and learn in new and novel environments. We briefly discuss the nature of mental representation and the ongoing debate between abstract symbol representations and grounded cognition theories. We discuss the kind of “mental models” that participants in the Last Will trial reported and how they transferred their learning from one task to another. Finally we look at the effectiveness of context sensitive to help players understand what they should do, what they cannot do and generally guide their comprehension and actions.

2. The Last Will experience.

Participants for the trial were invited to sign up for the experience by booking a half an hour time slot on a website. They were told that each game would involve two players and some players booked a slot with a friend or colleague whilst other players signed up individually. The background story was about a person called Madigan who had recently died and you would be experiencing his home either in physical or virtual form. When players arrived they were shown to a small waiting area and were assigned their roles, one as Dante and the other as Virgil.

To begin Dante is led down a dark corridor and through a door into a room styled as a 1940s lounge. In the room there is a chair, a TV a couple of cabinets and several objects such as a wicker wine container, candlestick and books. There are also two large paintings hanging on the wall. From this point the experience unfolds as a series of three major puzzles centred around a stage set of three interconnected physical rooms. Dante has to solve the puzzles by using clues in the environment, moving items within and between rooms and under the guidance of a computerised voice which can be heard in the rooms.

Virgil on the other hand is led to a room in which there is just a computer displaying a virtual representation of the physical game experience which the player can interact with.

Figure 1. Real lounge interior and virtual lounge interior in the Last Will space
Each of the rooms was instrumented with a variety of sensors and actuators allowing the state of the physical space to be monitored and changed programmatically. For example, it was possible both to tell whether a door was currently open or closed and to open that door programmatically. Other sensors included RFID readers used to determine whether (tagged) objects were in appropriate positions, light beams that had to be broken to unlock certain effects, and weighing scales capable of discriminating between humans and mannequins. Actuators included lights and audio feeds, a programmable television, and flaps allowing sand to pour out of a pair of mannequins at one of key points in the experience.

The three rooms were also modeled, with some artistic variation, in a virtual world accessed via a normal computer screen, keyboard and mouse. The physical and virtual rooms were used together to provide a rich, immersive puzzle to two audience members (players) at a time, one in the physical space and one online. Their task (taken from a larger narrative) was to explore the “house” and discover more about its former owner. Their actions were linked in that any changes made to the physical space were also reflected in and could be initiated from the virtual world. The online player could also (sometimes) see the physical player thorough webcams in the physical rooms, and (sometimes) send messages to the physical player through a text-to-speech system.

The Last Will MITE was open for a private view from nine days in late November, 2008. During that time, around 200 players experienced the immersive puzzle, playing for around thirty minutes for each pair.

3. Feedback from the Last Will experience.

To gather feedback from the experience we used questionnaires, interviews and observation to watch patterns of behaviour and try to understand how players felt about the experience and how they learnt what to do to be successful in the tasks. We gathered 158 questionnaires (86 for Dante, 72 for Virgil) and conducted 31 interviews. These interviews were transcribed and analysed for common themes, evidence of learning strategies and common problems.

Overall players enjoyed the experience. Mean scores for overall enjoyment were 76% for players who played Dante and 72% for players who played Virgil. Immersion scores were similar but a little lower (Dante 68% and Virgil 63%). The positive factors that were frequently cited in interviews were that it was intense, novel and thought provoking. Many players enjoyed the gaming interactivity: “I thought what was really brilliant about it was that you had the interactivity of game technology which was fun and participatory.”

Whilst the scores for Dante and Virgil do not appear to be very different there is a clear preference for playing Dante, 77% of players who played Dante would not have wanted to be Virgil and 34% of players who played Virgil would have preferred to have been Dante. Although the computer experience was good the physical experience was seen as the better thing summarised by the following player quote “... for me as I got the computer I feel I was missing out as she got the cooler thing. And I think that is an element of problem of the piece and I don’t know how you make it cooler to do what I am doing.”

Not surprisingly the feedback shows that a physical interactive experience is a very powerful experience and has more appeal than a purely virtual one.

3.1.1. Feelings of the players within each of the three major scenes.

The experience breaks down into three major scenes which we will refer to as the tableau scene, the Sand Room scene and the Beams scene. The tableau scene starts shortly after Dante has been led into the lounge and when a secret door automatically opens to reveal an adjacent room. The online player, Virgil, can see an image a painting of St. Jerome in his study beside a web cam view of the tableau room which Dante enters, this view is shown in Figure 2. The tableau room has been staged to look as much as possible like the painting which is hanging on the wall in the lounge next door. To succeed in the task the players must realise that the room is meant to be a replica of the painting and to notice that there are some objects missing from the room that can be found in the lounge. They then need to move those objects to their correct place which will be detected by an RFID tag reader built into the fabric of the room.
Virgil is able to type messages on the computer which get translated through a text to speech engine and are transmitted into the physical environment for Dante to hear. If Dante brings in an object from the lounge and places it in the right position in the tableau room the RFID triggers a signal and the corresponding object in the virtual representation which Virgil can see glows. In the room a number is heard which indicates that the object is in the right place and the number of items still to place. Once Dante has placed all of the necessary object in the right place and adopts the pose of St. Jerome at the desk then the task is automatically sensed as being complete.

The second scene is the sand room. When Dante leaves the tableau room he re-enters the lounge, the room light has dimmed, there is a film track playing in the background and a photograph of three uniformed men is illuminated on one of the cabinets. Dante again has to wait for around two minutes until another secret door automatically opens leading into a tent filled with crates and with sand on the floor. There are two mannequins on the floor, two large crates and an old fashioned camera on a tripod set up to point at the crates. Attached to the camera on a long cable is an old-style external shutter button. To succeed in the task Dante needs to move the mannequins onto the two crates stand in between and take a photograph. The sand room and the photograph are shown in Figure 5.

When Dante completes the task he returns to the lounge for the third and final scene. The lighting in the lounge is now semi-dark and there are two beams of light emanating from either side of a large picture of a firing squad executing a soldier across the room to light up the wall either side of a mirror. To succeed in the task Dante needs to stand with arms outstretched in the crucifix position blocking both of the beams of light until a musical score and recital of a court martial verdict have competed. If he drops his hands and unblocks the beams then the music stops and he has to restart the score.

The mood map in Figure 3 gives an overview of the average response that players reported for how they felt in each of the three scenes.

In general players reported higher scores in the first scene where they were most anxious, excited and challenged. These feelings were to do with not knowing what to expect and being excited by the new experience. The following quote is typical of how players reported their trepidation: “I was just nervous and anxious because I hadn’t done this kind of thing before. So I think you would be a bit more confident and a bit more experimental if it wasn’t so new. I think some people can go into that environment and be quite happy and just kind of play around with it. I felt anxious”.

Pain was included as a measure because in the original design it was intended that Dante would have to hold the crucifix position for around 4 minutes which would have resulted in severe arm and shoulder ache. As it turned out there were few players who actually did keep there hands outstretched for the whole of the verdict played for approximately 3 minutes. Most realised that if they dropped their hands 30 seconds after the talking started then it no longer cut off the sound and so they did not continue to hold the position. The spike in the score for the pain level for Dante in the Beams scene will have reflected those players who did keep the position held for a significant period of time. The physical exertion of the act made the experience more significant

“I didn’t want the narrative to stop if I dropped my hands. So I stayed there the whole time. But using the symbolism and the lights was really magical”
3.2. Cues, affordances and priming.

In a ubiquitous system the context and environment are all part of the experience and interfaces are not restricted to fixed and determinant sets of objects. For example a user may bring their own mobile device into an environment and use that to interact with physical devices or services found in the vicinity. They would need to know what connectivity was possible, what security measures there may be and the social protocols for using things found in the environment. On the other hand a user may enter a ubiquitous environment without a personal device and still be able to activate and use elements in the environment. How the user discovers what is possible and how they should interact with an object is largely down to the affordances of the environment.

The term affordance was first created by Gibson in his study of human perception. Affordance theory states that the world is perceived not only in terms of object shapes and spatial relationships but also in terms of object possibilities for action. Gibson discussed several ways in which perceptions of motion and movement have to be understood relationally. The affordances and abilities of an environment are the conditions in which the constraints of a successful activity or performance is held [2]. For example in Last Will one of the constraints on being able to complete the tableau scene was to have a doorway big enough for players to move through to get from one room to the next. At the beginning of Dante’s experience this was not possible as the door was locked and hidden and so there were no affordances to indicate that another room was there.

The idea of affordances were later appropriated by Norman [1] and extended so that it could be applied to the field of design. In Last Will we are interested in both the physical movement and perceptual learning of the players and the affordances in the environment.

Within the field of theatrical design lighting, sound and narrative cues are used to direct the attention of the audience to significant places within the set and help them follow the experience as the director intends. Studies within the visual context have examined how attention can be deployed toward objects and locations that are behaviourally significant to the observer in similar contexts in the past and how this context might cue people to automatically detect significant or changed objects in a familiar scene. This process is referred to as contextual cueing [3]. In simple terms once an object becomes significant people can easily spot it in the environment, for example if you buy a new car you will notice similar cars on the road far more than you did before you bought the car.
Considerable expertise is involved in set design and the use of media to facilitate contextual cueing and create ambience. In the design of Last Will lighting, sound and narrative cues were all used to highlight affordances of the physical space. Sometimes cues were used to great effect but some were unplanned or ineffectual and added confusion to the players understanding. To elaborate we will discuss some of the main intentional and non-intentional cues that were used.

For example the lounge in Last Will was deliberately designed to look like a home setting, the comfy chair was an easily recognisable object that afforded sitting on as it could offer comfortable support to players. Many players did indeed sit down in the chair at the beginning of the experience during the few minutes when the online player is hunting for objects in the virtual world where there is nothing obvious happening in the lounge and players do not know what they have to do. In the background there is a song playing and the lyric “Try to remember” gets repeated quite often. Quite a few players reported that they thought it might be a memory game and so were trying to remember the objects “in the first room I was like what on earth have I got to do and then there is this song about remembering so I am like trying to memorise everything in the room as I thought it was going to be like the conveyor belt” This cue may have also indirectly encouraged players in their instinct that they should memorise things. This strong memory model was not intended the Dante player was simply supposed to explore the room, notice the paintings and the objects and enter the tableau room when the secret door automatically opens.

![Figure 4. The secret door.](image)

On the other hand, regardless of their previous experience once the secret door opened all players walked into the next room. It was an unambiguous cue which obviously invited everyone to enter without having to be invited or told. The environment when the door opens is captured in Figure 4. Notice that illuminated on the wall next to the door is a large painting. This was intended as a prime for players so that when they entered the tableau room they would recognise that it was the same as the painting.

### 3.2.1. Comparison of effective and non effective primes

Within any environment there is a rich variety of sights, sounds and smells that we may be aware of but we can only consciously attend to a small subset of these perceptual inputs at a time. Some of this context will however enter our sub-consciousness through implicit channels without us even being aware that it is happening. This means that if we encounter a similar context at a later time then we might have a level of familiarity with that context and we may recall a significant fact related to that previous context. The ability to recall or be familiar with something that we have not consciously learnt is a phenomenon known as priming [4][5][6]. Cues are one of the physical ways to deliberately prime people. We will compare two pairs of similar primes that were used in the experience to highlight some of the differences that may have been important in terms of their effectiveness.
3.2.2. Comparison of St. Jerome painting in lounge versus Photograph of airmen

Recall from Figure 4 the painting of St Jerome is illuminated and quite prominent at the time the player walks through to the tableau room. Despite the prominence of the picture and the lighting cue above it none of the players that we observed or interviewed immediately recognised the room as being a replica of the painting. In contrast in a later task a small photograph of three airmen is used as a prime for the sand room task and this proves to be extremely effective. Figure 5 shows the two primes and the two environments which were intended to stimulate the memory of the prime. Why was it that the first prime was not effective whereas the second one was?

There are several possible explanations for why the players did not recognise that the tableau room is a replica of the painting:

- the fidelity of the set may not have been good enough
- players may not have paid attention to the content of the painting as they were paying more attention to the objects and the lure of the open door,
- players may have had a feeling of familiarity but not been able to realise why they had this familiar feeling
- the perception of the physical space triggered completely different cognitive processes to that of looking at a painting.

Priming experiments [7][8] have shown that priming is more effective when the priming object for example a word or picture is orthographically similar to the stimulus which might recall the prime. So a prime with a picture of a ball and then seeing the word “ball” will not act as effectively as seeing the word “BALL” and then later seeing the word “ball”. They have also shown that cognitive processing associated with the act of priming, for example asking people to solve an anagram of a word, will make that word far more memorable. The painting was a strongly visual prime with a two dimensional
representation and relatively small scale whereas the room was a three dimensional space that you could walk into. This dramatic change in perceptual representation was not a natural or obvious link to people in the physical space.

In contrast the view that the online player had is similar in scale and therefore perception (see figure 2) and so it is more likely that Virgil will realise that the room is meant to be the same as the painting. At this stage it is possible for Virgil to type messages to Dante which were converted automatically from text to speech and were played in the physical space. In many cases it was a clue from Virgil about what they could see that made Dante go back into the lounge, re-examine the painting and realise that it was meant to be the same as the room.

If players did realise that they were trying to recreate a painting then they became more sensitised to the idea of using a two dimensional image to prime a real environment. When Dante completes the tableau scene he again returns to the lounge. There are background sounds playing and this time the photograph of the three airmen is illuminated on the bureau. The photograph was not illuminated before and so this change in context acted as a contextual cue because now that the player has realised that pictures can act as strong cues for subsequent tasks they are far more likely to take notice of this particular object. Several players remarked on the fact that they had consciously noticed the photograph of the three airmen “there’s a photo in the other room of 3 guys in a row. But they are not in a tent in sand and stuff they are just in the street. So I was like ok maybe we have to make a picture of 3 people in a row”.

Another possible explanation for the success of the photograph was because the image was also shown, printed out on the wall of the waiting room which the players may have noticed if they had to spend much time there (Figure 6). Below the photograph are the words with the writing “Hector, me and John, 1942” written below it. Players may have sub consciously registered that the picture was important and then when they noticed it again later on in the room it would have had greater significance.

It is possible that had these tasks been reversed then the priming effects would also have been reversed, the photograph would not have been as effective a clue because it might not have been noticed in the excitement of absorbing the whole room and not knowing what you had to do and so not being sure which things are significant. On the other hand it might have been just as effective if its success was based on having registered it as being significant in the waiting room. But even players did think it was significant then it may not have been enough to prime them to reproduce it. It seems more likely that once you build up a task model of what you need to do in the experience then you become sensitised to what things to look for and notice and so a similar visual prime will work effectively. We will return to this idea in section 4.

3.2.3. Comparison 2. Sign versus verbal clue.

In the final beams scene we wanted to prime players so that they would hold their hands out in a crucifix position to block the lights. We knew that the most successful way to do this was to stand facing the mirror so that you could see the path of the light beams and stand forward of where they touched the wall so that your arms were long enough to block both beams. Two primes were given to players at the start of the experience, one verbal and one as a visual sign, to try to encourage the desired behaviour. One of these primes, the sign, was very effective whereas the other, the verbal clue, was confusing. We shall examine why this should be the case.

Figure 6. Airmen, press cutting and semaphore sign on the waiting room wall.
The semaphore sheet was posted on the wall of the waiting room which the player sat in before they were briefed. Also on the wall of the waiting room was a press cutting about Madigan and the picture of the three airmen shown in Figure 6. The semaphore sheet displayed the alphabet and against each letter was the semaphore signals that a person would make for that letter. The letter and semaphore sign for “R” was circled and the words “R is for” was hand written on the sheet. The circled R semaphore shows a person with outstretched arms. Despite the beams task being the last scene of the experience and the players have already spent on average twenty minutes doing the first two scenes the affordance of the light beams triggering a sound when they were blocked invoked the memory of the repentance semaphore and players realised that they were meant to stand with arms outstretched.

“I thought the thing with the lights and music was interesting ... an interesting way of making you do something. And I think the instruction is quite clear you can figure out the lights trigger the music. And you think ah I saw something on the wall about the R semaphore”.

The semaphore sign acted as an effective priming cue that was recalled in the most appropriate context. Despite the fact that the mode of the prime, an image, was different from the enactment of the prime, a gesture, the cryptic nature of the prime meant that players who noticed it may have spent some time thinking about what it meant and the images were clearly associated with bodily movement, they showed a person with hands outstretched rather than a text based description.

Unlike the implicit prime of the R semaphore some players were explicitly told that they would have to “face yourself at some point” prior to entering the room. Because there is a mirror in the lounge players quite naturally assumed that the prompt might be applicable at the beginning of the experience rather than at the time intended. The intention of the verbal cue was that Dante would enact the prime in the beams scene. However because Dante visited the room and encountered the mirror at the outset of the experience there was also an unintended opportunity to enact it then. This confused players as shown in the following two quotes:

“I was a bit misled by the statement before I went in that I had to face yourself so then I immediately thought I had to be by the mirror so I was hanging around by the mirror but that only really came in at the end scene. And so I think I side tracked myself so much that I wasn’t really taking note of anything else so I think that is why I got stuck in a rut because I was concentrating so much on that.”

“When I first started the task you said I had to face myself so I knew that was coming at some stage I just got completely thrown and thought it was at the beginning”

From this analysis it appears that the timeliness of the prime and the presentation of opportunities to enact it are important aspects for using priming in future designs.

Klein et al describe sensemaking as a motivated continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively. [9]. Factors that can be involved in or related to sensemaking are creativity, comprehension, curiosity, mental modelling and situation awareness. All of these factors were required in Last Will. Creativity was needed to generate solutions to the task, comprehension was required to understand that there was a task to complete, curiosity encouraged players to move from room to room and explore. The last two factors mental modelling and situation awareness will now be considered in more detail.

4.1. Mental representation and learning
The idea that people create abstract models of phenomena and systems that they encounter in the world in order to understand how they work or to solve problems has been a popular notion for many decades [10]. The cognitive revolution in the 1960s and 1970s popularised the idea that abstract symbols could represent knowledge akin to the mental representations that people may have in their head. These symbolic theories were powerful formalisms which largely neglected sensory motor experiences. They assumed that information is abstracted from the sensory system into an amodal representation. The language of thought then operated on these symbols.
This abstract symbolic representation was largely based around a computer metaphor and early artificial intelligence systems encoded knowledge in the form of objects, scripts, rules, knowledge frameworks or semantic networks [11]. The problem with this approach to cognition was that it largely ignored the process by which people encode knowledge and so the process by which symbols were grounded to reality were not resolved [12].

A more recent trend in cognitive science is that of embodied or grounded cognition which rejects traditional views that cognition is independent from the brain’s modal systems for perception, action and introspection [13] [14]. Instead, grounded cognition proposes that modal simulations, bodily states and situated action underlie cognition [12]. In this view the different senses and motor functions are all part of the felt experience.

Reflecting on Last Will much of the understanding for the experience was through the perception of visual, sensual and audio stimuli. Mental representations about the overall purpose or goal of the experience are constructed in a bottom up fashion through sensations and inputs gathered from within the environment. This physical form of learning is potentially very interesting for future ubiquitous applications. Experimental evidence is beginning to show that when children are asked to instantiate a new concept in their hands, learning is more lasting than when they are asked to instantiate it in words alone. That is using gestures when learning a new concept will make it more likely that they will remember and be able to apply that concept at a later stage [15]. This deep embodied form of learning is a great opportunity for the capabilities and potential of gesture and movement based interfaces.

Situation awareness (SA) is “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” [16]. Situational awareness is most frequently defined in operational terms and has been successfully applied to a wide range of domains which require operators to make critical decisions based on a wealth of information and events such as aircraft control and military campaigns. Whilst human long term memory stores are limitless we have a limited amount of working memory which means that we can only attend to a subset of the wealth of environmental input that may be around us at any one time. SA hypothesises that mental models are created to deal with these limitations in working memory so that we can attend to those factors which we judge are relevant to our internal model of the system or environment. In studies the difference between experts and novices has shown that experts will have a more accurate and better model of a system than novices do. Within SA the mental model is seen to direct attention to critical cues in the environment and pattern match between these critical cues and elements in the mental model to activate schemes and actions which will meet an active goal. Goals are central to the development of SA and SA can be viewed as purposeful behaviour that is directed toward achieving a goal in a specific task environment. We will now examine how goals were constructed during the process of acting out the Last Will experience.

### 4.1.1. Compositions of mental model

In Last Will players were thrown into an unknown environment with unknown goals and expected to work out what the goals were and how to achieve them. The experience was designed as a series of tasks, each with their own goal related by a background story. Within these tasks there were a number of actions and behaviours that the players needed to learn in order to succeed. Barsalou [17] defines a conceptual system as “a collection of category knowledge, where each represented category corresponds to a component of experience – not an entire holistic experience”. A break down of the Last Will experience into some of its significant components is shown in Table 1. In this analysis we will focus on the Dante experience as it was richer in terms of embodied learning actions. Components can be divided into three levels of sophistication in terms of understanding and mental model. The conceptual level is concerned with the understanding gained at the holistic level for the overall experience. The task level relates to the goal model or situation awareness that players had. The actions and behaviours level relates to the lower level activities which the player needs to learn that they can do in order to succeed in the goals of the designed experience. These components are learnt as situated or embodied actions through experimentation, exploration of the environment and working with the other player.
The three levels of understanding are based on evidence that players showed different levels of understanding as to what they were supposed to do and why they were doing it. For example some players never got beyond moving items around based on instruction from Virgil, they did not develop an understanding at the task level and had a very weak understanding at the conceptual level. Other players were able to construct accurate models of what needed to be done and link it to an overall sense of the story.

<table>
<thead>
<tr>
<th>Levels of Understanding</th>
<th>Mental models constructed for Dante</th>
</tr>
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<tbody>
<tr>
<td>Conceptual</td>
<td>You are in the house of &quot;Madigan&quot; and there are tasks that you perform which relate to unanswered questions about his past. You are progressing through levels of a game. Virgil is your guide who can see you but cannot hear you</td>
</tr>
<tr>
<td>Task</td>
<td>You need to replicate a picture physically and with you in it. You are repenting for the sins of Madigan with physical duress.</td>
</tr>
<tr>
<td>Actions And Behaviours</td>
<td>Put items in the correct place Block two beams of light simultaneously Walk around and between rooms Pick up objects that are not stuck down Look at details of objects Move objects around and between rooms Go back to a previous room Listen to the voice Ignore the attendant who is with you in the room</td>
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Table 1. Levels of understanding and corresponding mental models.

4.1.2. Action and behavioural observations.

When Dante first enters the physical set he is not sure what will happen or what he is expected to do. What he did depended very much on his previous experience. Players who were not familiar with games were reluctant to pick up objects or touch items on the cabinets as they did not know what the social protocol for the game would be and so reverted to polite guest behaviour of looking but not touching and waiting to be invited to do something as one lady reported “I was kind of waiting for instructions because when you first walk into a room and you don’t really know what you are meant to be doing in there I just thought I am going to sit here until someone tells me what to do.”

Players who were familiar with computer games were far more proactive, picking up items, looking in drawers and searching the room to see if there was anything subtle to find or if there were any clues as to what to do. They had learnt from games that you need to experiment and try out courses of action to solve puzzles or learn new interaction skills and were able to apply this learning to the physical context as illustrated by the following quote: “I was really just trying to work out what I was supposed to do next. It was really like being dropped into a real life version of tomb raider. I didn’t know what to do but I thought I would try some stuff and if it does something I will try it again. Sort of piecing it together.”

As we mentioned in the previous section regardless of their background as soon as the door to the tableau room opened players walked into the other room. This physical transition seemed to trigger a strong “progressive” model in peoples minds as many players were unsure or reluctant to go back to the first room even though the door remained open. “Once I went into the next room I thought I am now in this room and it took me a long time to realise that I was able to go out and get some objects from the other room”. Linear progression is a common pattern in life associated with things like ageing, grades, levels and tours. Perhaps this prior experience led players to assume that progress through the experience would be compartmentalised room by room or perhaps the physical boundary of two rooms made it cognitively difficult for people to associate a single task with two rooms. The effect of physical
separation of elements on the ability to understand a problem is an interesting area for future research. But for now it was evident that the natural instinct is to compartmentalise actions within physically bounded spaces.

As Virgil was able to type messages which could be heard as a computerised voice within the physical space it was possible for Dante to do what Virgil asked without understanding the higher level task. Table 2 is an extract from one of the games showing the text that Virgil typed to Dante and the time into the experience that was typed. In this extract Virgil does not articulate that they are replicating the painting and so it is up to Dante to work out this higher level task. In most cases once Dante starts to go back into the other room to collect items he will notice that the painting of St. Jerome is meant to be a replica of the room and then will rely on looking at the painting to work out where to put the items rather than rely on Virgil.

<table>
<thead>
<tr>
<th>Time</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:02:13</td>
<td>hello</td>
</tr>
<tr>
<td>00:02:25</td>
<td>hello dante</td>
</tr>
<tr>
<td>00:02:39</td>
<td>it's virgil</td>
</tr>
<tr>
<td>00:03:48</td>
<td>can you get the hat from the first room</td>
</tr>
<tr>
<td>00:04:33</td>
<td>place it on the floor to your right</td>
</tr>
<tr>
<td>00:04:52</td>
<td>5</td>
</tr>
<tr>
<td>00:05:33</td>
<td>can you get the bell book and candle from the first room</td>
</tr>
<tr>
<td>00:05:44</td>
<td>from the first room</td>
</tr>
<tr>
<td>00:07:53</td>
<td>4</td>
</tr>
<tr>
<td>00:08:09</td>
<td>put the book in the left alcove</td>
</tr>
<tr>
<td>00:08:17</td>
<td>3</td>
</tr>
<tr>
<td>00:08:18</td>
<td>standing up</td>
</tr>
<tr>
<td>00:08:33</td>
<td>4</td>
</tr>
<tr>
<td>00:08:49</td>
<td>5</td>
</tr>
<tr>
<td>00:08:53</td>
<td>stuffed bird and flask from first room</td>
</tr>
<tr>
<td>00:08:55</td>
<td>4</td>
</tr>
<tr>
<td>00:09:40</td>
<td>flask in right hand alcove</td>
</tr>
<tr>
<td>00:09:49</td>
<td>3</td>
</tr>
<tr>
<td>00:10:02</td>
<td>bird on floor to your left</td>
</tr>
<tr>
<td>00:11:30</td>
<td>put the slippers in place of the bird</td>
</tr>
<tr>
<td>00:11:53</td>
<td>2</td>
</tr>
<tr>
<td>00:12:30</td>
<td>open the second alcove from left</td>
</tr>
<tr>
<td>00:13:10</td>
<td>turn the book in first alcove</td>
</tr>
<tr>
<td>00:13:23</td>
<td>1</td>
</tr>
<tr>
<td>00:13:59</td>
<td>sit at the desk</td>
</tr>
<tr>
<td>00:14:13</td>
<td>left hand on book</td>
</tr>
<tr>
<td>00:14:22</td>
<td>head in right hand</td>
</tr>
<tr>
<td>00:14:47</td>
<td>right hand on top of head</td>
</tr>
<tr>
<td>00:16:35</td>
<td>zero</td>
</tr>
<tr>
<td>00:17:05</td>
<td>The Painting is complete. Leave now and enter the wilderness</td>
</tr>
</tbody>
</table>

Table 2. Example log of messages from Virgil to Dante.

4.1.3. Task level representations facilitate transfer of learning.

The task level representations were constructed by players as they explored the environment. Realising what a task was materialised in a kind of “eureka” moment. “I don’t think I am very observant for example it took me a very long time to realise that I was trying to recreate the picture. Really, really long time”. Players who were not familiar with games felt that they may have been at a disadvantage in recognising that there was a high level task to complete: “I have a sense of the painting of St. Jerome in the room but I don’t get a sense that I need to complete the painting and that is possibly because I don’t play that many games. I recognise that taking objects from one room to the next is something people do in games but I didn’t make that connection so I had to be prompted by the voice.”

Whilst the tableau scene took a very long time for most Dante players to realise that they were recreating a painting if they did reach that level of understanding then it was possible for them to transfer that learning to the Sand Room task. Several players reported that they could reapply this higher level task abstraction of replicating a picture to a different situation with different actions. It is summarised nicely by one player: “By that time I had basically got it. As I realised I had to complete the photograph. Because we had to complete the picture the first time I knew” and reiterated here by another “…because I could see the picture and the sand room and I had just done that so I thought oh obviously it’s the same thing”. Even though there were several differences between the sand room task and the tableau scene, in the tableau scene the image was a painting and the room was an absolute replica whereas in the sand room task the image was a photograph of men in a street and the set was an army tent, players had the ability to transfer the learnt model of the task from the tableau room and re-apply it to the new context.

This meant that on average players were much faster to work out what they had to do in the sand room scene than they were in the tableau scene. This is reflected in the questionnaire responses for players to
rate how much time they spent figuring out what to do in each of the tasks shown in table 3. It is also reflected in the average log times for each task (Tableau scene 13 minutes, Sand Room 5 minutes, Beams 8 minutes).

Dante, who has the physical learning experience, figures out the sand room task much more quickly than the tableau task. Virgil who does not have the same physical clues and cannot see the set up in the sand room cannot apply the same transfer of learning in the virtual environment.

<table>
<thead>
<tr>
<th></th>
<th>Tableau Scene</th>
<th>Sand Room</th>
<th>Beams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dante</td>
<td>59.9</td>
<td>36.8</td>
<td>40.6</td>
</tr>
<tr>
<td>Virgil</td>
<td>57.4</td>
<td>54.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>21.6</td>
<td>27.9</td>
<td>25.7</td>
</tr>
<tr>
<td>Number of responses</td>
<td>85</td>
<td>84</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 3. Mean rating response on a scale between Not at all and Very much to the question "Did you spend a lot of time figuring out what you had to do?".

The ability to transfer embodied learning from one task to another as is a positive sign that it is possible in ubiquitous environments for people to develop a representation about certain tasks or functions which can then be applied in other situations given the right cue and context.

4.1.4. Conceptual level representations.

Understanding at the conceptual level was extremely variable and again was influenced by the players previous experience and expectations. Players who were not familiar with gaming activities were not as quick to understand the structure of progressive gaming levels and expected the experience to be more story led than task led. Half of the players did not really develop a clear sense of purpose or link to story. “I found it engaging as a succession of experiences but I didn’t get a coherent narrative out of it. I didn’t feel I was going through a story”.

But some players did manage to piece together the story line and relate it to the scenes that they had been performing “I would hazard a guess that Madigan lied about escaping form some prisoner of war camp, that he had been arrested shot the three guys that had arrested him and then lied about it and got off a court martial and then escaped to make a fortune but that is just me piecing together a lot of random stuff”.

As Last Will was a prototype for a much larger idea the part of the story line that was experienced was incomplete and the relevance of the tasks rather opaque. In a future design the use of narrative to help guide the action will be explored much more rigorously.

The other main concept of the game was the role of Virgil as a guide. Several Dante players did not realise that Virgil was the voice that they could hear in the room and sometimes even forgot that there was another real player involved in the experience. “I still don’t know whether the voice was a live figure distorted or a machine responding to some kind of cues. I don’t know about that. Clearly I cued the voice by certain things that I did but I don’t think I had any verbal exchange with the voice.”


The final area that we will examine is the effectiveness of context sensitive help to guide comprehension and actions.

Several different strategies for helping players were deployed to ensure that all players were able to move through the whole experience and not run out of time if they got stuck and were unable to work out what to do. The first and most dynamic form of help was to have an attendant in the physical space who assumed a passive, non interactive role and would only do something if things went very wrong or if the player was taking too long to work out what they needed to do and thus needed a little prompt or clue. The presence of the attendant was unnerving for some players. Those players who were least confident would ask the attendant if it was ok to do things such as go back to a previous room or move objects.
In the majority of cases the assistant did little more than compensate for some of the limitations in the physical set. For example the tolerance for objects being placed in the right position was quite precise, if players had more or less placed an item in the right position but it failed to trigger the RFID reader then the assistant might move the object slightly to force the trigger to fire. Feedback when placing an object should have been immediate and unambiguous but unfortunately technical limitations meant that feedback was delayed for over a second which meant users did not know whether they had successfully placed an item in the right place and orientation.

5.1.1. Automated context specific help
A computerised voice was used to provide context specific help at the appropriate time. For example when a task was complete the system let the player know that they should move on. This helped to keep the flow of the experience timely and not encourage players to dwell longer in a room than was necessary if they had completed the game task. Whilst the help cues were done in a cryptic form, for example “Leave your friends now and enter the wilderness” it was enough to inform the player that they needed to leave the current room. The prompt could be cued because the system knew that a certain number of actions had taken place and that the task was complete. In this case the goal of the room was pre-determined and so it is simple to know when a task was complete. In a more general ubiquitous system it is unlikely that a room would have a specific goal or task that needed to be performed within it but it may still be possible to infer some intentions based on sensing actions in the room. For example if a person stands gazing at a whiteboard without trying to use it then the way the whiteboard operates could be conveyed in some form, perhaps by illuminating the operating interface, projecting a simulation onto the surface or even transmitting localised audio to the person who is looking at the whiteboard. The idea of highlighting certain aspects of an interface to aid problem solving has been found to be effective in experiments leading to the suggestion that environmentally controlled perceptual properties can guide attention and eye movements in ways that assist in developing problem-solving insights that dramatically improve reasoning [18].

5.1.2. Guidance from Virgil
The same computerised voice was used to convey the text to speech messages from the online player Virgil. This caused confusion as often players could not distinguish between the system level help and the messages from Virgil. The helpfulness of the advice depended on whether the online player had gathered a good understanding of what was going on and was predisposed to help rather than hinder the physical player. 90% of Dante players trusted the voice and tried to take note of what the voice suggested or asked. In the majority of cases it is a clue or hint from Virgil which helps Dante realise that they have to replicate the painting in the tableau scene. However after the tableau scene it is much harder for Virgil to work out what is going on which is reflected in the self assessment scores for understanding shown in table 4. Each player was asked to rate whether they had a good understanding of what was going on and how they rated the other players understanding of what was going on.

<table>
<thead>
<tr>
<th>Understanding (Mean scores)</th>
<th>Tableau Scene</th>
<th>Sand Room</th>
<th>Beams Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dante</td>
<td>You 54</td>
<td>Other player 57</td>
<td>You 63</td>
</tr>
<tr>
<td>Virgil</td>
<td>You 42</td>
<td>Other player 71</td>
<td>You 32</td>
</tr>
</tbody>
</table>

Table 4. Mean rating response on a scale between Not at all and Very much to the question "Did you have a good understanding of what you/the other player had to do?".

With poor understanding of what was happening in the Sand Room the suggestions made by Virgil would often act more as a hindrance rather than a help as shown by the following quote from a Dante player “when you said plates I thought ‘what plates?’ so that actually distracted me from what I was going to do which was to put the mannequins in place”.

If Dante players thought that the voice of Virgil was meant to be controlling or dictating what they should do this became debilitating when Virgil did not show any awareness of the physical set up in the Sand Room. One player who had no experience of games and was very unsure about what to do explained that they assumed a dependence on Virgil after the initial scene “once you start being told what to do it is a bit like when someone starts map reading for you when you are driving a car and trying to find your way somewhere. What happens is you are perfectly ok at finding the way on your
own but you cease to actually take that agency for yourself, you allow someone else to do it. You stop thinking for yourself. And I don’t know how you get round that. For example my instincts when I went into the room where you had to take the photograph. My instinct was absolutely I need to recreate the photo but I didn’t because nobody told me what to do”

Being able to work out the authority or reliability of a referral or suggestion is a critical skill for confederated systems. Social protocols for referral systems on the web have emerged over time and testimonials, references and rating systems help users make a choice as to whether to trust and use a service or to make a purchase. In a ubiquitous system it is possible for remote services and data streams to be used to facilitate a local service or give advice. It seems likely that for a system to be successful and trusted then a means to identify the source of any information used in terms of timeliness, accuracy or reliability should be made transparent to the user. The way that this is done in a tangible interface in other means than through a display is an interesting challenge for interface and experience design.

6. Conclusion

In this paper we have discussed priming, sense-making and contextual help based upon behavioural observation and feedback of players in the Last Will prototype trial. We have seen that visual primes can be effective for signalling actions that should be performed at a later time but that they rely on a sensitisation or understanding of the nature of the task at hand and an awareness of what kind of actions and behaviours are permissible in that environment. The opportunity for ubiquitous computing is the fact that interfaces and interactions can be performed in shared or public spaces where others may notice and learn implicitly through background exposure. Primes that could be found or observed in the general environment could relate to artefacts of a tangible interface and so predispose people to learn how to use them. The potential for priming users to the availability of ubiquitous services is a rich area that we intend to research further.

In our analysis of sense-making we discussed how users construct mental models in order to understand a system or task and then use this in situation awareness. Embodied cognition as a philosophy matches the style of learning and felt experience that we observed in Last Will and has implications for how technology systems might reflect this form of bottom up learning. We might imagine capabilities to sense inputs from a variety of modes, visual, auditory, olfactory, locative and touched and use these in a bottom up fashion to record contexts and actions. These components might then be of a form that can be combined to match higher order tasks.

A very positive result that we found from Last Will was the ability for players to transfer learning that they had developed from one task to another task in a different context that had the same goal, to replicate a picture physically with you in it. If we are able to design ubiquitous systems so that users can develop a good representation of the actions and tasks that they do then they should more easily be able to transfer that learning to a new task or service if they recognise that it has the same kind of form.

Based on our experience of using a computerised voice help system one thing that we will consider for a subsequent design is to have varying degrees of context appropriate help delivered as part of the system. It was evident from Last Will that the background experience of a person has a big influence on how quickly they adapted to the interaction and gaming style of the Dante experience. Players who were unfamiliar with games or who felt less confident about what they should be doing relied more on the guidance and help either from the online player or the attendant. A context specific help system should gauge the actions within the environment and offer assistance if users seem to be inactive or the actions appear to be associated with a task but are insufficient to succeed at a task. In the scenario of Last Will the experience is completely task driven and so it would be possible to infer from length of time and the actions sensed whether a player needed more explicit guidance. For example if players were not actively engaging with the right things or had not done anything for a long time a prompt could be delivered at that time. This would mean the players who were more natural and adept at the tasks would not require or receive as much help as those who were more anxious or unsure about what they should be doing or allowed to do. For time limited games this kind of context specific help would also be a way of resolving the tension between game complexity and the need to schedule and restrict the time spent by players. In Last Will players were given prompts to help them get through the tasks otherwise they would run out of time and not experience all three scenes.
The Last Will trial has given us the opportunity to see general patterns of behaviour that we can now explore further in more controlled experiments to look at particular aspects of interest such as priming affordances of tangible interfaces and situation awareness in ubiquitous systems.

7. Acknowledgements
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8. References


