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Exploring the Use of Audio-Visual Feedback within 3D Virtual Environments to Provide Complex Sensory Cues for Scenario-Based Learning

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The continuous quest for ever increasing fidelity in 3D virtual worlds is running parallel to the emergence and adoption of low-cost technologies to implement such environments. In education and training, complex simulations can now be implemented on standard desktop technologies. However, such tools lack the means to represent multisensory data beyond audio-visual feedback. This paper reports on a study that involved the design, development and implementation of a 3D learning environment for underground mine evacuation. The requirements of the environment are discussed in terms of the sensory information that needs to be conveyed and techniques are described to achieve this using multiple modes of representation, appropriate levels of abstraction and synesthesia to make up for the lack of tactile and olfactory sensory cues. The study found that audio-visual cues that used such techniques were effective in communicating complex sensory information for novice miners.

Keywords: synesthesia; human-computer interaction; serious games; engagement, e-learning

Introduction

Explore any website and it is immediately apparent that text and graphics and, to a lesser extent, audio dominate as the primary modes of digital information. Such approaches, however, are inherently limited in the nature of the information that they convey. In e-learning settings, where concepts such as authenticity and situatedness are often cited as powerful means to promote transfer of learning (Brown, Collins, & Diguid, 1989), then the abstract nature of much media becomes increasingly problematic. As technologies mature and 3D representation becomes increasingly easy. 3D game engines are providing effective alternatives to workplace learning because of their low cost and limited need for programming skills to develop rich applications (Garrett & McMahon, 2010).

One way in which 3D game engines frequently provide sensory cues is through the use of a Heads Up Display (HUD). While a very common approach to information presentation, HUDS have recently come under criticism for the abstract nature of their representation of information:

> Many elements found on a typical HUD are there not out of necessity, but out of convention; they represent a sort of "info overkill" that, for the vast majority of players, has no impact on gameplay at all. For every piece of information you offer the player, ask, "Is this information essential to the game experience?" In doing so, you might find that you don't need to bombard the player with quite as much data as you once thought you did. (Wilson, 2006).

As a potential refuge of lazy design, it is certainly true that HUDs are not always necessary. It can also be argued that not all authentic information needs to be represented within a given simulation. Factors that relate to aspects of the learning such as the nature of the task to be performed and the feedback inherent within that may need to be represented with a high fidelity, however this is not true of all situations and hyperfidelity may be as disorientating when there are specific learning goals as hypofidelity may be inadequate (Stone, 2008).

However, the continued existence of HUDS highlights that even in the most realistic 3D environment there are some sensory cues that are extremely hard to replicate. Since the 1970s the dominant mode of computer interaction has been through a keyboard, with typical output in the form of video on a monitor and speaker-based audio. Despite the introduction of the mouse and more recently surround sound, the standard computer interface has varied little over the years. With that in mind, consideration needs to be given to how existing technologies can best represent the multisensory feedback that is so relevant to real-world decision-making.

Modes of sensory feedback

There have been various attempts to augment audiovisual experiences with other sensory cues. Some, such as the notorious ‘Smell-O-Vision’ of b-grade cinema, later refined as ‘Odorama’ by director John Waters, can best be viewed as gimmicks that are used for comedic or promotional purposes (Gilbert, 2008). The sense of taste is even more problematic in that any taste ‘interface’ is likely to be quite invasive, which may explain the paucity of examples of such interaction modes in traditional media and interface research.

Haptic interfaces on the other hand have fared far better. From early manipulators, through to desktop systems, the history of haptic devices is one of continuous refinement and development (Stone, 2000). Their value lies in their capacity to provide kinaesthetic and tactile feedback that allows the user to experience both texture and movement associated with authentic tasks (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-De-La-Torre, 2004). As such they are highly suited to a range of training scenarios which require the representation of physical motion, force feedback and touch at a high level of fidelity. The cost of such systems are also coming down, with, for example, the Nintendo Wii which uses accelerometers and cameras in its ‘wiimote’ to register motion and the Novint Falcon, which operates as a haptic mouse providing force feedback, entering the consumer marketplace. However the range of software for which these devices have drivers is still somewhat limited.

In most cases, a developer is required to represent such forms of feedback using other means. While the sensations of sight and hearing may seem somewhat removed from those of taste, touch and smell, research into synaesthesia suggests that specific senses may be stimulated by alternate modes of representation.

Pierce (1911) noted this phenomenon in a range of specific cases including, ‘colored hearing’ where certain French vowel sounds were perceived as belonging to a certain color. Put simply, it is the crossover of sensation, where certain sensory stimuli are perceived by other senses. For the most part, this has been considered something of a rare neurological phenomenon experienced purely at an individual level (Harrison, 2001). Some experiments, however, such as the classic Booba/Kiki effect by Gestalt psychologist Wolfgang Köhler, suggest that certain visual cues are quite salient in terms of how shapes are perceived as sounds. In examining two irregularly shaped objects (Figure 1) 95-98% of participants select the left angular shape for Kiki and the right rounded shape for Booba (Ramachandran, 2004).

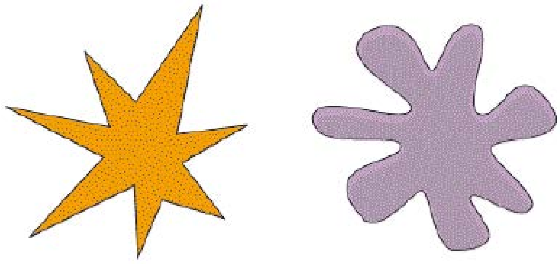

Figure 1. Kiki (left) and Booba (right)

Ramachandran (2004) suggests that a natural link is formed by the circular shape of the mouth when making sounds such as ‘ooh’ in combination with the softer sound of ‘b’ to the more rounded shape of Booba compared to the more acute sound of‘eeh’ and ‘k’. Similarly, the shapes of the objects are more closely aligned with their counterpart consonants. In any case,it is evident that there are some predictable relationships between concepts that are represented across a range of sensations that could prove useful for game interfaces.

Alternative and multimodal sensory representation

Synaesthetic cues have been used in games in informal ways for a long time. Weir (2004), for example, notes how music can enhance the tactile experience of a game, using the case of a dark first person shooter game where bumping into a metal chain hanging from the ceiling could play a sinister chord, the pitch of which modulating as the chain swings. The Gears of War game series (Epic Games, 2006) also demonstrates this in the way that health is represented. The physical sensation of poor health cannot be fully replicated within the game so instead the character grunts when he is hit and, at a more abstract level, the periphery of a screen turns blood red and vision is obscured the more damage your character receives. The blood motif is a reminder in that sensory information has the potential not only to be provided in the form of informational cues but also at a higher level of abstraction through metaphor. Iconography is one primary means of achieving this. Icons can exist at a variety of levels of representation. Preece (1994) identifies the following modes in descending order of concreteness:

- Resemblance Icons
- Exemplar Icons
- Symbolic Icons
- Arbitrary Icons

While resemblance icons accurately represent the concept to be communicated (e.g. a ‘rocks falling’ road sign), exemplars provide a specific instance (such as a knife and fork representing the availability of a restaurant). Symbolic icons are readily identifiable but may not actually be a specific example. A fractured wine glass, for example, may denote fragility even though it may not actually be glass that is fragile. As the name suggests, arbitrary icons do not have a direct meaning. In computer terms, for example the USB icon does not directly map onto a recognizable concept, just as the biohazard icon operates at an equally high level of abstraction. While the USB icon’s three-pronged form seeks to mimic the physical process of plugging a device in and transferring data, it could be argued that the biohazard sign, while deliberately designed to be ‘memorable but meaningless’ (Cook, 2001), operates synaesthetically because the combination of soft circular imagery and sharp points where they intersect provide resemblance to molecular structures with a sharpness suggestive of penetration (Figure 2). As such it is a very relevant sign for devices like needle disposal bins.

Figure 2. Biohazard Symbol

Audio also operates at similar levels of abstraction. Audio can function in both direct and ambient ways to achieve a range of functions such as:

8. Localization, which lets you know where you are
9. Sonification, turning information into sounds
10. Ambient effects, to add depth and realism
11. Sensory substitution, which replaces one sensory stimulus with a sound
12. Annotation and help, to guide the user (Ardito, Costabile, De Angeli, & Pittarello, 2007)

Sensory substitution in particular operates at a synaesthetic level to reproduce other physical stimuli through audio. It has found widespread acceptance, especially in the domain of design for the disabled such as those with visual impairments (Proulx, 2010). There is therefore a range of audiovisual cues that can be used to enhance the types of feedback in 3D serious game environments where direct representation is not possible.

Such interface features need not be used discretely. Media Richness Theory argues that providing multiple cues including communicative modalities through rich media can facilitate shared understanding. Research into multimodality suggests that multiple channels for information delivery and presentation assist in the sense-making process in learning (Ritterfeld, Shen, Wang, Nocera, & Wong, 2009). Proponents of serious games based education have successfully utilised such an approach to convey the impression of severe weather conditions in a levee patroller training application (Houtkamp, Schuurink, & Toet, 2008) and facilitate memory and navigation training in virtual representations of real world environments (Larsson, Vastfjall, & Kleiner, 2001), for example. Consideration, therefore needs to be given to how both audio and visual cues can represent the full range of sensory information required to effectively complete tasks in serious games that that make the best use of the affordances of those modes. In particular consideration of the synaesthetic quality of those cues and the potential for multimodal representation may greatly assist in providing effective interfaces for such environments.

About this study

Alternative and multimodal representation was explored through the design, development and implementation of a problem-based learning scenario, using 3D game technologies. An industry partner was selected to provide a real world context in which to situate the design of the simulation environment. Dominion Mining was selected for this purpose with a focus on their Challenger underground mining facility located in South Australia.

Dominion had acknowledged that a computer-generated simulation environment could be used to conduct emergency evacuation training within a virtual representation of the Challenger underground mine. Such a training platform could be used to develop knowledge of Dominion's existing evacuation procedures which could be transferred and applied within the real world mine during an emergency. Dominion's existing procedures direct personnel to locate a refuge chamber in the event that an evacuation is required. Refuge chambers are self-contained steel structures that are capable of accommodating multiple miners with independent power and oxygen supplies which are utilised in the event that the supply of these essential services from the surface is interrupted. The Challenger facility has a number of these refuge chambers situated in specific locations in order to provide coverage for the entire mine in the event that an emergency evacuation is initiated.

In order to assist personnel to reach a refuge chamber safely in the event that smoke, excessive dust, or noxious fumes are present within the mine, personnel are outfitted with a self- rescuer, which is a portable gas mask which supplies oxygen via a controlled chemical reaction. Self-rescuers have a finite supply of oxygen which is depleted at a rate proportional to how quickly and deeply the individual who is wearing it is breathing. Dominion protocol mandates that during an emergency, personnel are to equip their self-rescuers if their breathing is obstructed, and that personnel should minimise the amount of physical effort they expend on the way to a refuge chamber in order to prolong their oxygen supply.

Thus, during an emergency evacuation, personnel need to reach a refuge chamber as quickly and efficiently as possible in order to maximise the duration of oxygen supplied by their self-rescuer. To this end, personnel have to be aware of the levels of physical effort required to traverse the mining environment and the effect that this has on their breathing rate and subsequent oxygen consumption in order to be able to evacuate effectively during an emergency underground.

Development of the simulation environment

Given the objective of developing knowledge of Challenger's emergency evacuation procedures, the simulation environment was designed in accordance with the Simulation, User, and Problem-based Learning (SUPL) design framework (Garrett & McMahon, 2009), whereby learning was situated within problem-solving activity with the goal of facilitating learning transfer.

The simulation was constructed using the DirectX-based DX Studio development suite (http://www.dxstudio.com) which provided an integrated platform for the development and configuration of necessary content. The development suite consisted of a mouse and keyboard operated GUI which enabled content to be imported, arranged, configured, and previewed dynamically as changes and modifications were made. In this manner, a virtual representation of the mine was able to be rapidly prototyped which was desirable given the available time frame for development and financial constraints imposed by the study.

The simulator, designated FUMES (Fire in Underground Mining Evacuation Scenario), was developed in this manner in order to expose users to a three-dimensional, simulated representation of an underground fire emergency situated within a section of the Challenger mine. In order to facilitate the development of knowledge that could be utilised during a similar emergency in the real world mine, users were tasked with evacuating to a refuge chamber within the virtual mine in accordance with Dominion's existing evacuation procedures. To this end, users were provided with the ability to walk, run, and orientate themselves from a first person perspective and could equip a virtual self-rescuer in order to safely negotiate simulated smoke. User interaction was facilitated via a standard mouse and keyboard based setup common to many First Person Shooter (FPS) games, with the mouse being used to control orientation, and the keyboard handling movement and the use of the self-rescuer.

The virtual mining environment itself was modeled using AUTOCAD architectural data from the Challenger mine supplied by Dominion such that FUMES could accurately depict the spatial characteristics of the real world mine in three dimensions. The speed at which users could be expected to be able to walk and run, the resultant physical effort required to do so, and the effect this had on oxygen consumption when using the self-rescuer were also modeled as authentically as possible using information supplied by subject matter experts at Challenger.

Depiction of sensory modalities

Developing an understanding of the significance of movement, physical exertion, and self-rescuer oxygen consumption during an emergency evacuation of the Challenger mine necessitated the representation of these concepts, their characteristics, and interrelationships within the simulation environment. The nature of these concepts within the real world mine was identified via consultation with subject matter experts at Challenger in order to inform the design of the simulation environment in this regard, as detailed in Table 1.

Table 1. Concepts relating to movement, physical exertion, and self-rescuer oxygen consumption

Concept	Characteristics	Interrelationships
Movement	Personnel can remain stationary, walk, or run within the mining environment.	Remaining stationary requires a low amount of physical exertion. Walking requires a moderate amount of physical exertion. Running requires a high amount of physical exertion.
Nature of the terrain	The underground mining terrain can be level or on a slope.	Traversing level terrain requires the least amount of physical exertion. Traversing downward sloping terrain requires more physical exertion than level terrain. Traversing upward sloping terrain requires more physical exertion than downward sloping terrain.
Physical exertion	The amount of effort required to conduct physical activity	The extent of physical exertion is proportional to breathing rate
Breathing rate	The frequency at which personnel are breathing	The frequency of breathing is proportional to the rate at which oxygen is consumed in a self-rescuer
Self-rescuer oxygen consumption	The rate at which the finite oxygen supply provided by the self-rescuer is consumed	

Given the technical capabilities of standard desktop computer hardware, representing the concepts detailed in Table 1 necessitated the use of visual and auditory feedback to approximate the sensory information which would be implicitly available within the real world mining environment. Table 2 details the manner in which the feedback representing movement, physical exertion, breathing rate, and self-rescuer oxygen consumption was represented within the simulation environment to this end.

Table 2. Representation of movement, physical exertion, breathing rate, and self-rescuer oxygen consumption using visual and auditory feedback

Feedback	Representation	Details
Movement	Auditory cues for footsteps.	Sound effects depicting walking or running on gravel in response to user movement
	Visual cues for movement speed	Icon representing user movement speed (stationary, walking, or running)
Nature of the terrain	Visual cues for inclination of the terrain	Icon representing inclination of the terrain that the user is moving over (level, uphill, or downhill)
Physical exertion / breathing rate	Auditory cues representing breathing	Sound effects depicting breathing at different rates depending on the current extent of physical exertion.
	Visual cues indicating the user's current physical exertion	Animated icon depicting a heart which beats more rapidly as physical exertion increases.
Self-rescuer oxygen consumption	Auditory cues representing breathing with a self-rescuer	Standard breathing sound effects are replaced with those of breathing with a self-rescuer

The visual icons described in Table 2 for representing movement speed, inclination of the terrain, and physical exertion were collated into a two dimensional interface which was rendered along the bottom of the screen, as detailed in Figure 3. Tables 3, 4, and 5 denote the states these icons could assume in order to represent movement speed, inclination of the terrain, and physical exertion as the user moved throughout.

Figure 3. Screen-shot from the simulation environment, with two dimensional icon interface rendered along the bottom edge of the screen

Table 3. Icons used to represent movement speed within the virtual mine

Concept	**Icon states**					
Movement speed		Stationary	Walking			Running

Table 4. Icons used to denote the inclination of the terrain within the virtual mine

Concept	**Icon states**					
Inclination of the terrain		Level sloping terrain	Downward sloping			Upward sloping

Table 5. Animated icon used to represent physical exertion within the virtual mine.

Concept	Icon states		
Physical exertion	 Animated heart beats slowly for low physical exertion	 Animated heart beats moderately for moderate physical exertion	 Animated heart beats quickly for high physical exertion. Additional text also denotes high physical exertion

Movement, inclination and physical exertion were considered key to the training outcomes for this scenario and the above icons were supplemented with five further status icons that existed as a single toggle on/off. They were:

- The self-rescuer, which is lit when the user is wearing it. This icon reinforces the fact that breathing apparatus is in use and therefore the user has a limited level of oxygen available
- A walkie-talkie, which is lit when the user is receiving verbal instructions via audio
- A ladder, which clearly marks whether an escape shaft is in the immediate vicinity
- A cap lamp, which combines with the simulated light within the scenario to reinforce whether it is switched to high or low intensity
- Stench gas. An onion odour is released into the mine when noxious gas is detected to remind the miners to use self-rescuer equipment

The first four of these operate at quite a clear level of resemblance. The second is inherently synaesthetic in that it seeks to replicate an odour in a visual form. Ironically, this level of abstraction is carried through into the mine itself because many poisonous gases that can be released during the mining process are in fact odourless and colourless. In all cases, multimodality was used to enhance the icons. The first three were visually represented within the scenario itself while the final was supplemented with an audio cue.

In order to reinforce the concepts detailed in Table 1, auditory cues were also implemented to complement the icons representing movement speed and physical exertion within the simulation environment. Auditory cues depicting footsteps walking and running over gravel were played in response to user movement through the virtual mine. These were played concurrent to additional auditory cues which depicted breathing both with and without a self-rescuer, with relaxed breathing sounds utilised where the user's physical exertion was low, and rapid breathing sounds utilised where the user's physical exertion was high. A rapid beating heart auditory cue was also utilised in the event that physical exertion was high in order to reinforce the user's heightened level of physical activity.

Results

The feedback mechanisms described in Table 2 were evaluated in the resultant product FUMES in order to determine their effectiveness to approximate real world sensory information and facilitate an understanding of movement, terrain inclination, physical exertion, and self-rescuer oxygen consumption during an emergency evacuation.

A total of 41 participants comprised of personnel with varying levels of experience at Challenger were tasked with completing three emergency evacuation scenarios within FUMES in which they were tasked with safely reaching a refuge chamber in accordance with Dominion's existing emergency evacuation procedures. The user's starting position, the location of the fire, and the severity and spread of the resultant smoke varied in each of the three scenarios such that the scenarios became progressively more demanding. At the end of each scenario, the user was provided with feedback in relation to their performance, detailing how long they took, how far they traveled, how much effort they exerted, how much oxygen they consumed, and whether or not they took the best route to the refuge chamber, with this information being recorded in a database.

Analysis of the performance measures recorded in the database generally suggested that users were able to effectively perform the evacuation procedure within the virtual mine, with 100% of users successfully able to reach a refuge chamber in the first scenario, 85% in the second scenario, and 43% in the third. While this did demonstrate a general decline in performance across the series of three scenarios, this could be attributed to the deliberate design decision to make the second and particularly third scenarios more challenging in terms of the user's initial proximity to the fire, the severity of smoke, and the subsequent effects this had on visibility within the virtual mine. This was reflected in the data recorded in the database denoting the time taken and effort exerted by participants, which tended to be greater during the second and third scenarios, on average. While the database data did not provide a great deal of insight in relation to whether the feedback mechanisms provided within FUMES were effective in approximating real world sensory information, it did suggest that this sensory information was at least sufficient enough to allow participants to perform Dominion's emergency evacuation procedure within a virtual representation of the Challenger mining environment.

In order to determine how effectively the feedback mechanisms approximate real world sensory information that was necessary during an emergency evacuation procedure, participants were required to complete a questionnaire in relation to their experience at the conclusion of the third scenario. More detailed interviews were also conducted with five of the participants.

Movement

Questionnaire responses indicated that users could discern their movement speed during the simulation, with 82% of participants agreeing or strongly agreeing that they were aware of how fast they were moving within the virtual mining environment. This suggested that the icon used to represent movement speed and the auditory cues which represented footsteps were sufficiently adequate to allow the user to know the difference between when they were stationary, walking, or running.

Inclination of the terrain

Participants indicated that they were aware of the inclination of the terrain they were traversing, with 75% of participants agreeing or strongly agreeing that they knew whether they were moving uphill, downhill, or over a level surface within the virtual mine. These responses implied that the icon used to denote changes in the inclination of the terrain was effective in informing the user as to the nature of the mining environment in this regard.

Physical exertion

Participants demonstrated an awareness of their physical exertion during the simulation, with 79% of participants agreeing or strongly agreeing that they knew how much physical effort they were expending within the virtual mining environment. Interview responses reflected this awareness, with participants making repeated references to the role of the auditory cues which represented breathing in informing them as to the extent of their physical activity. This suggested that the animated heart icon depicted in Table 5 in conjunction with the aforementioned auditory cues were effective in establishing the user's level of physical activity within the simulation environment.

Awareness of relationships

Questionnaire responses further indicated that participants understood the effect that movement speed had on physical exertion, with 90% of participants agreeing or strongly agreeing that running required more physical effort than walking within the simulation. Furthermore, participants were also aware of the effect that the inclination of the terrain had on physical exertion, with 87.5% of participants agreeing or strongly agreeing that moving up an inclined surface required more effort than moving down one, and 95% of participants agreeing or strongly agreeing that the physical effort they expended was affected by the slope of the terrain. These responses demonstrated that participants were successfully able to acknowledge movement speed and the inclination of the terrain as factors which affected physical exertion within the simulation environment. This indicated that the participants were able to establish a connection between the feedback mechanisms used to denote movement speed and the inclination of the terrain, and those used to represent their physical activity.

Additionally, participants indicated that they understood the relationship between physical effort and self-rescuer oxygen consumption, with 77% of questionnaire respondents agreeing or strongly agreeing that they had to be aware of their physical effort when using their self-rescuer, and 80% of participants agreeing or strongly agreeing that the physical effort they expended affected the rate at which oxygen was consumed. Interview responses again predominantly referenced the auditory cues used to represent breathing in delineating the relationship between physical exertion and self-rescuer oxygen consumption. All interviewees also stated that the relationship between movement speed, physical effort, and oxygen consumption was clearly demonstrated within the simulation environment. This provided evidence to indicate that the feedback mechanisms used to delineate movement speed, the inclination of the terrain, and the subsequent effects on physical exertion and self-rescuer oxygen consumption were effective in developing an understanding of these concepts and their interrelationships within participants as a result of using the simulation environment.

Findings and conclusion

Responses from participants indicated that the simulation environment provided a clear sense of movement speed, the inclination of the terrain, and physical exertion. This information was effectively conveyed via a combination of visual and auditory feedback which was used to approximate sensory information which would be implicitly available within the real world environment being represented. These feedback mechanisms were deemed effective enough to facilitate an understanding of the relationships between movement speed, terrain inclination, physical exertion, and self-rescuer oxygen consumption which could be applied during an emergency evacuation of the real world Challenger mining environment.

While the use of such cues do impact on the fidelity of the environment and therefore potentially the transfer of learning that can occur, it was evident in this study that learners were quickly able to formalize the meaning of the visual an auditory stimuli in a manner that facilitated their performance in the simulation. It is a tangible reminder that even the most abstracted symbols can be powerful and useful performance cues once their meaning is internalized by the end user. One interesting finding from the study was that while the techniques identified here proved effective cues for mine evacuation, some subtle real-world cues that were not represented within the simulation were seen as a limitation by the participants. For example, the crude depiction of cabling in the interior of the mine was seen as a limitation for those participants who found value from it as a tool for navigation and identifying waypoints within the mineshaft. Also, one participant argued that in an evacuation scenario he would also use the real-world tactility of the tunnel wall to guide his movements, particularly where visibility could be hindered by smoke. The first of these is something that could be remedied with a higher level of fidelity in the visual representation of the cabling. The latter could either be represented using a haptic mouse or, given the success of the use of synaesthetic cues in this study by providing collision feedback in the form of an audible brush against the rock wall.

Despite such limitations, therefore, it is evident that approximating complex sensory stimuli using visual and auditory feedback can be effective in 3D training scenarios using simple desktop technology. Such stimuli may be depicted using multiple modalities, represented at variety of levels of abstraction, and using sensory substitution to provide a synaesthetic experience for end users.

References

Ardito, C., Costabile, M. F., De Angeli, A, Pittarello, F. (2007). Navigation Help in 3D Worlds: some empirical evidences on the use of sound. *Multimedia Tools and Applications*, 33(2), 201-216.

Brown, J.S., Collins, A., & Duguid. P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.

Cook, J. (2001). Symbol Making in Symbol Making, Series Symbol Making.

Epic Games. (2006). Gears of War (Computer software). Microsoft.

Garrett, M., & McMahon, M. T. J. (2010). Maximising Efficiency of Training Outcomes using Inexpensive 3D Technologies in *Proc. SIMTECT 2010 Conference*, Brisbane Australia, 30 May-3 June, 2010.

Garrett, M., & McMahon, M. T. J. (2009). Developing knowledge for real world problem scenarios using 3D gaming technology within a problem-based learning framework in *Proc. Simtect, 2009*

Gilbert, A. (2008). Hollywood Psychophysics. What the Nose Knows., USA: Crown Publishers.

Harrison, J. (2004). *Synaesthesia: The Strangest Thing*. New York: Oxford University Press.

Hayward, V., Astley, O.R., Cruz-Hernandez, M., Grant, D., & Robles-De-La-Torre, G. (2004). Haptic Interfaces and Devices. *Sensor Review*, 24(1), 16-29.

Houtkamp, J., Schuurink, E., & Toet, A. (2008). Thunderstorms in my Computer: The Effect of Visual Dynamics and Sound in a 3D Environment in *Proc. Visualisation 2008 Conference*, London, United Kingdom, 09 Jul-11 Jul, 2008.

Larsson, P., Vastfjall, D., & Kleiner, M. (2001). Ecological acoustics and the multi-modal perception of rooms: real and unreal experiences of auditory-visual virtual environments in *Proc. 2001 International Conference on Auditory Display*, Espoo, Finland, 2001, 245-259.

Pierce, A. H. Synaesthesia. *Pyschological Bulletin*, 8(5), 157.

Preece, J. (1994). *Human Computer Interaction*. Wokingham, England: Addison-Wesley Publishing Company.

Proulx, J. (2010). Synthetic synaesthesia and sensory substitution. *Consciousness and Cognition*, 19(1), 501-

503.
Ramachandran, V.S. (2004). *A Brief Tour of Human Consciousness: From Imposter Poodles to Purple Numbers.* New Jersey: Pi Press.
Ritterfeld, U., Shen, C., Wang, H., Nocera, L., & Wong, W.L. (2009). Multimodality and Interactivity: Connecting Properties of Serious Games with Educational Outcomes. *Cyberpsychology & Behaviour*, 12 (6), 691-697.
Stone, R. J. (2000). Haptic Feedback: A Brief History from Telepresence to Virtual Reality in Haptic Feedback: A Brief History from Telepresence to Virtual Reality, Springer-Verlag, 2000, pp. 1-17.
Stone, R. J. (2008). Human factors guidelines for interactive 3d and games-based training systems design., Birmingham, UK: Human Factors Integration Defence Technology Centre.
Weir, P. (2004). Color Sound: Synaesthesia in Games. *Game Developer*, 11(1),22.
Wilson, G. (2006). Off With Their HUDs!: Rethinking the Heads-Up Display in Console Game Design, in:Gamasutra, 2006, [cited 10 October 2010] Accession no. Accession Number| Available from Database Provider|.

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http://www.ascilite.org.au/conferences/hobart11/procs/Garrett-full.pdf