Human Factors Guidelines for Interactive 3D and Games-Based Training Systems Design

Edition 1 (V6)
(August, 2008)

Professor Robert J. Stone
Research Director, Human Factors Integration Defence Technology Centre
Director, Human Interface Technologies Team, University of Birmingham (UK)

This work is part-funded by the Human Capability Domain of the UK Ministry of Defence Scientific Research Programme, and was initiated by the MoD Research Director, Human Capability.

All recipients of this report are advised that it must not be copied in whole or in part or be given further distribution outside the authority without the written permission of the Research Director (Human Capability).

© Human Factors Integration Defence Technology Centre, February 2008.

The authors of this report have asserted their moral rights under the Copyright, Designs and Patents Act, 1988, to be identified as the authors of this work.

Please visit www.hfidtc.com for further information.

This project was co-funded by the Technology Strategy Board's Collaborative Research and Development Programme, following an open competition.

The Technology Strategy Board is a business-led executive non-departmental public body, established by the government. Its mission is to promote and support research into, and development and exploitation of, technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life. It is sponsored by the Department for Innovation, Universities and Skills (DIUS).

Please visit www.innovateuk.org for further information.

Contents

				Page
Preface				5
1.0	Introduction			6
	1.1	Document Structure		8
2.0	Background: Why Human Factors Guidelines for i3D and Games-Based Training?			10
	2.1	So Why Do We Need Guidelines Now?		11
	2.2	Why Guidelines for Games-Based Training Developers?		13
	2.3	Why Guidelines for Training System Procurers and End Users?		13
	2.4	Not Just Interactive Hardware … Why Guidelines for Human Factors Practitioners?		14
	Section 2.0 Key Points Summary			18
3.0	Real-World Examples			19
		3.0.1	Minimally Invasive Surgical Trainer	20
		3.0.2	Early Surgical/Clinical Procedural Trainers	21
		3.0.3	Desktop Minigun Trainer	22
		3.0.4	Explosive Ordnance Search, Disposal and Incident Planning Tool	22
	3.1	Real-World Examples & Relevance to Fidelity – Some Introductory Comments		27
	Section 3.0 Key Points Summary			29
4.0	Task Design Issues & Task Fidelity			30
	4.1	i3D or Games-Based Technologies for *Skill* or *Decision* Training Tasks?		30
	4.2	Hypo-/Hyper-fidelity and Distractive Elements in Simulated Tasks		34
	4.3	Task Reference Frames		37
		4.3.1	Egocentric Presentations	38
		4.3.2	Exocentric Presentations	39
			4.3.2.1 Over-The-Shoulder	39
			4.3.2.2 Low-Angle Projection	40
			4.3.2.3 High-/Distant-Angle Projection	40
		4.3.3	Exocentric "Tethering"	40
	4.4	Task Coupling		44
	4.5	Other Task Coupling Examples		47
	Section 4.0 Key Points Summary			49

			Page
5.0	Interactive Fidelity		50
	5.1	Don't Expect Too Much of the Mouse!	54
		5.1.1 Mouse Function Cueing	56
		5.1.2 Inappropriate Use of the Mouse	59
	5.2	Don't Expect Too Much of the Keyboard!	60
	5.3	Novel Commercial Off-The-Shelf (COTS) Interactive Hardware	62
	Section 5.0 Key Points Summary		64
6.0	Context Fidelity		65
	6.1	Task-Supportive Context Elements	66
	6.2	Task-Hindering Context Elements	66
	6.3	Inappropriate Context Elements & Distraction	67
	6.4	Consistency of Context Fidelity	72
	6.5	Context Fidelity – Special Case: Avatars, "Non-Playable Characters" and Virtual Agents	73
	Section 6.0 Key Points Summary		81
7.0	Concluding Comments		82
	7.1	Future Editions	82
Abbreviations			84
Bibliography			86

Preface

When considering innovations in e-learning for 2008, it is tempting to focus on advances in technology - such as the use of games, virtual reality, and pedagogical agents. However, the most important innovations in e-learning will involve advances in our understanding of how to design e-learning environments that help people learn - such as how to design serious games, VR environments and online agents that promote appropriate cognitive processing during learning. Basic research on learning and instruction will provide new guidance for instructional design, including which instructional features promote which kinds of learning for which learners.

Richard E. Mayer, University of California, Santa Barbara, USA, writing for *eLearn Magazine*, 22 January, 2008 (elearnmag.org).

This Human Factors (HF) Guidelines Document has been produced to satisfy research deliverables for two UK-based projects conducting research into the effective exploitation of computer games technologies for education and training.

The first, sponsored by the Ministry of Defence (MoD; www.mod.uk), is being undertaken by the **Human Factors Integration Defence Technology Centre** (HFI DTC; www.hfidtc.com). Funded jointly by the participants and the MoD, Defence Technology Centres are formal collaborative arrangements between industry and academia who work together to generate and enhance technologies vital to the delivery of future UK defence capabilities. The HFI DTC was launched in April 2003.

The second project, sponsored by the **Technology Strategy Board** (www.innovateuk.org), is addressing the application of skills and technology used in the production of video games to create serious training applications (http://sg-ets.webexone.com/). The Technology Strategy Board was established by the UK government to support research, development and the exploitation of technology for the benefit of UK business and is sponsored by the Department for Innovation, Universities and Skills (DIUS).

1.0 Introduction

Figure 1: Early British Virtuality *Visette* head-mounted display and glove.
Source: www.babeledunnit.org

The 1980s and 1990s were marked by a series of important events in the evolution of interactive digital technologies. In particular, rapid developments in computer graphics hardware and software prompted the launch of a number of "movements" throughout the globe, including computer-generated imagery (CGI) and animation (e.g. for the film and TV industries), scientific visualisation, Virtual Reality (VR) and wearable computing. Whilst these groups did much to bring a range of previously expensive, unique and (superficially) impressive technologies to the attention of a much wider global audience than ever before, they were also responsible for creating a culture of myth, hype and false promise. This was particularly the case for VR (e.g. Figure 1). From the perspective of potential adopters in domains such as engineering, defence, medicine and so on, VR provided a roller coaster ride of achievement and failure throughout the 1990s. To use the terminology used to describe *Gartner Hype Cycles*[1], VR was already well past its "peak of inflated expectations" by 1995 and on course to hit the bottom of the "trough of disillusionment" (Figure 2), where it is still struggling today to make a comeback.

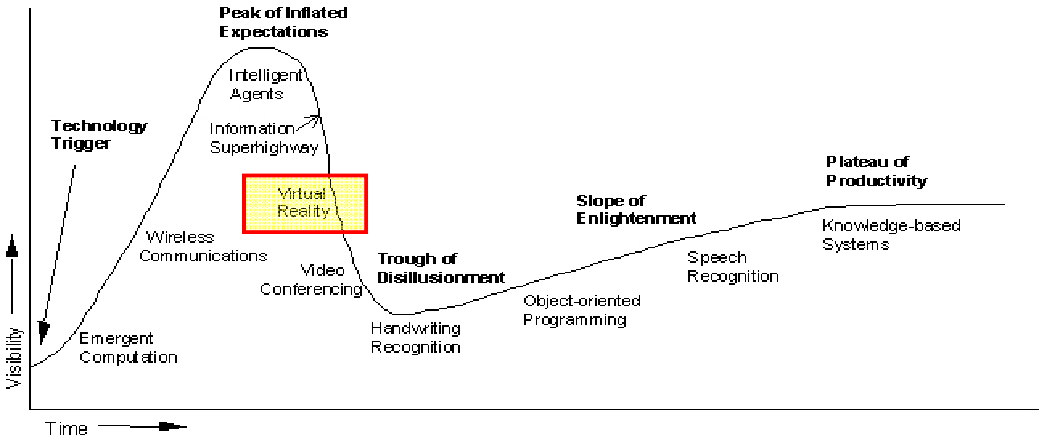

Figure 2: Gartner *Hype Cycle* for emerging technologies, 1995.
Source: Gartner Inc.[4]

One of the most important, if not ***the*** most important lesson to be learned from the Virtual Reality / Virtual Environments / Synthetic Environments (VR/VE/SE) era of the 1990s is that input from HF specialists **must** be given credible recognition throughout the entire design process underpinning a whole- or part-task training simulation based on interactive 3D (i3D; including applications based on gaming technologies, often referred to as "serious games"). For example, task analysis, concept demonstrations/presentations, the definition of learning outcomes and metrics, pedagogy[2; 3], Virtual

[1] The first (1995) Hype Cycle for Emerging Technologies can be seen in: Fenn, J. & Linden, A. (2005), "Gartner's Hype Cycle Special Report for 2005"; Gartner Inc. Report ID Number: G00130115, 05 August 2005.
[2] *Pedagogy*: the science, theory and practice of teaching – based on contents of Clark, D. (2006), "Pedagogy and e-Learning"; Epic White Paper; www.epic.co.uk.
[3] Pedagogical issues associated with serious games and simulations are also contained within a Web-based *Style Guide for Serious Games and Simulations*: http://clarkaldrich.blogspot.com/.

Environment content and usability design, interactive technology assessment and evaluation – **all** demand a solid understanding of human-centred design issues.

Unfortunately, the VR and games-based learning communities – even the HF community – have not yet produced evidence and data of sufficient quality and quantity to warrant the publication of a comprehensive, science-based handbook of generic value to multidisciplinary i3D design teams[4]. The speed with which i3D hardware and software technologies have evolved over the past two to three decades, with "serious games" representing the latest stage of evolution, has, unfortunately, not been matched by the timely delivery of appropriate HF knowledge from the academic sector. What might have been usable and relevant data from studies at the time they were conducted – and the technology on which they were based – are often no longer of generic applicability when the study is finally published. Criticism of the authors of these studies is in no way implied here, as the publication schedules of the (few and far between) journals in this field are such that, by the time a paper is published, many of the technology-specific HF issues are no longer relevant.

In the author's opinion, conferences such as the US Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Europe's International Training and Education Conference (ITEC), *Laval Virtual* in France, the annual Virtual Systems and Multi-Media (VSMM), Medicine Meets VR (MMVR) and Human Computer Interaction (HCI) International Conferences, and so on, have been useful to a limited extent in that some of the studies presented have shown some evidence of an HF input. However, as with relevant journals, such studies are also too few and too far between. Many are highly technology-focused and good HF practice and data relevant to this field are only rarely reported in a format that supports the generation of usable guidelines. The early serious games events in the UK and US have, at the time of writing, yielded very little of HF substance that would be suitable for inclusion in a guidelines document of this sort.

The VR era, then, demonstrated that, no matter how "good" the pedagogy, the capability of a simulation-based system to educate and train can be completely destroyed if content, fidelity and interactive technologies are implemented inappropriately and without a sound Human Factors underpinning. Consequently, the present document focuses primarily on an area that is, at the time of writing, reasonably well understood (from an experiential perspective, at least), namely the application of fundamental Human Factors knowledge to the design of i3D and games-based simulations. These issues include physical and psychological fidelity (topics considered in a little more detail later in the document), the appropriate use of interactive technologies, and the importance of capturing relevant end user behaviours during early task analyses based on observations in the field.

An important point relating to the contents of this document should be stressed here. Many of the comments and recommendations presented throughout these guidelines are based on over 20 years of involvement in the i3D community. A significant amount of "evidence" underlying the recommendations comes not from academic investigation, but from the results and real-life experiences of applying i3D technologies to a range of domains, from defence part-task training to surgery and from aerospace, automotive and petrochemical engineering to cultural heritage. Nevertheless, the high-level goal of this document is:

To expose Human Factors, games development and end user communities to basic issues relating to human-centred design in games-based training (and other forms of media based on interactive 3D) to help avoid the mistakes of the Virtual Reality "era" of the 1990s by ensuring that "human pull" prevails over "technology push".

[4] Whilst of general interest to the VR developer and user communities, the only serious attempt to produce such a document resulted in a collection of stand-alone chapters (papers) published under a rather misleading "handbook" title: Stanney, K.M. (Ed., 2002), "Handbook of Virtual Environments: Design, Implementation and Applications", Lawrence Erlbaum Associates Inc. (Human Factors & Ergonomics Series).

1.1 Document Structure

This guidelines document has been written in a "top-down" format, dealing first with general issues relating to interactive 3D (i3D) and games-based training simulations, thereafter expanding on key Human Factors issues, as summarised below. At the end of each section (from Section 2 onwards), a "Key Points Summary Table" is presented that collates the main recommendations presented in the preceding text, together with the most relevant references for that section. References throughout this document have been presented within footnotes and a general bibliography is available on the final page. A brief overview of each section is given below.

Section 1 – ***Introduction*** – and **Section 2 – *Background: Why Human Factors Guidelines for i3D and Games-Based Training?* –** are very much introductory in nature. They provide brief overviews of the "rise and fall" of related i3D initiatives over the past two decades and go on to justify the need for Human Factors guidelines at this relatively early stage in the history of games-based learning. Section 2 describes the emergence of games-based software and hardware technologies and what they offer in contrast to their costly and unreliable VR predecessors. The discussion then touches on the question "Why Human Factors Guidelines?" and attempts to provide answers of relevance to games developers, training system procurers and Human Factors specialists.

The Key Points Summary Table for Section 2 is presented on page 18.

Section 3 – ***Real-World Examples*** – provides an introduction to a small selection of medical and defence projects that have been instrumental in helping to develop the guidelines contained herein. This section stresses the importance of conducting early Human Factors task analyses and attempts to give guidance on important task and context features that warrant attention when observing humans conducting real-world tasks for which an i3D part-task training simulation is being considered. At the end of Section 3, a brief introduction to the important concepts of physical and psychological fidelity is presented, effectively setting the scene for the remainder of the document.

The Key Points Summary Table for Section 3 is presented on page 29.

Section 4 – ***Task Design Issues & Task Fidelity*** – addresses the issue of fidelity in simulated task design, based on whether the task to be trained is fundamentally perceptual-motor or cognitive in nature, and whether or not all or only a percentage of the target audience possesses pre-existing (task-relevant) perceptual-motor skills and domain knowledge. This section also addresses "appropriateness" when specifying levels of task fidelity and the potential consequences of designing too much or too little fidelity into the simulated content. Other issues discussed include frames of visual reference (e.g. first-person or third-person perspectives) and how *task coupling* – the degree to which an end user's performance is influenced by the features and qualities of his or her immediate working environment – can affect the design of i3D systems.

The Key Points Summary Table for Section 4 is presented on page 49.

Section 5 – ***Interactive Fidelity*** – expands on the topic of *task coupling*, relating it to the selection or design of appropriate data input devices (a subsequent edition of these guidelines will cover display devices). This section addresses how well the interactive device selected physically maps onto the role and activities expected of the end user, how well the discrete and dynamic input commands from the interactive device map onto the displayed function and how acceptable the design features of the device are from an ergonomics perspective. Caution is recommended when considering the adoption of present-day, commercial-off-the-shelf hardware (particularly multifunction or "high-tech" games controllers). However, this section also warns against expecting too much of the mouse and keyboard when providing data input devices for i3D implementations.

The Key Points Summary Table for Section 5 is presented on page 64.

Section 6 – ***Context Fidelity*** – concentrates on the design of appropriate “background” sensory and behavioural detail in i3D or games-based learning systems. Background effects and scenarios should complement – and not interfere with – the task being performed. Therefore, as much Human Factors attention needs to be given to the content and fidelity of the scenario as to the design of the simulated tasks themselves. This section also considers the design and portrayal of avatars (virtual humans), “non-playable characters” and virtual agents, as these constitute a special case of context fidelity. If strict attention is not paid to the design of their visual and behavioural qualities, then this can make or break the acceptance and credibility of the simulation at a very early stage.

The Key Points Summary Table for Section 6 is presented on page 81.

2.0 Background: Why Human Factors Guidelines for i3D and Games-Based Training?

Whilst it is not the goal of this guidelines document to provide a comprehensive critique of Virtual Reality and associated technologies, it is important to appreciate why the discipline failed to deliver (in all but a very small number of applications domains) and why the lessons learned should not be forgotten at this early stage in the development of gaming technologies and related i3D simulations.

Figure 3: Defence and automotive engineering applications of HMD and CAVE technologies.
Source: Author's Image Archive

In the late 1980s and the early 1990s, the die-hard proponents of VR were convinced that, come the end of the 20th Century, users of today's real-time, multi-sensory computer environments would be exclusively wearing head-mounted displays (HMDs – Figures 1 and 3 – upper image), instrumented gloves, suits and body-mounted spatial tracking systems. As can be seen today, this vision simply did not come to pass in the real world. Neither did similar claims that VR users would be found sitting at *Star Trek*-like consoles with stereoscopic displays, or stand within multi-wall projection display facilities ("CAVEs"[5] – Figure 3, lower image), driven by "graphics supercomputers".

Instead, these users are, today, to be found in domestic, commercial and defence settings, using a mouse and keyboard – possibly a joystick or gamepad – facing a conventional computer screen displaying images from an off-the-shelf domestic PC, equipped with a graphics processor costing a significant fraction of the price of the supercomputers of the 1990s.

As illustrated earlier, VR both "peaked and troughed" in the 1990s, for a variety of commercial, technical and human-centred reasons. Commercial naïvety on the part of VR companies, significant failures to deliver meaningful and usable intellectual property on the part of so-called academic "centres of excellence", expensive and unreliable hardware, an absence of case studies with cost-benefit analyses and a widespread absence of attention to the requirements and limitations of the end users all took their toll by the end of the 1990s[6].

Yet, despite the failure of VR to deliver, today's interactive 3D users – those equipped with conventional computer equipment – are beginning to benefit from the products of a strongly-focused, market-driven movement – one that was originally labelled as technically and academically inferior by the proponents and purists of VR. That community is the gaming community – home to graphics hardware manufacturers such as nVidia and ATI, and "populated" with entrepreneurs and programmers responsible for such memorable First-Person/Third-Person Shooter (FPS/TPS) and Role-Playing Game (RPG) titles as *Delta Force*, *Operation Flashpoint, Medal of Honor*, *Half-Life*, *FarCry* and *Crysis* and *Assassin's Creed*, to mention but a few.

---

[5] **C**ave **A**utomatic **V**irtual **E**nvironment – a registered trademark of the University of Illinois – describes a room-like enclosure comprising back-projected video walls exposing occupants to virtual environments, edge-blended to create seamless wrap-around presentations.
[6] Stone, R.J. (2004), "Whatever Happened to Virtual Reality?", *Information Professional*, October/November, 2004, Institute of Electrical Engineers (IEE; now Institute of Engineering & Technology - IET), 12-15.

Impressive entertainment products such as these have, over recent years, captured the attention of training and education specialists, many of whom were beginning to question whether there would ever be a breakthrough in delivering accessible, modifiable and affordable i3D for serious applications. Exit VR, enter the "serious game". There is no one single definition of the term "serious games", although it is widely accepted that they are games "with a purpose". In other words, they move beyond entertainment *per se* to deliver engaging interactive media to support learning in its broadest sense. In addition to learning in traditional educational settings, gaming technologies are also being applied to simulation-based training in defence, healthcare and cultural awareness, in the fields of political and social change and, slowly, to the domain of virtual prototyping and simulation-based acquisition.

Another aspect of serious games – accessibility – makes their application potential even stronger than their VR predecessors. Not only are many of the emerging applications simply deliverable either via CD, DVD or memory stick, increasingly, the power of the Web (and the promise of Web 2.0, particularly for Massively Multiplayer Online (MMO) games) is offering a natural medium for launching serious games and recording and archiving participant's performances for the purposes of proving a variety of learning outcomes.

In addition, tools are becoming available that support the development of i3D content by a much wider range of contributors than was the case with, for example, simulation, Synthetic and Virtual Environments in the 1990s. Many of these tools – and the engines that bring their results to life – are made available by mainstream entertainment games companies such as Crytek (*CryEngine 1* and *2* and *SandBox* 1 and 2 from *FarCry* and *Crysis*), Valve (*Half-Life 2*) and id Software (*Quake*). Whilst many of the commercially-oriented tools and engines demand significant investment for commercially exploitable applications (i.e. applications other than modifications to a game for personal interest ("modding") or research and development), other, Open Source systems often permit licence-free development and distribution[7].

2.1 So Why Do We Need Guidelines Now?

One important and relevant study drawing attention to i3D user interface issues was conducted by Barnett and others at Boeing's St Louis facility (Barnett *et al*., 2000)[8]. Although a number of their conclusions had been known for some time prior to this, their paper added considerable weight to a growing concern in some quarters of the Human Factors community that the majority of VR and i3D proponents were concentrating excessively on technological issues, as opposed to meeting the needs of the end user. The same trend is evident today with early developments in serious games.

The project, reported at the 2000 Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), was performed in support of a virtual maintenance training concept for Boeing's *Joint Strike Fighter* (JSF) proposal. The Boeing team set out to evaluate the use of 3D Computer-Aided Design (3D CAD) models, implemented within a VE, as a low-cost partial replacement for physical mock-up aircraft maintainer trainers. Participants were required to carry out simple remove-and-replace maintenance procedures using 3D representations of JSF components. One of the results of the early part of this study was that users equipped with so-called "immersive" VR equipment, namely an HMD and spatially-tracked mouse (or "wand"), experienced longer training times than those provided with more conventional "desktop" interactive 3D training methods (Figure 4), and also showed diminished task performance.

[7] For an update on the availability and terms and conditions of use of commercial and Open Source game engines and toolkits, visit DevMaster.net (http://www.devmaster.net/engines/); over 280 engines were referenced on this site as of July, 2008.
[8] Barnett, B., Helbing, K., Hancock, G., Heininger, R. & Perrin, B. (2000), "An Evaluation of the Training Effectiveness of Virtual Environments", in *Proceedings of the Interservice/Industry Training, Simulation & Education Conference* (I/ITSEC; Orlando, Florida), November 27-30, 2000.

Of relevance to the present document, Barnett *et al*. noted that:

> *… as a result of … unique features of the VR[9], four of the participants commented that they* ***focused more on interfacing with the VR than with learning the task*** *…*
> [Author's emphasis]

It is for this very reason that a document containing basic HF guidelines is required at this point in time, especially with the surge of interest in serious games. Even though VR is, as stated earlier, still at the bottom of Gartner's "trough of disillusionment", there is early evidence that its comeback – long-awaited by some – may have already started. Proponents of so-called "immersive" VR technologies are becoming more and more conspicuous on the Web and at international serious games events (e.g. Figure 5).

Figure 4: Boeing JSF desktop virtual maintenance set-up (fuel valve manipulation).
Source: Boeing I/ITSEC Presentation (2000)

Even Gartner Inc. is helping to fuel a resurrection of sorts. Their 2007 Hype Cycle for Emerging Technologies[10] placed Virtual Environments / Virtual Worlds right at the top of the "peak of inflated expectations". However, some commentators have noted that Gartner's use of the terms "Virtual Environments" and "Virtual Worlds" refer not so much to i3D or simulation, as is the focus of this document, but to online virtual communities, such as *Second Life*. Nevertheless, the very mention of these terms in a Gartner Inc. report is likely to stimulate a partial revival of interest in technologies like those shown in Figure 5. Gartner also highlights the potential commercialisation of novel user interaction techniques, such as gesture recognition (examples given include the *Wii* interface (discussed later in the document) and Microsoft's *Surface* "multi-touch" system[11]).

Figure 5: Trimersion head-mounted display and instrumented weapon for gamers (left), Toshiba "Bubble Helmet", originally demonstrated in 2006 with Microsoft's *Flight Simulator* (middle) and Novint's $189.00 (August 2008) *Falcon* haptic (force/touch) feedback system (right).
Sources: www.gearlog.com, www.usatoday.com and home.novint.com/

[9] Poor field of view, poor depth perception, object distortions and object manipulation artefacts.
[10] Fenn, J., Raskino, M., Basso, M., Phifer, G., *et al*. (2007), "Hype Cycle for Emerging Technologies, 2007", Gartner Inc. Report ID Number: G00149712, July 2007.
[11] http://www.microsoft.com/surface/.

2.2 Why Guidelines for Games-Based Training Developers?

The current evolution in rich, interactive and dynamic media brings with it a unique set of Human Factors concerns, especially when exploiting gaming technologies for serious applications. Anecdotes (from researchers on both sides of the Atlantic) of working with some games companies have included reports of "not invented here" attitudes, or insular approaches to serious games design, even when part of a collaborative team. There is no doubt that the experience, intellectual property and assets these companies bring to the games-based learning or training arena are significant and invaluable. However, serious games are ***not*** mainstream entertainment games, and the same kind of marketing techniques, storyboarding and content design processes applied to entertainment titles may be totally inappropriate for organisations keen to exploit packages supporting education and training.

Games companies have to change. Not only must they accept the differences between serious and entertainment games, they must also accept that their target audiences – which may or may not consist of experienced gamers – are different. Furthermore, the design stages for serious games are different (this is especially true of the defence arena). Industrial and commercial Information Technology (IT) adopters work differently to their normal customer bases (and do not always respond favourably to over-selling of capabilities). End users may themselves want to effect basic changes to the delivered serious game via simplified editors, rather than return regularly to the source company for what may be expensive modifications. Finally, and most importantly, entertainment companies wishing to become involved in the serious games arena have to realise that they will be working with new, multidisciplinary team members outside of their normal in-house complement (these teams will, increasingly, include HF and pedagogy specialists). Therefore, accepting a commission and then "withdrawing to the trenches" to deliver an insular, home-grown solution sometime thereafter is **not** an option.

Consequently, these guidelines have been written to help introduce HF concepts and modes of thinking to games developers in the hope that caution will be exercised as the content and interactive elements of a serious game develop. Topics such as avatar behaviour, sensory and functional fidelity, the avoidance of distracting "wow" effects (appropriate in mainstream games, but not necessarily in serious games) and the sensible exploitation of interactive technologies are as important to i3D and serious games developers as they are to HF specialists.

Don't include it just because you can …
include it because it's crucial to the
success of the learning process.

2.3 Why Guidelines for Training System Procurers and End Users?

Early research for the UK Government's Department of Trade & Industry (DTI) by Stone (1996)[12] and Stone & Swann (2002)[13] set out to develop a simulation tool to demonstrate the fact that selling strategies in technologies such as i3D, VR or, today, serious games can have significant effects on the ultimate market potential. Selling costs can be very high at early, formative stages of the market, essentially because potential customers, or "adopters", know little about the technology and have to be educated – often at the expense of the pioneering producer. If selling organisations try to reduce costs by pressure-selling or cutting corners (for example, over-hyping the capabilities of a particular technology or by selling systems to customers who do not really stand to gain from the

[12] Stone, R.J. (1996), "A Study of the Virtual Reality Market", Unpublished Report Prepared for the Department of Trade & Industry (Communications & Information Industries Directorate).
[13] Stone, R.J. & Swann, P. (2002), "Virtually a Market? Selling Practice and the Diffusion of Virtual Reality", in Stanney, K.M. (Ed.), *Virtual Environments Handbook*, Lawrence Erlbaum Associates, Inc., Chapter 28.

purchase), then this adverse experience can reduce the market potential for the technology. Good selling practice at an early stage – **including investment in sector-focused and relevant case study demonstrators** – may be costly for the pioneering producer, but by gradually building a community of highly satisfied users, this can help to establish a strong market potential for the technology in the long run.

Unfortunately, the selling practices of many semi-academic, semi-commercial VR "centres of excellence" in the mid-1990s were in part responsible for the demise of the VR market in the late-1990s and from 2000 to 2003. Not only were there too many claims made relating to how VR could solve most, if not all human-computer interface problems, a good number of VR centres simply failed to understand the commercial demands of end-user companies. To make significant investments in such a new and high-risk technology, evidence was essential. Relying on irrelevant demonstrations (e.g. to sell VR to a petrochemical company using a surgical training study as a case study) was a sure-fire recipe to alienate big names in key market sectors. Many of those companies that did invest on the basis of early over-selling suffered the consequences. Indeed, part of the problem in trying to secure interest in serious gaming today stems from the fact that key market sectors have "had their fingers burned" by becoming involved far too soon in what turned out to be an unproven, costly and unreliable technology.

Simulators based on gaming and related i3D technologies will NOT solve all of the training requirements of a specific system and should always be considered as part of a blended solution, exploiting real-world facilities or equipment and other forms of media as appropriate.

For serious games and related i3D developments to be successful this time around, it is important that the end user or customer has some early knowledge of what is and is not possible, and what is and is not appropriate. These guidelines are designed to impart a small amount of knowledge to help achieve the aim of ensuring that customers are more informed than before, are aware of just some of the key issues in design and development and are no longer in a position to have to take the claims of selling organisations at face value.

2.4 Not Just Interactive Hardware … Why Guidelines for Human Factors Practitioners?

The guidelines contained herein do not only address interactive hardware, as was the preoccupation of many during the VR era. Whilst there is little doubt that the selection of inappropriate hardware for i3D applications can seriously compromise information uptake and learning from VE-based learning or training systems, as noted earlier in the Barnett *et al*. (2000) study, it is as important (if not more important) to introduce HF knowledge into the design of interactive content as well. Rich 3D worlds, sound effects and dynamic action – even simple haptic (force and tactile) effects, such as "rumble" forces in joysticks and gamepads, all contribute to today's game players' immersive experiences. Some of the effects can even induce quite strong proprioceptive[14] and reactionary behaviours on the part of the players – reeling back from the screen to "avoid" an incoming object, or head and torso movements – apparently "looking" around a virtual corner or door frame – or leaning into the turning direction of a simulated car or aircraft. Yet these players are not wearing immersive VR hardware, such as the items shown in Figure 5; they are reacting to the i3D content of the game with which they are playing via a basic keyboard, mouse and 19-inch screen!

[14] *Proprioception*: unconsciously perceived sensations relating to posture and movement, including translation, rotation and acceleration ("vestibular") information generated from the organs of the inner ear.

From a serious games perspective, only when an *integrated* human-centred design approach has been adopted during the design phases will a games-based simulation system deliver immersion, engagement, presence and believability to its end users. The illustration in Figure 6 emphasises the importance of ***not*** separating data display, data input and simulation content issues when designing Virtual Environments or serious games. The human operator's perceptual-motor skill sets and cognitive capabilities are highly honed subsystems which can only perform efficiently as an integrated whole. Forcing the human operator to perform a simulated task by introducing an item of advanced interactive technology in isolation, without early Human Factors consideration, will most likely result in failure. Indeed, whilst researching this very subject in 1988 (when considering the use of remote stereoscopic viewing systems), the author wrote that inconclusive results relating to the benefit of such technologies will probably continue …

> *… until researchers realise the importance of an* ***integrated*** *perceptual-motor approach to designing MMIs for remotely operated systems* [or i3D systems – author's insert]*, rather than assuming that technologies such as stereoscopic viewing will, in isolation, bring significant performance benefits ...*[15]

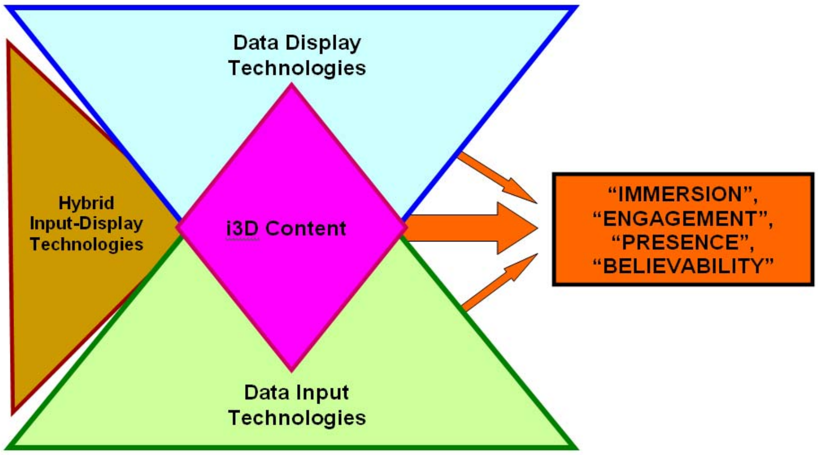

Figure 6: An holistic approach to i3D and serious games design. Human Factors knowledge MUST be exploited in all components on the left of the diagram to achieve the components on the right.

For example, using a single instrumented glove or hand-held / wrist-mounted spatial tracking system to control activities on a conventional flat computer screen is not to be recommended. Human proprioceptive and kinaesthetic[16] systems are likely to adapt poorly to the fact that incoming visual stimuli do not match the "expectations" generated by these conscious and unconscious processes. Put simply, under normal circumstances, the brain knows where one's real arm and hand are at any given time. If the visual system is receiving information relating to events that are not in scale with the real world – as one might find when controlling a virtual human, or "avatar" displayed on a standard TV or computer screen – then kinaesthetic or proprioceptive mismatches may occur. These mismatches may lead to performance degradation and/or frustration on the part of the end user, especially in tasks demanding *ballistic* movements (i.e. movements that, once initiated, cannot be controlled, as found with many sports activities).

---

[15] Stone, R.J. (1988), "Future Trends in MMI Design for Telerobotics in Hazardous Environments", CERT Discussion Meeting *Designing the Human-Machine Loop*, Toulouse, France, June, 1988.

[16] *Kinaesthesis*: the conscious perception of sensations relating to movement of the body and limbs, including forces exerted by the human muscular system.

The Nintendo *Wiimote* and *Nunchuk* controllers (shown in Figure 7) are a good illustration of this problem. Whilst these devices may provide considerable entertainment for gamers in home settings, their use as intuitive interactive control devices for serious games and other i3D applications is highly questionable, despite the findings of recent small-sample studies. Take, for example, a report in the medical training domain which resulted in considerable Internet news announcements (e.g. technology.newscientist.com, 19 January, 2008). The researchers reported that, on the basis of a sample of only 8 trainee doctors, playing with certain *Wii* games can improve a surgeon's performance in the operating theatre! One of the researchers even stated that: "the whole point about surgery is to execute small, finely controlled movements with your hands, and that is exactly what you get playing *Wii*". Surgical dexterity demands much, much more than the rather gross manual experiences delivered by games exploiting wrist and arm movements alone.

Figure 7: Nintendo *Wiimote* and *Nunchuk* in use.
Source: Edmonton Journal *(www.canada.com)*

To summarise then, inappropriate use of data display or data input devices, either in isolation or combined within an integrated interface, can seriously compromise any attempt on the part of the simulation designer to achieve engagement or believability (sometimes referred to as the "suspension of disbelief" – a term first coined by Samuel Taylor Coleridge in 1817 and applied more recently to the immersive goals of VR and mainstream entertainment games).

"Hybrid" input-display technologies refer to devices where display and control elements are evident within a single device. For example, controls exist that provide the end user with haptic feedback or some other form of sensory stimulus (e.g. confirmatory visual or auditory cueing), integrated within a multi-axis data input device, such as a mouse, joystick or other multi-axis controller. The Novint *Falcon* haptic (force/touch) feedback system, shown earlier in Figure 5, is a good example of a hybrid input-display technology.

To conclude this section, it should be stressed that, as well as a technological arena in desperate need of significant and regular Human Factors contributions, the i3D and serious games communities also have the potential to revolutionise the way the Human Factors specialists themselves conduct their research. One of the biggest problems facing those in the HF and Systems Engineering communities has been the absence of affordable, accessible tools supporting rapid and timely investigations into new equipment concepts, hypothetical scenarios, user interface designs, ergonomics prototypes, part-task training needs, and so on. In other words, uncomplicated tools that are usable in the defence and industrial arenas by more than just those with strong software or i3D competencies.

The serious gaming community looks set to provide those tools – not only under "free-for-research" licensing conditions, but, increasingly, as freely distributable, Open Source engines, many of which are emerging from academic institutions and defence research organisations[17]. The HFI DTC has, since 2004, been investigating the suitability of i3D and serious games technologies for concept demonstration and early HF assessment purposes.

[17] See also www.devmaster.net.

The early studies described within this document, together with those reported at recent international events, suggest that real-time simulation and serious games technologies look set to provide a credible alternative to more conventional early Human Factors investigations and experimental trials (not to mention scenario generation), especially at a time when defence material and personnel resources are stretched to the limit in support of Western coalition forces in many corners of the world. What is also becoming apparent is that the software tools and hardware resources necessary to produce the content and run-time functionality demanded by high-quality simulated environments are no longer the sole province of specialist companies.

The financial shackles imposed by the "supercomputer" and "black-box" vendors of yesteryear – especially the enormous start-up costs and year-on-year maintenance charges – have been broken. Today, games engine software and associated content development packages can be hosted on a reasonably-priced, yet powerful laptop, equipped with an appropriate graphics card and a joystick or games controller from a local high-street computer vendor. This means that the simulation community now has access to portable hardware and software products that can easily compete with their defence-procured counterparts, most of which – even today – still cost many hundreds of thousands of dollars.

Despite these important cautionary remarks, there is now a realisation that serious games *are* affordable, *can* deliver effective multi-agent simulations and *can* be modified by the end users at a mere fraction of the cost it takes, for example, just to import a new 3D military vehicle model into some of the world's legacy military synthetic environment (SE) trainers. Web articles also point anecdotally to evolving expectations on the part of new recruits to the Armed Forces that gaming technologies will form a part of their early and ongoing training. The gaming skills of future generations of military personnel cannot, therefore, be ignored:

> "It is worth noting that given the date scheduled for completion of the aircraft [*Joint Strike Fighter* – author's insert], the future initial maintenance trainees are today 11 years old and the future initial pilots of the aircraft are 8 years old. These kids are the *PlayStation* and *Xbox* generation. They know their way around 3D gaming technologies as never before. It seems logical that as they grow up and graduate to their professional military and commercial careers, the best way for them to learn and grow in their jobs is through the compelling communicative power of hands-on interactive 3D learning".

Right Hemisphere Product Graphics Management for Interactive 3D Training White Paper (2005)

Human Factors is the study of the relationship between the human and his or her working environment.
It makes no difference if the working environment is real or virtual.

Section 2.0
Background: Why Human Factors Guidelines for i3D and Games-Based Training?
Key Points Summary

- **The "vision" of *Virtual Reality* (VR) in the late 1980s and 1990s – in particular achieving "immersion" within computer-generated environments using wearable or user-enclosing interactive technologies – was not fulfilled, due to a combination of commercial, technology-push and human factors issues.**
- **Real-time engine and content development technologies underpinning entertainment games have captured the attention of a wide range of training and education specialists.**
- ***Serious games* go beyond entertainment to deliver engaging, familiar, affordable and accessible interactive media to support a wide variety of learning applications.**
- **Human Factors guidelines are required now to ensure that lessons learned from the VR era of the 1990s are adopted early in the development of this new interactive 3D (i3D) arena.**
- **Human Factors guidelines will help games development companies understand the importance of integrating knowledge about the end user early on in the design process (remembering that serious games users may not be accomplished entertainment "gamers").**
- **Games developers must only deliver interactive media that is relevant and appropriate to the learning, training, or educational process – no more, no less. "Special effects" of no relevance to the task and context MUST be avoided.**
- **Human Factors guidelines will also help end users and their organisations to become "informed customers" and to play more critical and proactive roles in the development of products for their particular area of application.**
- **Human Factors guidelines will also support the exploitation of serious games and related i3D technologies for experimental research involving virtual prototypes and scenarios.**
- **ONLY when an INTEGRATED human-centred design approach has been adopted (addressing the appropriateness of simulation content, interactive input and display technologies) will a serious game or i3D product deliver immersion, engagement, presence and believability.**
- **Serious games and related i3D technologies will NOT solve all of the training requirements of a specific system or applications and should always be considered as part of a blended solution, exploiting real-world facilities or equipment and other forms of media as appropriate.**

Section 2.0 – Main References

Barnett, B., Helbing, K., Hancock, G., Heininger, R. & Perrin, B. (2000), "An Evaluation of the Training Effectiveness of Virtual Environments", in *Proceedings of the Interservice/Industry Training, Simulation & Education Conference* (I/ITSEC; Orlando, Florida), November 27-30, 2000.

Fenn, J., Raskino, M., Basso, M., Phifer, G., *et al*. (2007), "Hype Cycle for Emerging Technologies, 2007", Gartner Inc. Report ID Number: G00149712, July 2007.

Stone, R.J. & Swann, P. (2002), "Virtually a Market? Selling Practice and the Diffusion of Virtual Reality", in Stanney, K.M. (Ed.), *Virtual Environments Handbook*, Lawrence Erlbaum Associates, Inc., Chapter 28.

3.0 Real-World Examples

In many instances of applications demanding innovative approaches to equipment and systems design or – increasingly – training programmes, it is necessary to analyse, in detail, how end users perform their tasks and exercise their experience and skills in real operational settings. Task analysis is a key human-centred process by which one can formally describe the interactions between a human and his or her working environment at a level appropriate to a pre-defined end goal.

Without a properly executed task analysis, systems or items of equipment may be designed or specified that fail to take account of the most relevant components of human knowledge, skills and attitudes. This is especially true for training régimes exploiting simulation and serious games technologies. Task analyses are crucial prerequisites, not only to the design processes leading to appropriate content and interface technologies, but also to the highlighting of factors central to the definition of learning outcomes, learning metrics and other pedagogical issues.

It is not the aim of this document to be prescriptive with regard to the most appropriate form of task analysis to adopt for developing Human Factors inputs to i3D and serious games development projects. Indeed, there are many techniques for carrying out a task analysis, yet no single, proven "magical" formula exists, particularly for this field of endeavour. Readers from the HF community will no doubt have their preferences. The HFI DTC has, since its launch in 2003, been developing both hierarchical and cognitive task analysis tools and those interested in this topic are recommended to visit the DTC's website (www.hfidtc.com) for further information[18].

The type of analysis employed, then, often depends on a range of factors, including the Human Factors specialist involved, whether or not the task exists in reality or has yet to be designed, the goal of the analysis, any constraints imposed by the analysis environment and, of greatest importance, the support and input of the end users and subject matter experts (SMEs).

Gaining access to the end users and SMEs, particularly in operational or field training settings, is always difficult, particularly throughout the defence community. When opportunities arise, they are typically characterised by short-duration sessions of quite intense activity, leaving the Human Factors specialist with little time to record relevant data for use in subsequent task analyses or other human-centred design processes. This problem is particularly acute where the outcome of a project is to take the form of a simulation or Virtual Environment.

When there is a need for rapid results from analyses, the more popular techniques involve observational and interview techniques, often supplemented with video and audio records (as have been exploited for many of the HFI DTC case studies mentioned throughout this document). Other techniques employ quite sophisticated computer-based solutions, from mixed media data recording (video, computer keystrokes, physiological parameters, voice, etc.) to simulations based on models of human physical and psychological performance.

As stated at the outset, this document aims to help make the i3D and serious gaming community more aware of fundamental human interface issues, such as content, fidelity and interactive technologies. Before tackling these issues, however, it is important to understand what to look for when presented with an opportunity to undertake an observational analysis in the field. In addition to the project outlines presented in Sections 3.0.1 to 3.0.4, below, Figures 13, 14, 15 and 16 (presented on pages 25 and 26) summarise the key observational factors recorded during end user observational sessions undertaken in support of each of them.

3.0.1 **Minimally Invasive Surgical Trainer** (MIST; Figures 8 and 13)**.**

The MIST system evolved from a project sponsored by the Wolfson Foundation and UK Department of Health, the aim of which was to assess the potential of emerging Virtual Reality technologies to deliver cost effective technology-based training for future surgeons. MIST was an early example of the successful outcome of an HF task analysis undertaken in support of an i3D part-task skills trainer, in conjunction with surgical subject matter experts. It was possible to isolate eight key task sequences common to a wide range of laparoscopic cholecystectomy (gall bladder removal) and gynaecological interventions and then define how those sequences might be modified or constrained by such factors as the type of instrument used, the need for object or tissue transfer between instruments, the need for extra surgical assistance, and so on. The close "coupling" (see Section 4.4) between the surgeon and the patient, via the laparoscopic instruments, drove an early decision to implement replica instruments, suitably modified to provide digital position and rotational inputs into the computer.

Uniquely, MIST fosters laparoscopic skills *not* by training on virtual human bodies, but on carefully selected task "primitives" (e.g. spheres, blocks, cylinders and wireframe task volumes of low visual detail, or low "physical fidelity" – see Figures 8, 20 and Section 3.1), each designed following a psychological breakdown of the perceptual and motor behaviours of observed surgeons[19]. MIST

[18] See also: Stanton, N., Salmon, P., Walker, G., Baber, C., & Jenkins, D. (2005), "Human Factors Methods: A Practical Guide for Engineering and Design", Ashgate (December 2005).
[19] Stone, R.J., & McCloy, R. (2004), "Ergonomics in Medicine and Surgery", *British Medical Journal*, 328 (7448), 08 May, 2004, 1115-1118.

was the first VR surgical training product of its kind to be adopted worldwide for the *objective* assessment of surgical skills in laparoscopic cholecystectomy and gynaecology[20].

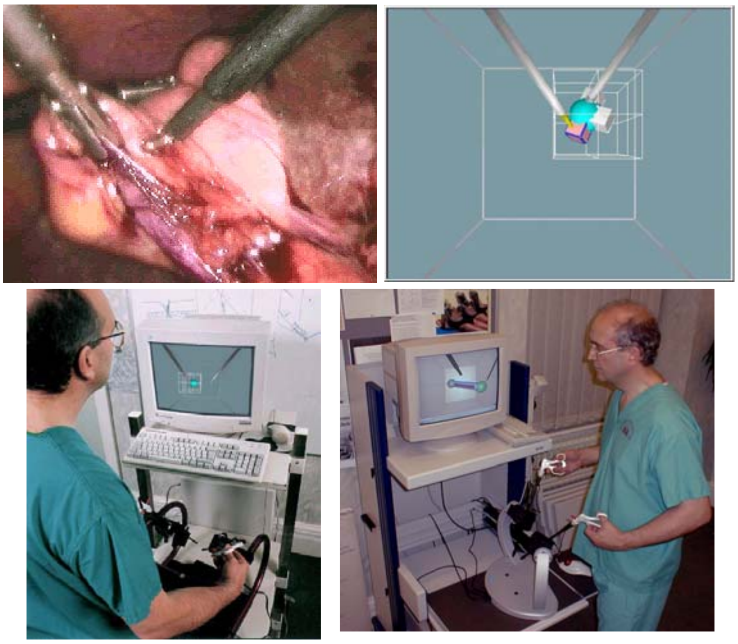

Figure 8: MIST task decomposition example (top images) and final surgical trainer (bottom images).
Source: Author's Image Archive

3.0.2 Early Surgical / Clinical Procedural Trainers (Figures 9 and14).

Closely related to the early aspirations of the MIST system are two defence medical projects with which the HFI DTC has been closely involved. The need in these examples was defined by defence surgical teams who expressed a desire to exploit low-cost, part-task simulations of surgical procedures for combat casualty care, especially for refresher or *just-in-time* training of non-trauma surgeons who might be facing frontline operations for the first time. The two projects were the *Interactive Trauma Trainer* (ITT)[21], developed with the serious games company Trusim, and *Pulse!!*, a US virtual healthcare project funded by the Office of Naval Research[22]. Early HF observations and interviews contributed not only to the definition of learning outcomes and

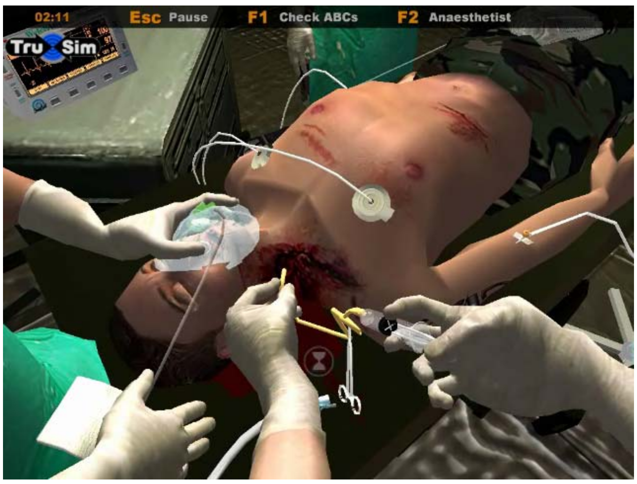

Figure 9: Screen shot of ITT demonstrator.
Source: Author's Image Archive

[20] MIST, now known as *Procedicus MIST*, is marketed by the Swedish company Mentice (www.mentice.com).
[21] Stone, R.J., & Barker, P. (2006), "*Serious Gaming*: A New Generation of Virtual Simulation Technologies for Defence Medicine & Surgery", *International Review of the Armed Forces Medical Services*, June 2006, 120-128.
[22] *Pulse!!* is coordinated by Texas A&M University, Corpus Christi; www.sp.tamucc.edu/pulse/.

metrics, but to key design features of the simulations and human-computer interfaces. In the case of the ITT, one of the early decisions made, based on observing defence surgery subject matter experts perform, was that the final simulator would not take the form of a surgical *skills* trainer (such as MIST, described above). Rather than replicate the basic surgical handling skills the user would already possess (e.g. instrument usage and patient "hands-on" checks), the simulator would enhance the *decision-making* skills on the part of the surgeon – the casualty's life would be lost within 5 minutes if appropriate decisions were not taken or appropriate procedures were not applied.

Consequently the ITT not only exploits games engine software technology, it also exploits a typically simple gaming interface – mouse control for viewpoint change, option selection and instrument acquisition. The HF analysis helped to define the end shape and form of the ITT, applying high fidelity effects only where they would add value to the surgeon's task (although see Sections 4.3 and 6.3). The analysis also ensured that highly dextrous tasks (e.g. the use of a laryngoscope, stethoscope, intubation tubes, Foley's Catheter, and so on – as shown in Figure 9) were committed to clear and meaningful *animation* sequences, rather than expecting the surgical users to interact with 3D versions of these via a complex input-output device with limited or no haptic feedback.

3.0.3 Desktop Minigun Trainer (Figures 10 and 15)**.**

This experimental "desktop" game-based trainer, again designed from the outset based on HF observations, has also been developed as part of the HFI DTC research programme. The aim behind this work was to establish whether or not games-based technologies could offer a credible onboard "desktop" alternative to the training of close-range weapon aimers within dedicated (and costly) land-based ranges or simulators.

Figure 10: HFI DTC desktop Minigun trainer.
Source: Author's Image Archive

Two observational sessions onboard Royal Navy (RN) vessels defined important task sequences, such as arming and safeing the weapon, issuing important verbal statements relating to safety and carrying out directed visual scanning of the outboard scene. The close "coupling" (see Section 4.4) between the aimer and the weapon dictated the need (a) for a method of simulating the "pulling" of the body posture towards the weapon to bring the ring sight closer to the head, ready for target engagement, (b) for a replica firing interface with procedural arming/safeing components, and (c) for a bespoke, electromechanical control interface to reproduce the unique, torque-induced "kick-down" effect when the weapon is fired (an important "task modifier"). Moving the simulated weapon in azimuth and elevation is accompanied by visual changes in outboard scenery via a "window-on-the-world" display (as opposed to a helmet-mounted or large-screen projection display). This implementation was chosen not only because VR-like "immersion" was not warranted from an HF perspective, but also because of the cost and negative experiences on the part of the RN with previous HMD solutions for close-range weapons training.

3.0.4 Explosive Ordnance Search, Disposal and Incident Planning Tool (Figures 11 and 16)**.**

This HFI DTC project focuses on the development of virtual rural and urban databases to demonstrate a variety of i3D features and control options relating to possible future exploitation of gaming technologies to incident planning and search/disposal training. Dealing with Explosive Ordnance Disposal (EOD) incidents, both at home and abroad, involves coordinating a wide range of assets, including logistics support vehicles, human avatars, explosive ordnance device (EOD) detection equipment and remotely controlled EOD removal systems. It has been suggested that using i3D technologies will improve the spatial awareness of specialist personnel, especially in relation to the deployment of human and robotic assets and to their threat and safety assessments.

In stark contrast to some of the other demonstrators above, this has been developed more in the form of a procedural trainer, based on the *loose coupling* (see Section 4.4) between the Army participants and the wide area scenarios they are typically presented with. The results of observations conducted at UK EOD search training sites defined the need for a flexible training and planning solution, such that search and disposal strategies could be presented both in a classroom set-up – by displaying the rural scene in a third-party "bird's eye" view (also known as *exocentric* – see Section 4.3) – and as a first-person (or *egocentric*) trainer.

The former requirement enabled the progress of the virtual search and disposal personnel (or *avatars* – discussed in Section 6.5), to be animated to a greater extent, particularly in the case of the main route and flanking parties. The latter requirement drove the need for very high visual detail (i.e. high *physical fidelity* – discussed in Section 3.1) in the virtual scene in order to support the realistic concealment by both natural and man-made features of explosive ordnance, command wires, pressure pads, and so on. From an end user interaction perspective, the exocentric presentation would require quite simplistic data inputs, triggering the animated motion of the avatar teams to their next location and allowing simple scene scanning. The egocentric presentation would require a slightly more complex interface, supporting local motion, detailed scene scanning, both visual and via the operation of specialist, hand-held detection equipment. In both cases the coupling between operator and task is still quite loose, as a result of the wide search area and absence of constraining physical equipment. An important exception to this would be the close coupling between the remotely-operated EOD vehicle operator and his or her console (Figure 12).

Figure 11: Scene from EOD planning / training tool.
Source: Author's Image Archive

Figure 12: Wheelbarrow EOD vehicle control console.
Source: Defence Image Database
CROWN COPYRIGHT

At the time of writing, this search and disposal asset has not been implemented in the EOD Planning Tool. However, it is highly likely that once it is, HF consideration will need to be given to whether or not commercial off-the-shelf (COTS) interactive devices will be sufficient to reproduce the main control and display elements provided to EOD operators located within one or more logistic support vehicles, as shown in Figure 12.

Throughout these examples, a number of important topics of Human Factors interest become evident that relate to one of the main goals of this document; namely to draw attention to a range of

HF issues that warrant consideration when undertaking task analyses or when presented with observational records of end user activities. To be expanded upon in subsequent sections, they are:

Task Issues

(e.g. skills *vs*. cognition, fidelity, knowledge, skills and attitudes, exocentric *vs*. egocentric frames, "task modifiers" and task coupling),

Interaction Issues

(e.g. replica/bespoke vs. "conventional" or COTS interactive technologies), and

Context Issues

(e.g. fidelity, "task modifiers", virtual human (or avatar) representations).

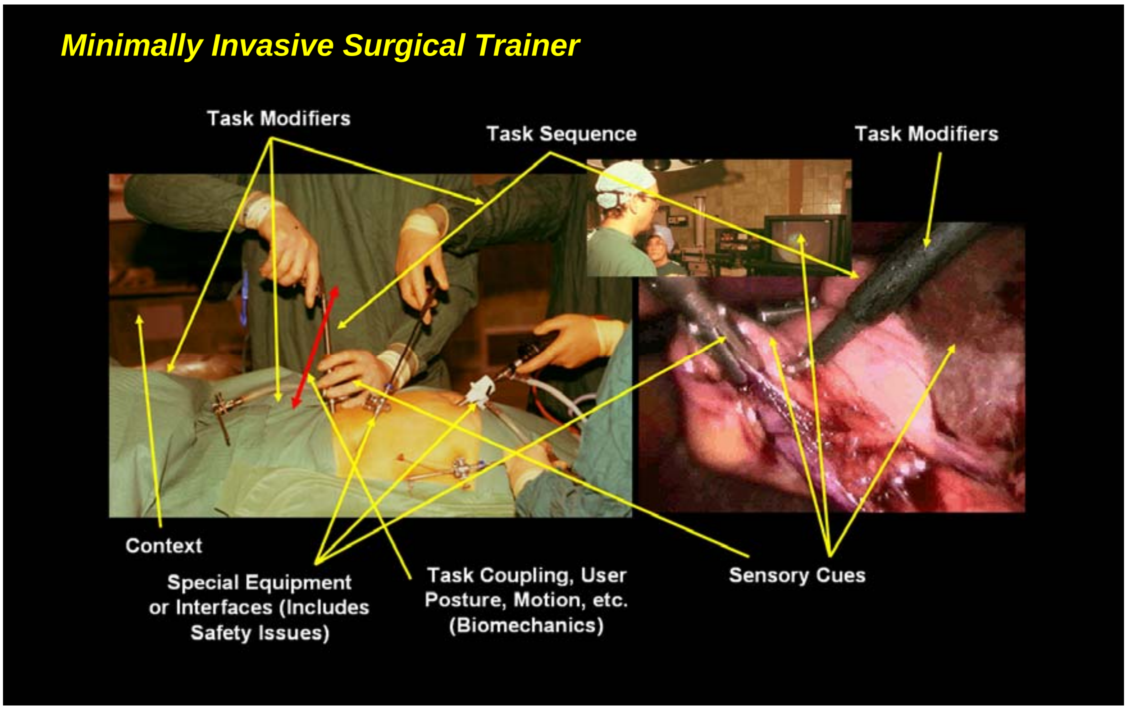

Figure 13: Observational features underpinning Minimally Invasive Surgical Trainer (MIST) development.
Source: Author's Image Archive

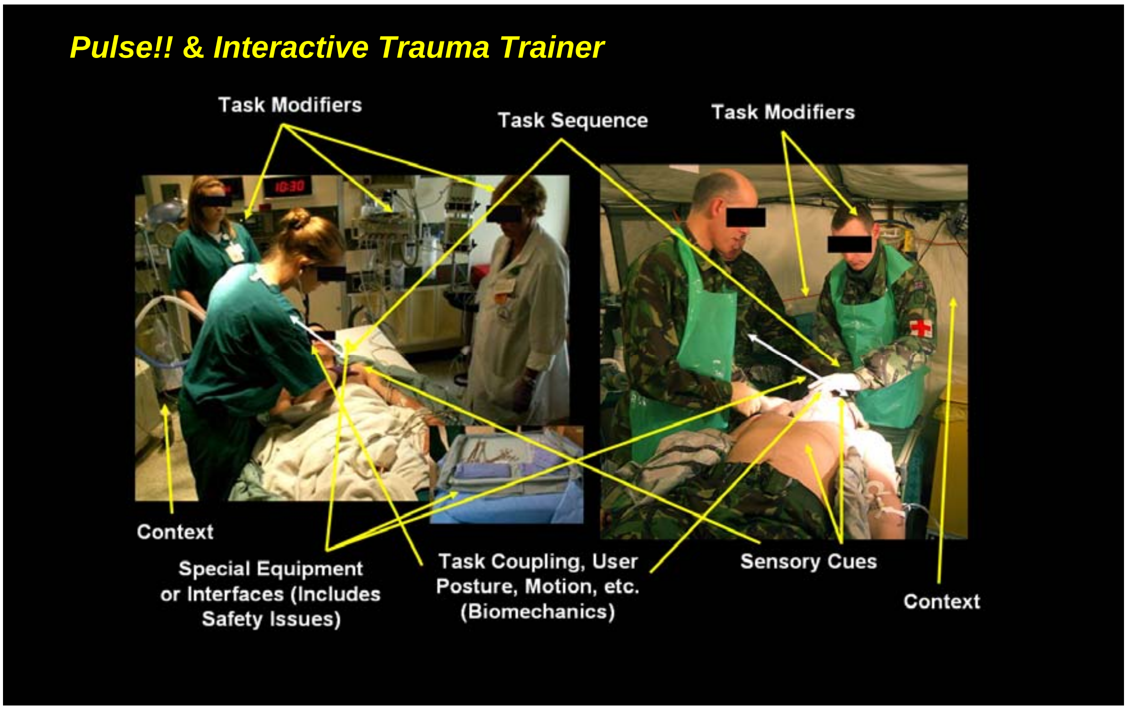

Figure 14: Observational features underpinning early *Pulse!!* Virtual Healthcare System and Interactive Trauma Trainer development.
Source: Author's Image Archive

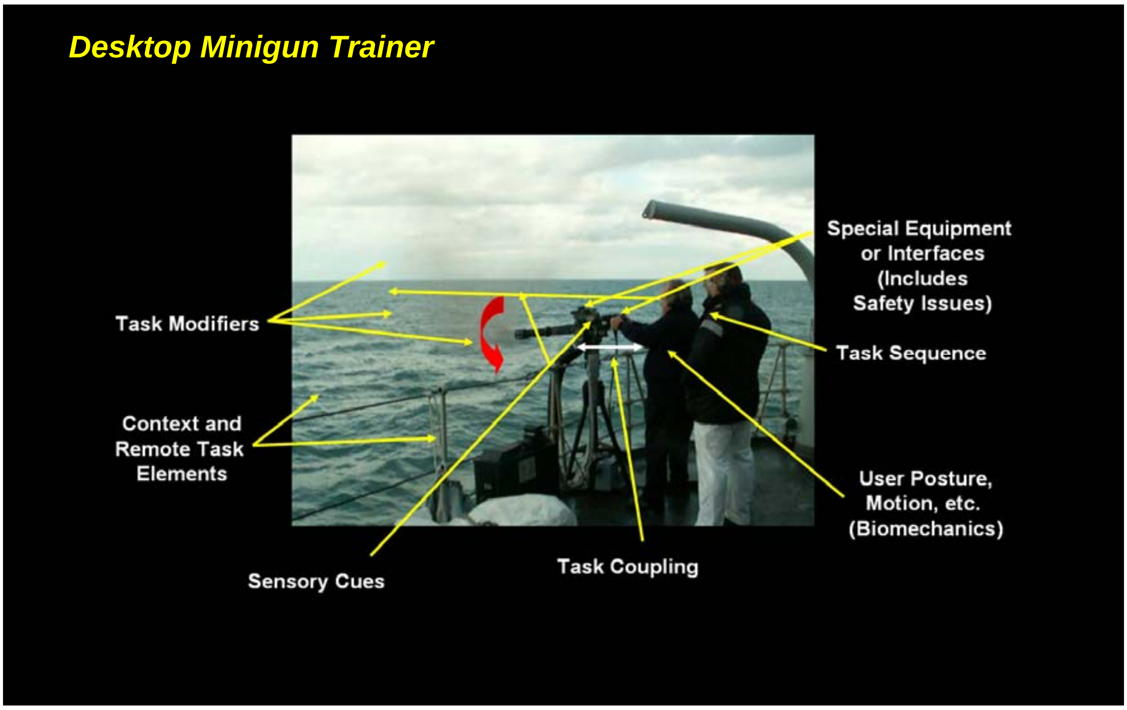

Figure 15: Observational features underpinning Minigun "Desktop" trainer development.
Source: Author's Image Archive

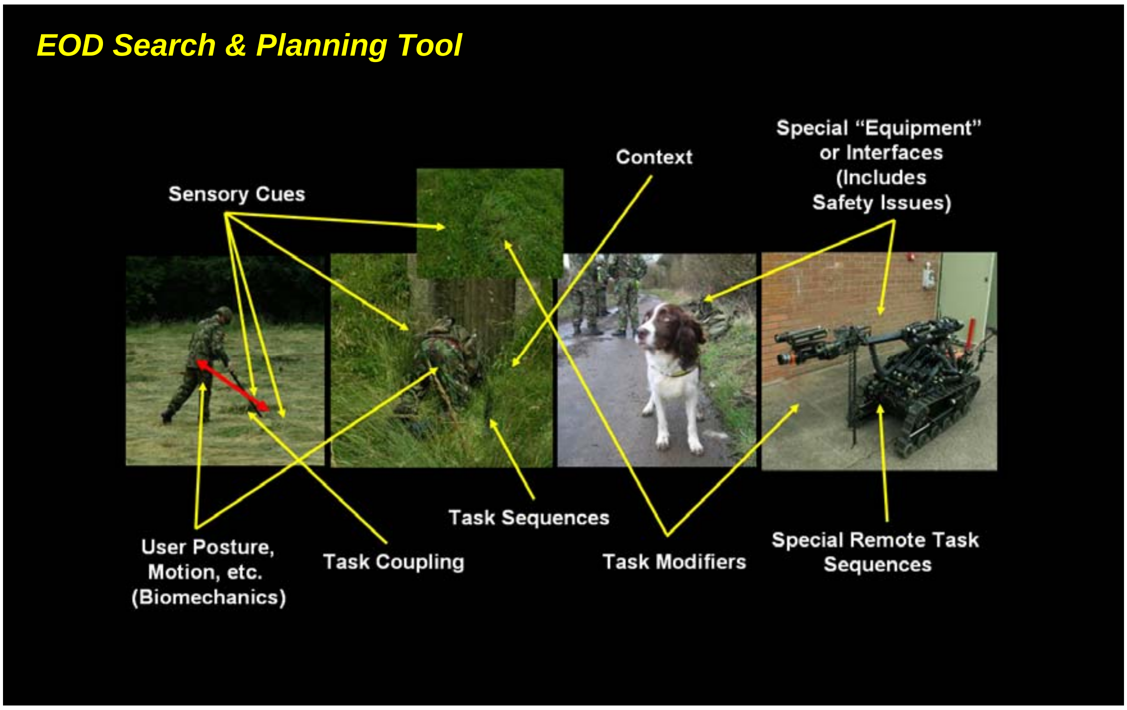

Figure 16: Observational features underpinning early explosive ordnance search & disposal training / planning system demonstrator.
Source: Author's Image Archive

3.1 Real-World Observations & Relevance to Fidelity – Some Introductory Comments

In very general terms, *fidelity* is a term used to describe the extent to which a simulation represents the real world, including natural and man-made environments (Figure 17), systems and, increasingly, participants or *agents*. However, when applied to simulation, it becomes apparent from the literature that there are many variations on the theme of fidelity.

Figure 17: Real (upper) and virtual scenes from *Project Gotham Racing 3* (*Xbox*).
Source: www.schrankmonster.de

Physical fidelity, or *engineering* fidelity (as coined by Miller in 1954[23]), relates to how the Virtual Environment and its component objects mimic the appearance and operation of their real-world counterparts.

In contrast, *psychological* fidelity can be defined as the degree to which simulated tasks reproduce behaviours that are required for the actual, real-world target application. Psychological fidelity has also been more closely associated with positive *transfer of training* than physical fidelity and relates to how skills and/or knowledge acquired during the use of the simulation – attention, reaction times, decision making, memory, multi-tasking capabilities – manifest themselves in real-world or real operational settings.

In many examples of simulation design it has become apparent that physical and psychological fidelities do not necessarily correlate well – more and more physical fidelity does not necessarily guarantee better psychological fidelity. In Figure 18, for example, can the same learning and skills transfer (psychological fidelity) be achieved by exploiting the lower physical fidelity virtual human anatomy in this sequence (i.e. images 1 or 2), or those of higher physical fidelity (4 or 5, with associated higher costs and longer development times), or something in between?

Establishing the components of a task that will ultimately contribute to how psychological fidelity is implemented within a simulation is not an exact science[24]. Observational task analyses need to be conducted with care if those human performance elements of relevance to defining psychological fidelity are to be isolated effectively.

Recent experience in developing serious games or Virtual Environments for part-task training applications (in defence and medical sectors, at least) suggests that, when observing tasks, there are four key classes of fidelity to be aware of, each of which impact on defining the ultimate physical and psychological attributes of the simulation and each of which will be discussed in more detail in subsequent sections of this document. They are:

- **Task Fidelity -** the design of appropriate sensory and behavioural features into the end user's task that support the delivery of the desired learning effect.
- **Interactive Technology "Fidelity" -** defined by real-world task coupling observations, interactive technology fidelity is the degree to which input (control) and display technologies

[23] Miller, R.B. (1954). "Psychological Considerations in the Designs of Training Equipment", Wright Air Development Center, Wright Patterson Air Force Base, Ohio.
[24] Tsang, P.S. & Vidulich, M. (2003), "Principles and Practice of Aviation Psychology", *Human Factors in Transportation Series*, Lawrence Erlbaum Associates.

need to be representative of real life human-system interfaces and, where they do not, the careful management of control-display mapping and acknowledgement of human stereotypes. Understanding the benefits/limitations of virtual *vs*. real control set-ups.

- **Context Fidelity** - the design of appropriate "background" sensory and behavioural detail (including avatar/agent styles and behaviours) to complement – and not interfere with – the task being performed and the learning outcomes.
- ***Hypo*- and *Hyper*-Fidelity** - the inclusion of too little, too much or inappropriate sensory and/or behavioural detail (task, context and interaction systems) leading to possible negative effects on serious game/simulation performance and on knowledge or skills transfer.

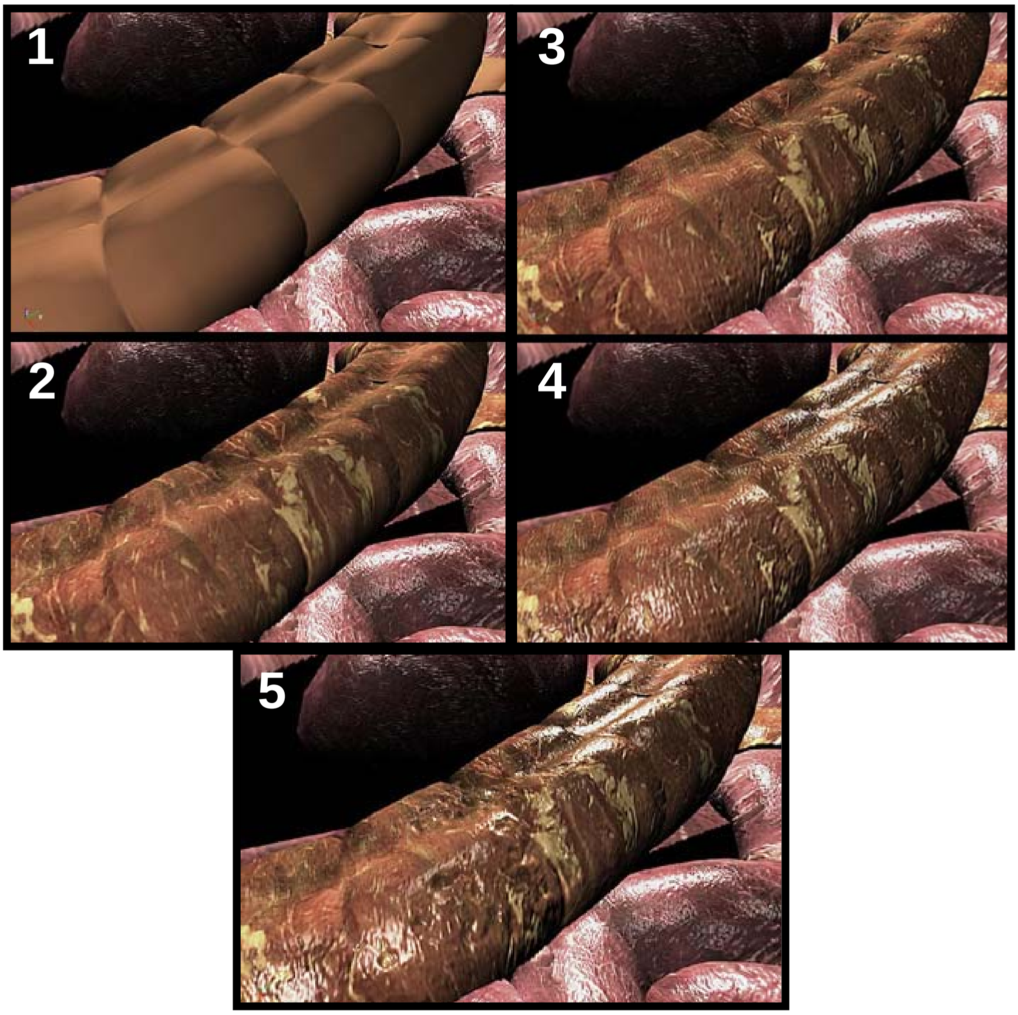

Figure 18: Different physical fidelities, same psychological fidelity?
Source: Author's Image Archive

Section 3.0
Real-World Examples
Key Points Summary

- **A Human Factors task analysis is an ESSENTIAL early component of a serious game/i3D product/prototype development process.**
- **There are a variety of task analysis techniques available – the choice of which technique is appropriate for which application will often depend on the analyst involved.**
- **Whenever possible, affording the analyst opportunities for "hands-on" experience is to be recommended (depending, of course, on such issues as task complexity, health and safety, impact on a training régime's resources, etc.).**
- **To date, guidelines appropriate to interpreting the results of task analyses, particularly those based on in-the-field observational sessions and where the end goal may be a serious games/i3D system, have not been made available under a single cover.**
- **Task analyses will help support early design decisions relating to whether the serious game/i3D- based trainer is anticipated to support perceptual and motor skills development and/or whether the aim is to foster domain-specific decision-making (cognitive) capabilities.**
- **Task analyses will also support early decisions relating to the appropriateness of control and display technologies for the end user – will commercial-off-the-shelf (COTS) technologies deliver sufficient interactivity, or does the application demand a bespoke solution (possibly based on physical mock-ups or redundant, real-world devices)?**
- **Task analyses will also support early decisions relating to the correct "blend" of *physical* and *psychological* fidelities, bearing in mind that more and more physical fidelity (i.e. how well the game or i3D environment mimics the real world) does not necessarily guarantee better psychological fidelity (i.e. how well simulated tasks and contexts reproduce and foster specific learning behaviours that are required for the real-world application).**

Section 3.0 – Main References

Miller, R.B. (1954). "Psychological Considerations in the Designs of Training Equipment", Wright Air Development Center, Wright Patterson Air Force Base, Ohio.

Stanton, N., Salmon, P., Walker, G., Baber, C., & Jenkins, D. (2005), "Human Factors Methods: A Practical Guide for Engineering and Design", Ashgate (December 2005).

Stone, R.J., & McCloy, R. (2004), "Ergonomics in Medicine and Surgery", *British Medical Journal*, 328 (7448), 08 May, 2004, 1115-1118.

4.0 Task Design Issues & Task Fidelity

4.1 i3D or Games-Based Technologies for *Skill* or *Decision* Training Tasks?

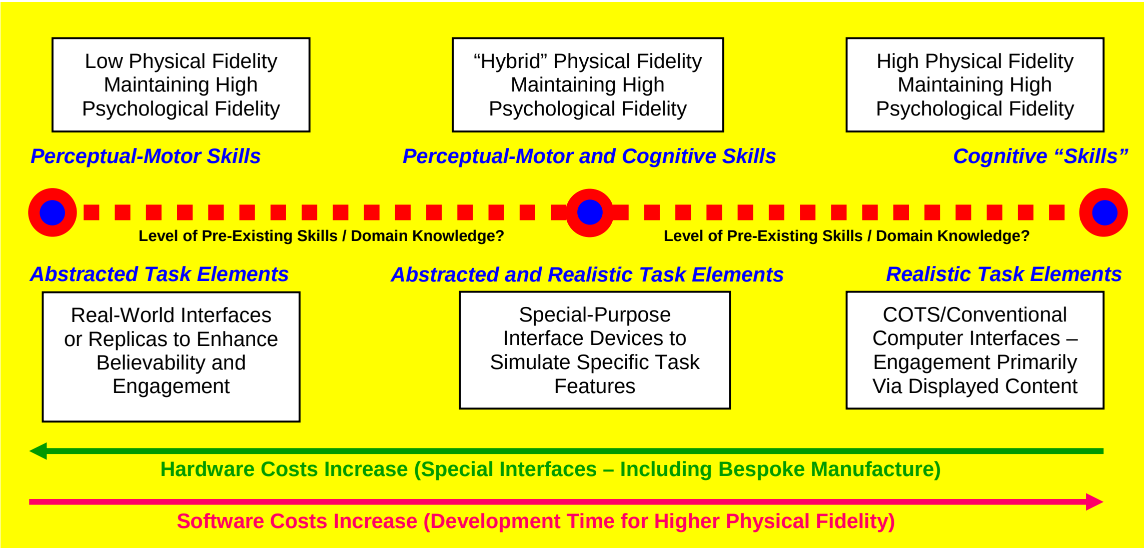

Figure 19: A suggested perceptual-motor / cognitive skills "continuum" relevant to i3D and serious games part-task training systems design.

As was emphasised in Section 2.4 (see also Figure 6), only when an *integrated* human-centred design approach has been adopted during the design phases will an i3D games-based simulation system deliver immersion, engagement, presence and believability to its end users.

Building upon this, Figure 19 presents a design continuum based on the experience of applying i3D and serious games technologies to a variety of real-world training domains, such as those described earlier. In essence, the continuum proposes that, to achieve a successful learning outcome when developing part-task simulators, the design of the simulated tasks and the interaction with those tasks should take into consideration:

(a) whether the task to be trained is fundamentally **perceptual-motor** (e.g. skills-based) or **cognitive** (e.g. decision-based) in nature (or a combination of the two), and
(b) whether or not all or only a percentage of the members of a target audience possess pre-existing (task-relevant) perceptual-motor skills and domain knowledge.

The impact of these issues on physical and functional fidelity (as defined in Section 3.1) is of considerable importance, as is their impact on such issues as the choice of hardware and software and, of course, developmental costs. Task analyses, supplemented with real-world observations and briefings or interviews, should strive to uncover what pre-existing skills and domain knowledge already exist, together with the experience and attitudes of end users to computer-based training technologies.

To illustrate some of the issues contained within Figure 19, the real-world experiences outlined in Section 3.0, together with other examples to back up the claims made, will now be described in more detail. Turning first to the left-hand extreme of the continuum, experience has shown that, when considering i3D hardware and software solutions, simulators designed to foster *basic perceptual-motor skills* should, in the main, rely on the end user's interaction with simplified, abstracted virtual tasks (i.e. low physical fidelity), as long as the Human Factors task analysis and/or observations conducted in the real world support the fact that, in doing so, high psychological fidelity is preserved. The continuum also suggests that, to enhance the end user's "belief" in the simulator and its abstracted training content, or to ensure the simulator establishes an early degree of credibility and acceptance on the part of its end users, the use of interface devices representative of those used in the real world should be given serious consideration.

A good example of this is the MIST "keyhole surgery" trainer, as described in Section 3 (see also Figures 8 and 13), where visually and functionally simplistic objects were presented to surgical trainees – graphical spheres, cubes, cylinders, wireframe volumes and so on. At the time of development of the MIST trainer, to attempt to build an anatomically and physiologically accurate simulation of the liver, gall bladder and associated structures would have been extremely expensive and would have necessitated the use of a top-of-the range graphics "supercomputer".

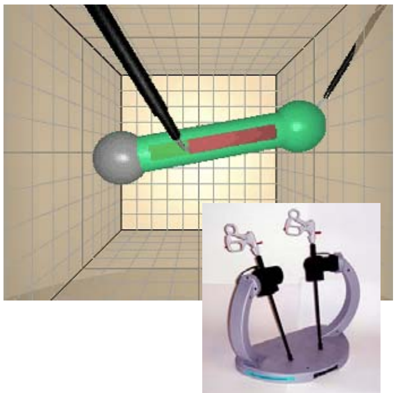

Figure 20: MIST task fidelity and replica instrument frame.
Source: Author's Image Archive

Furthermore, earlier experience with surgical SMEs suggested that, even with current software tools and graphics computer hardware, it was highly unlikely that appropriate levels of realism could be achieved in models of human anatomy, leading to distractive and unbelievable experiences on the part of specialist surgical trainees. This is still an issue, even with today's computing power and simulation software tools. Interaction with the low physical (but high psychological) fidelity elements of MIST was achieved using a built-for-purpose laparoscopic instrument frame, as shown in Figure 20. Early feedback from the users of MIST confirmed that the provision of a realistic instrument frame did much to accelerate their acceptance of MIST as a surgical skills trainer.

A similar situation evolved during the early design stages of the Desktop Minigun Trainer, also described in Section 3 (see also Figures 10 and 15). Again, the graphical content of the trainer was kept reasonably simple, as the observational analyses dictated that the physical procedures undertaken to make the weapon ready for firing, plus the initial firing experience itself, were of greater importance to early training objectives than engaging targets. Hence the early design process focused more on the electro-mechanical features of the replica weapon interface, as shown in Figure 10, than on the features of the naval Virtual Environment.

In contrast, and considering now the right-hand extreme of the continuum in Figure 19, the Interactive Trauma Trainer described earlier was designed following early observational analyses based on a simulated intubation and cricothyroidotomy[25] intervention using a cadaveric specimen and (as shown in Figures 14 and 21) staged procedures using volunteers at a field hospital exercise. The outcome of these analyses confirmed that the more dextrous tasks observed (e.g. Airway-Breathing-Circulation (ABC) checks, use of catheters, syringes, laryngoscope, stethoscope, intubation tubes, Foley's Catheter, etc.) should be committed to clear and meaningful *animation* sequences. It was confirmed by SMEs that trainee trauma surgeons would already be competent in handling standard items of medical equipment (with the possible exception of a laryngoscope – in which case, the intubation process would be conducted by a more experienced member of the team). Therefore, incorporating commercial off-the-shelf (and to a large extent, unproven) interface technologies that attempted to reproduce the look and feel of surgical instruments, or the sensation of "hands-on" interactions with the patients, would have been both risky and costly, not to mention unnecessary from a Human Factors perspective.

---

[25] An emergency airway established by making an incision between the thyroid cartilage and the uppermost ring of the trachea, thereafter inserting an appropriately-sized endotracheal tube.

The ITT, therefore, was designed to deliver *decision-based training* with the aim of enhancing or refreshing the *knowledge* of those defence surgeons being deployed on operations – many of whom may not have had prior exposure to trauma incidents and procedures. In order to foster the correct decision-making behaviours under the pressure of time, the ITT presents trainees with high physical fidelity scenes of the hospital tent environment. At certain stages throughout the 5-minute virtual life-saving procedure, multiple-choice questions are displayed relating to procedures such as blood testing and fluid administration. Medical instruments are also displayed to a high level of physical fidelity, as are the animations depicting their application to, and effect on the virtual casualty. However, to interact with these high physical fidelity items, the end user only has to undertake simple mouse movements and mouse button clicks, indicating which item he or she requires and where he or she wishes to apply that item.

Figure 21: Image taken of patient preparation activities during field hospital observation opportunity.
Source: Author's Image Archive

The term "hybrid" physical fidelity, as shown in the middle of the continuum in Figure 19, refers to instances where a task analysis highlights the need for a simulator to possess higher physical fidelity in one sensory attribute over another. In such a case, it may become necessary to develop, procure and/or modify special-purpose interfaces in order to ensure the stimuli defined by the analysis as being essential in the development of skills or knowledge are presented to the end user using appropriate technologies. Take, for example, a medical (mastoidectomy[26]) simulator developed as part of a European Union-funded project called IERAPSI[27]. Here, the task analysis undertaken whilst observing ear, nose and throat (ENT) surgeons, together with actual "hands-on" experience using a cadaveric temporal bone, drove the decision to adopt a hybrid physical fidelity solution based on:

(a) a simplified visual representation of the temporal bone region (omitting any features relating to the remaining skull areas or middle/inner ear structures);
(b) a sophisticated software simulation reproducing the physical effects of penetrating different layers of hard mastoid cortex and air-filled petrous bone with a high-speed drill (Figure 22, main);
(c) an interface (Figure 22, insert) consisting of a stereoscopic viewing system and two haptic feedback stylus-like hand controllers (*PHANTOMs*)[28], capable of reproducing the force and tactile sensations associated with mastoidectomy and the vibration-induced sound effects experienced when drilling through different densities of bone.

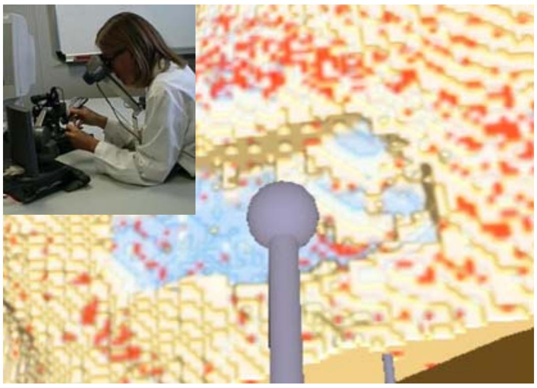

Figure 22: Hybrid fidelity interface solution for temporal bone surgical training.
Source: Author's Image Archive

[26] Mastoidectomy is a surgical procedure to remove part of the temporal bone behind the ear with the aim of removing infected bone volumes, to implant assistive hearing technologies, to repair middle or inner ear structures or to remove deeply-situated tumours.
[27] *Integrated Environment for Rehearsal and Planning of Surgical Interventions*; http://www.crs4.it/vic/cgi-bin/project-page.cgi?acronym='IERAPSI'.
[28] The *PHANTOM* haptic feedback system was developed by SensAble Technologies (www.sensable.com).

A MIST-like low-physical fidelity solution was also investigated, based on a multi-layer volumetric abstraction of the bone penetration process using drills and other medical tool representations. However, concerns were raised regarding the low psychological fidelity inherent in a solution that ignored the significance of stereoscopic vision, haptic feedback and sound effects in the training process. All three of these effects are crucial to the safe execution of a mastoidectomy procedure, helping the surgeon to avoid drill over-penetration and the inadvertent destruction of key nerve paths and blood vessels (particularly the facial nerve and sigmoid sinus).

From a cost perspective, real-world or replica interface devices, as used with MIST, are relatively easy to integrate with simplified 3D task representations, although initial bespoke development and manufacturing costs can be high. However, if special-purpose interfaces are to be exploited, then the cost of programming will inevitably increase as attempts are made to generate believable sensory effects (visual, sound, haptics, etc.) that feature in both the simulation content and in the device drivers of the interface equipment.

Turning now to the subject of pre-existing skills or knowledge, the *Tornado* F3 Avionics Maintenance Trainer delivered to RAF Marham in the late 1990s[29] was a good example of the importance of understanding the knowledge, skills and attitudes of end users. The Avionics Maintenance Trainer was designed to train avionics engineers to isolate (pre-programmed) faults in line replaceable units (LRUs), either by inspecting individual virtual LRUs, or by applying appropriate virtual test equipment at various points in the avionics systems network.

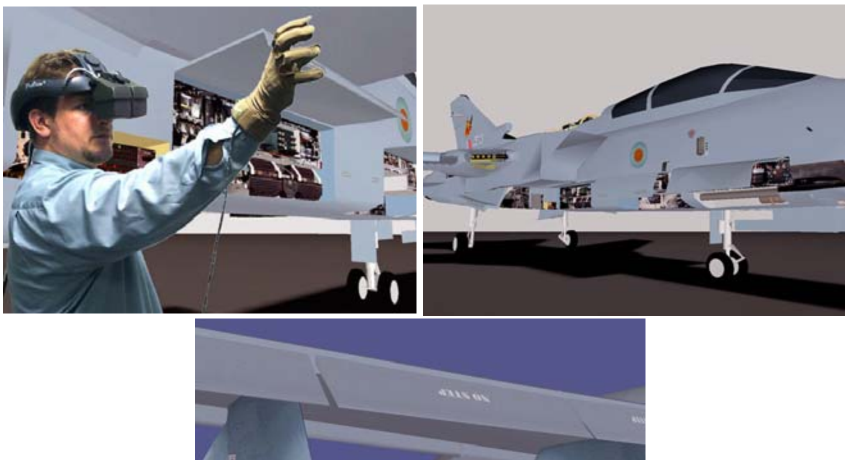

Figure 23: RAF *Tornado* F3 Avionics Maintenance Trainer. Top left – illustration of the VR technology NOT adopted for line replaceable unit exposure and extraction. Other images are desktop VR views of the "virtual *Tornado*" showing open LRU access panels operated by simple mouse clicks.
Source: Author's Image Archive

As with the ITT, the virtual *Tornado* F3 was developed on the assumption (confirmed by SMEs) that, by the time technician trainees undertook the avionics simulation course, they would already possess the basic manual skills and knowledge necessary to select and use the correct tools to

[29] Stone, R.J. (2004), "Rapid Assessment of Tasks and Context (*RATaC*) for Technology-Based Training", *Proceedings of I/ITSEC 2004* (I/ITSEC; Orlando, Florida), 6-9 December, 2004.

remove LRU cover panels and the LRUs themselves. It was decided, therefore, that the simulated maintenance task would not benefit from a VR-like interface (see Figure 23) that attempted to reproduce the use of spanners, screwdrivers and other common tools. Not only was this level of technology unacceptable from a cost and reliability perspective, its use, as noted much earlier by Barnett *et al*. (2000), would probably focus the trainees' attention more on interfacing with the VR through what would have been quite cumbersome and unreliable wearable equipment than on performing the task. Consequently, LRU panel opening, LRU extraction and inspection operations were achieved using "point-and-click" mouse inputs, combined with simple drop-down task sequence menus. This approach has since been exploited in the HFI DTC's *SubSafe* submarine safety games-based demonstrator (described later in this document).

One interesting finding relating to end user computer experience and attitudes was made just after the Avionics Maintenance Trainer was delivered to RAF Marham. One of the trainee Sergeants, having attended a classroom demonstration of how to use the simulator (note that the instructor's keyboard and mouse were not visible during the time of the demonstration), was subsequently observed to lift his mouse off the simulator desk and move it around in space in order to elevate his virtual viewpoint up and over the virtual *Tornado*. This instance confirms that one cannot assume a uniform distribution of computer interactive skills in one's sample of end users.

Despite the apparent knowledge, skills and attitudes of today's "gamer" generation, for the foreseeable future it is important NOT to assume that all members of a target audience will have experience with BASIC computer interface technologies, let alone games controllers.

4.2 Hypo-/Hyper-fidelity and Distractive Elements in Simulated Tasks

Given the visual and dynamic qualities available with today's serious gaming tools, there is an understandable tendency for developers to stop at nothing to endow their simulations with what *they* believe to be the highest (and, therefore, the most appropriate) fidelity possible. Cursory glances at the effects in such titles as *FarCry*, *Crysis* and *Half-Life 2* demonstrate this. The impressive images of helicopter down-draught effects over water, vehicle explosions, weapon discharge and the use of "rag doll physics" to simulate the flailing bodies of the recently deceased certainly capture the attention of the player.

There is no doubt whatsoever that these effects far outclass anything the VR community has had to offer to date. However, do these effects actually contribute positively to the development of relevant skills and learning? Do they improve the probability of the transfer of said skills and knowledge to real operational settings? Does it actually matter that the underlying particle physics engine is capable of supporting real-time water spray or the dynamic collision effects of barrels rolling down uneven terrain? Are these wonderfully impressive visual and behavioural effects actually representative of what happens in the real world, or have they been exaggerated to achieve maximum player satisfaction? Just as the VE/VR community was plagued throughout its early existence by the proponents of "reality or nothing", so too are the current and future developers of games-based simulations. In some instances, their perception of reality may result in the delivery of one special effect too many.

As summarised earlier, *hypo*- and *hyper-fidelity* are terms used to describe the inclusion of too little, too much or inappropriate sensory and/or behavioural detail into a simulated task or context and may lead to negative knowledge or skills transfer from the virtual to the real. Hypo- and hyper-fidelity effects can be classified according to the broad headings shown in Table 1.

In the majority of cases, hypo- and hyper-fidelity effects can be overcome following a few pre-training exposures of the end user to the simulation. In the case of hyper-fidelity, once the "wow" effects are no longer seen as a novelty, then it is likely that many users will ignore them. However, it is also likely that there will be tasks, especially those associated with completion time and decision pressures, where extreme hyper-fidelity effects will distract, no matter how much the end user has appeared to have adapted or "desensitised" him or herself. In addition, resources spent delivering hyper-fidelity effects during development could be put to better use elsewhere. The case for hypo-fidelity is of greater concern, as an absence of appropriate content, or effects that are below an end user's expectations for a given task and/or context can lead to poor learning uptake, a lack of credibility, negative transfer and so on.

Table 1: Simple classification of hypo-fidelity and hyper-fidelity as applied to i3D and serious games-based trainers.

HYPO-FIDELITY		APPROPRIATE	HYPER-FIDELITY	
"Hypo-Extreme"	***"Hypo-Limited"***	***"Appropriate"***	***"Hyper-Limited"***	***"Hyper-Extreme"***
Extreme paucity of task- and/or context-relevant sensory and functional effects. Highly likely to distract, prevent learning uptake and/or promote negative training transfer	**Limited instances of absent or impoverished sensory and functional effects relevant to the task and/or context. Likely to distract but not significantly affect negative training transfer (More likely to be noticed by Subject Matter Experts as opposed to novices)**	**Visual and functional fidelity relevant to the task and context and, thus, to the skills being trained and/or knowledge being acquired**	**Limited instances of sensory and functional effects not directly relevant to the task and/or context. Likely to distract but not significantly affect negative training transfer (More likely to be noticed by Subject Matter Experts as opposed to novices)**	**Excessive use of sensory and functional effects not directly relevant to the task and/or context. Highly likely to distract and promote negative training transfer**

One good example of the *successful* exploitation of hypo-fidelity effects in a simulation was the MIST keyhole surgery example described in Section 3 and 4.1. Here, the use of hypo-fidelity – the use of simple geometric "task primitives" to represent anatomical objects – was acceptable because of the early findings of the Human Factors analysis and the isolation of key perceptual-motor skills (thereby preserving a high psychological fidelity, even with the low physical fidelity of the simulated tasks – see Section 3.1). Even so, steps were taken to ensure that digital video sequences of actual laparoscopic interventions were made available on demand (Figure 24), thus reassuring surgical students that the tasks they were expected to perform were representative of, or relevant to real-life surgical procedures. In contrast, the mastoidectomy tasks in IERAPSI, on the other hand, would not have benefited from a hypo-fidelity "treatment", due to the need to deliver multisensory stimuli to the end user – stereoscopic vision, sound and haptics – as described earlier.

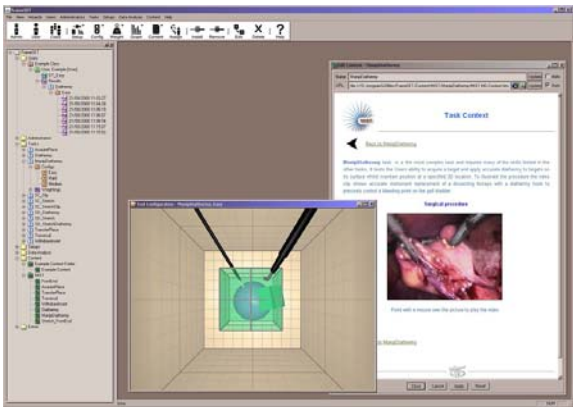

Figure 24: Supporting hypo-(physical) fidelity with the MIST trainer – on-demand "relevance videos" for students.
Source: Author's Image Archive

Turning now to task hyper-fidelity, and continuing with the medical theme, the Interactive Trauma Trainer, also described earlier, was the subject of a number of examples of hyper-fidelity, both proposed and actual. Many of these were not evident in the final concept demonstrator deliverable, but serve to illustrate some of the concerns described above.

Facial Hair. There was an early proposal to include substantial facial hair on the virtual casualty. However, this was advised against, as members of the Armed Forces (and especially those in the Army) are encouraged to remain as clean-shaven as possible at all times in order to ensure a good seal between the facial skin and nuclear, biological and chemical protective respirators (such as the UK's S10 assembly). A similar proposal was put forward to animate a fly landing on the casualty during the procedure. The final right-arm tattoo was a concession and, interestingly, did not attract adverse comments from the early users! The casualty's nipples also appeared later in the development process!

Stethoscope Tubing Dynamics. In the original ITT, developers had programmed quite dramatic flexing algorithms into the stethoscope tube object. During the Airway-Breathing-Circulation (ABC) animation sequence, as the avatar hand moved the stethoscope towards the casualty, the tube flailed quite dramatically around the scene (Figure 25) which many end users found both comical and distracting.

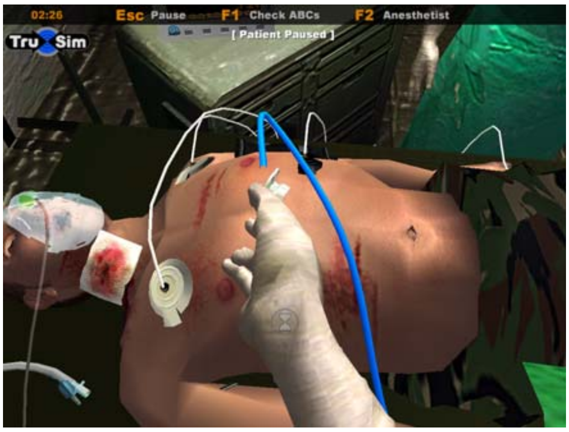

Figure 25: Excessive virtual stethoscope tube flexing effects.
Source: Author's Image Archive

"Hovering canula". This is actually not a significant item but was noticed by one or two surgeons during the early reviews of the original ITT. Once the virtual canula had been acquired for blood extraction and fluids had been administered, the animated process by which the surgeon inserted it into the casualty's right arm depicted the canula "hovering" slightly in front of the surgeon's hands, describing its own insertion path just ahead of the surgeon's hand movements.

Laryngoscope Environment Mapping. This was considered to be so distracting that it even created a virtual "glare" effect when using the laryngoscope in conjunction with the suction and intubation tubes. Some users also noted – having stopped the intubation procedure – that the reflection on the laryngoscope surface was actually wrong, showing the casualty's body, DPM trousers and nurse instead of parts of the surgeon's own virtual body (Figure 26)! This may appear too critical, but it was surprising that this was actually detected by at least 3 of the early users of the system!

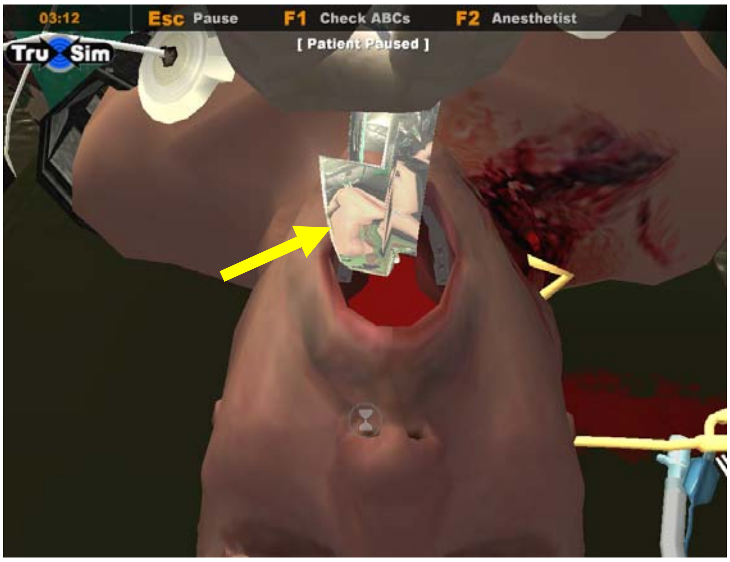

Figure 26: "Impossible" reflections on virtual laryngoscope surface.
Source: Author's Image Archive

Do not assume that end users will not notice shortcomings in fidelity and other aspects of game design. Hypo- and hyper-fidelity effects or task-irrelevant features may adversely affect an end user's acceptance of and performance on a part-task simulation.

4.3 Task Reference Frames

Does the task demand a first-person, "self-based" (egocentric) frame of reference/display or a third-person, "world-based" (exocentric) frame of reference/display?

Figure 27: Two examples of frames of reference in computer games: upper two images show *exocentric* frames from *Tomb Raider*; lower two images show *egocentric* (first-person) frames from *Half-Life 2 Episode 2* (left) and *Crysis* (right).
Source: Author's Image Archive

Numerous research papers exist addressing the issue of display presentations (or "reference frames") in Virtual Environments (Figure 27)[30; 31]. The significance of delivering the appropriate visual frame of reference with regard to VE design is very clear and relates to the role of, and tasks undertaken by the end user of the simulation, as observed during real-life scenarios. During observational analyses, it is important to establish how the human operator interfaces globally with his or her task and context, as this will dictate (to some extent) the most appropriate reference frame(s) with which to display and interact with the simulated scenarios.

---

[30] A good introduction to the topic of reference frames can be found in: Howard, I.P. (1991), "Spatial Vision Within Egocentric and Exocentric Frames of Reference", in Ellis, .R., Kaiser, M., & Grunwald, M. (Eds.), *Pictorial Communication in Virtual and Real Environments* (2nd Edition), pp. 338-358, Taylor & Francis (London).

[31] Shah, P. & Miyake, A. (Eds., 2005), "The Cambridge Handbook of Visuospatial Thinking", Cambridge University Press.

For example, one might have to decide if the human user is operating from a ***Local*** or ***Remote*** location. If the user is local to the tasks and events (i.e. an integrated participant who is "part of the action"), then this may well demand a different display reference frame than one who is operating remotely, be he or she in control of (for example) a telerobotic device for undersea or space exploration or bomb disposal, piloting an Unmanned Air Vehicle (Figure 28) or overseeing the development of multi-agent scenarios, as might be the case in command and control or safety supervision contexts. In each case, the need to consider how the final simulation content will be displayed is crucial to the effective interaction with, and uptake of simulated content. For instance, is a first-person "here-and-now" perspective important to support rapid reactions and judgements, or will a third-person "overview" frame of reference enhance the end user's situational awareness and timely decision-making capabilities?

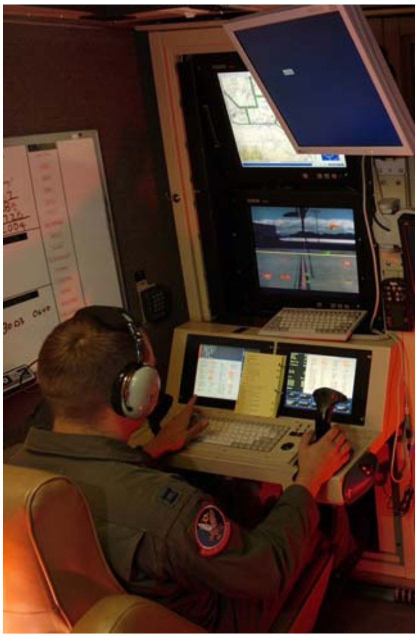

Figure 28*: Predator* UAV pilot station.
Source: www.defenselink.mil

Other issues to be aware of include whether or not the human user is a passive ***Observer***, active ***Explorer*** or active ***Modifier*** of individual or group tasks or scenarios. For example, a passive Observer of simulated scenarios or environments may only require a simple directional control interface (translation and limited rotation throughout the scene) and fixed motion paths embedded within the Virtual Environment. In contrast, an end user with an active Modifier role may require a more sophisticated control and display interface to support his or her free exploration of a simulated environment (see also Section 5). Such a role may also require the end user to be able to interrogate, relocate, actuate or even construct objects within that environment. Taking this discussion a step further, the Human Factors literature often makes a distinction between *egocentric* and *exocentric* presentations, as defined below.

4.3.1 Egocentric Presentations

Egocentric visual frames display the Virtual Environment (VE) or games-based scenario as it would look from the observer's own ("first-person") viewpoint. Sometimes referred to as an "immersive" presentation, (erroneously, due to restrictions in instantaneous field of view, low display resolution, exaggerated head movements induced by spatial tracking technologies, especially when a helmet-mounted display is used), egocentric frames present a more natural view to the VE user, avoiding any perceptual transformations or distortions to objects in the field of view and along the axis of control (or movement). Egocentric presentation also enhances perception of relative motion and monocular cues to depth distance such as motion parallax.

However, an effect known as "cognitive tunnelling"[32] may exist, such that VE users focus their attention on specific areas of the display, effectively excluding information that exists outside of those areas. Cognitive tunnelling can result in poorer information uptake and compromised situation awareness when compared to an exocentric display (described below). Additional cues to important objects and/or processes occurring outside the VE user's instantaneous field of view may be required, especially in safety-critical or life-saving applications, such as the Interactive Trauma Trainer mentioned earlier (see also Figure 29). Here, the end user needs to remember what instruments are available on the trolley to their right. Actions undertaken by the nurse avatar (a non-playable character, or "NPC" – see Section 6.5), including setting up the patient monitor to the

[32] Thomas, L.C., Wickens, C.D. & Merlo, J. (1999), "Immersion and Battlefield Visualization: Frame of Reference Effects on Navigation Tasks and Cognitive Tunneling", University of Illinois Institute of Aviation Final Technical Report (ARL-99-3/ARMY-FED-LAB-99-2), Savoy, IL: Aviation Research Lab.

upper left of the end user's view, help to establish peripheral visual cues and non-visual cues (e.g. heart rate audible beats and other warnings), thereby helping to avoid excessive cognitive tunnelling.

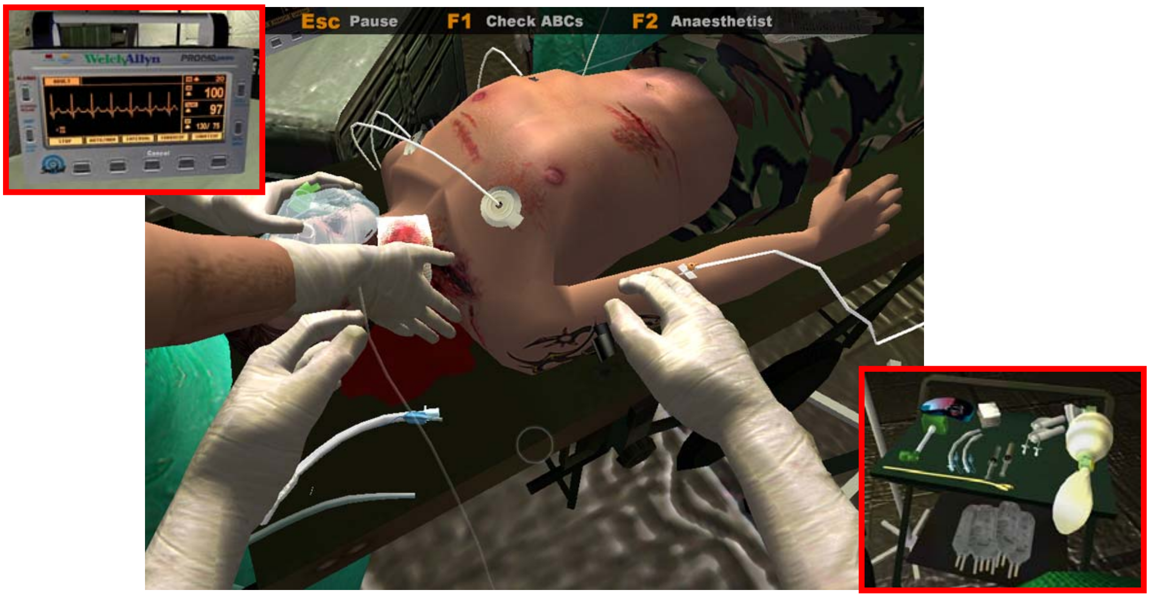

Figure 29: Cognitive tunnelling potential in an egocentric frame of reference, Illustrated using the Interactive Trauma Trainer (ITT) virtual workspace layout.
Source: Author's Image Archive

4.3.2 Exocentric Presentations

Exocentric presentations typically display the VE as if from a viewpoint detached from the observer's actual 3D position in the VE, which is often represented by a virtual human, or *avatar* (see Figure 30 and Section 6.5). The frame of reference is sometimes referred to as a "bird's eye" or "third-person" view. An exocentric frame helps to preserve the situational awareness of the observer or VE user by bringing objects and events occurring around the VE user's virtual position into view. This is in contrast to the restricted instantaneous field of view and cognitive tunnelling inherent with egocentric presentations (especially those presented via an HMD). However, exocentric frames of reference bring with them certain control problems for the VE user. For example, distance perception from the avatar representation to an object or adversary can be compromised. In addition, the control of avatar motions and engagement with objects (equipment interaction, combat, etc.) can be difficult, especially during fast-action sequences.

Three basic types of exocentric presentation can be considered:

4.3.2.1 Over-The-Shoulder (OTS; e.g. *Tomb Raider II*; Figure 30)

OTS preserves something of a First-Person (FP) "look and feel". However, monocular visual cues to depth and distance – parallax/interposition, shadowing, size constancies and texture gradient in particular[33] – are

Figure 30: *Tomb Raider II*.
Source: www.pause.com

[33] http://ahsmail.uwaterloo.ca/kin356/cues/mcues.htm

fundamentally different, due to the displaced viewpoint. Consequently, over-the-shoulder control requires a considerable amount of practice to master the movement of the avatar and its interaction with local objects and features. Viewpoint scrolling (in azimuth and elevation) is typically avatar-centric and can sometimes produce distorted field-of-view effects and occlusions based on nearby structures, such as walls (see also comments on *tethering*, below).

4.3.2.2 Low-Angle Projection (LAP; e.g. *Hospital Tycoon*; Figure 31)

LAP exocentric reference frames may be used when the preservation of situational awareness is required on a local scale (e.g. key events occur nearby – in different rooms, compartments and decks, for example). LAP exocentric frames should also be used for scenarios where the ability to identify ("bond") with specific characters may be important to gameplay. In contrast to High-Angle Projections (see below), LAP supports an end user viewing frame that permits the use of higher fidelity avatars and clearer interactions between them. Careful consideration needs to be given to interaction (end user-centric, selected avatar-centric, zoom-in/zoom-out, etc.). There may also be a requirement to "zoom-in" to "become" the avatar and then exercise First-Person control (e.g. as might be the case with explosive ordnance disposal (EOD) training, see Figure 34).

Figure 31: *Hospital Tycoon*.
Source: gamemovies.blogspot.com

4.3.2.3 High-/Distant-Angle Projection (HAP; e.g. *Civilisation III*; Figure 32)

HAP exocentric projections are reserved for extensive multi-agent scenarios and strategy games where individual avatar recognition or identity/bond-forming is not an issue. Situational awareness is typically required on a *geographical* scale. Movement fluidity needs to be carefully implemented so as not to introduce artefacts in the representation of large crowds. Trade-offs between fidelity (see Section 3.1) and the complexity/density of the VE may be required.

Figure 32: *Civilisation III*.
Source: www.amazon.com

4.3.3 Exocentric "Tethering"

In addition to the three basic types of exocentric presentation given above, *tethering* effects can also be considered with exocentric displays. *Rigid tethering* exocentricity refers to the situation where the VE user's viewpoint maintains a fixed position vis-à-vis the avatar. *Dynamic tethering* supports the user's situation awareness by allowing him or her to rotate the viewpoint in azimuth and elevation, centred on the avatar (this was first demonstrated to good effect in the early *Tomb Raider* games – see Figure 33). Dynamic tethering effects can also occur automatically as the avatar moves throughout a scene. However, as in the *Tomb Raider* example, this can produce frustrating effects (particularly in interior environments), when the viewpoint slews to a location where the avatar's position is obscured by an object, such as a pillar, wall or other architectural feature, for example.

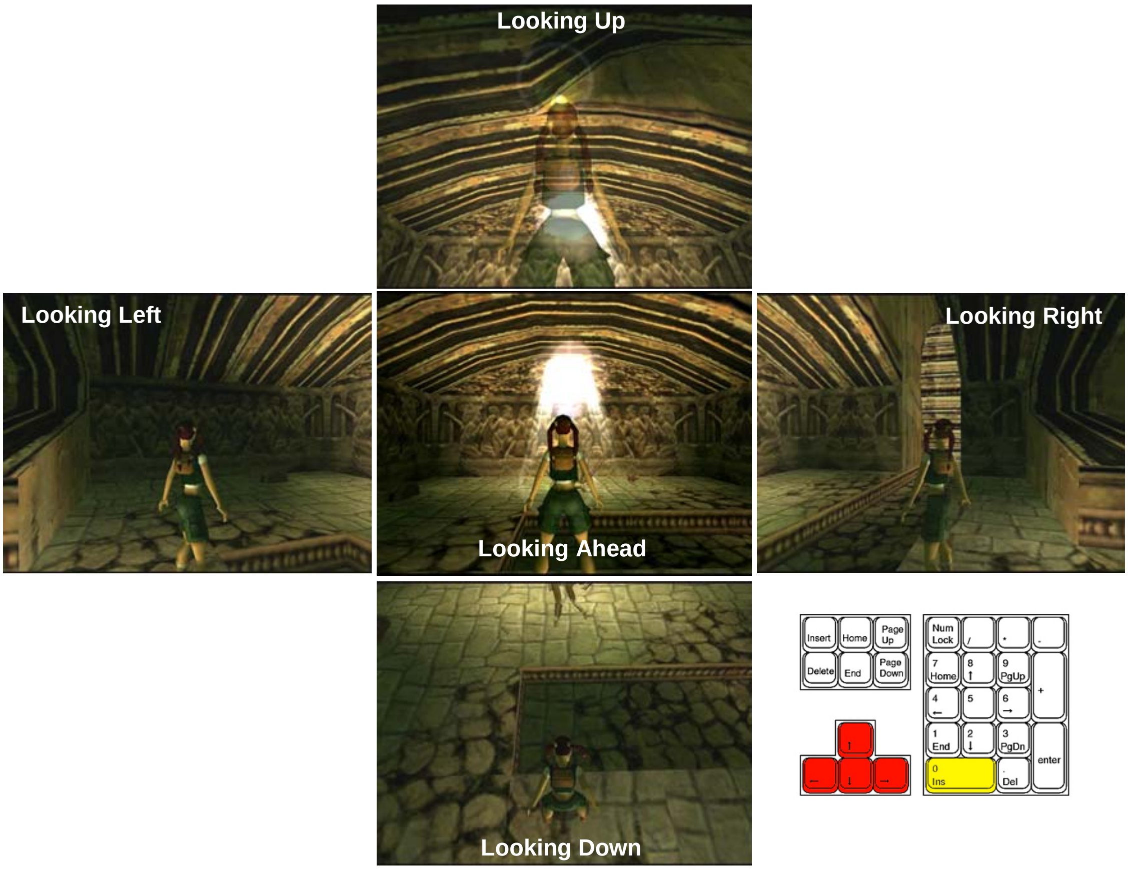

Figure 33: User-controlled dynamic tethering – an exocentric mode of display first demonstrated in *Tomb Raider*. Pressing the "Ins" key enables the user to disengage the look-ahead default view and press the arrow keys to look up, down, left and right.
Source: Author's Image Archive

Exocentric presentations are not only confined to single user set-ups. For example, an i3D application designed to train one or more observers to be aware of the status of specialist personnel and hardware resources in support of a terrorist incident (as described earlier – Section 3 and Figures 12 and 16) would best be served by an exocentric frame of display (as shown in Figure 34, for example).

In this scenario, the incident team avatars could be programmed to prepare and deploy remotely-operated equipment, such as EOD vehicles, followed by route search and flanking parties. Each stage of the operation could be animated, with the viewpoint displayed to the observer(s) tethered to an appropriate avatar, other active asset or even a "central node of activity" within the VE, calculated based on the spread of assets at a given point in the simulation. The same, or very similar, software could also be used as a classroom training session, and then exploited operationally as a "here-and-now" incident planning tool.

Figure 34: Exocentric presentation of EOD deployment scenario showing incident control vehicles, remotely-operated vehicle (left of centre) and early personnel search positions.
Source: Author's Image Archive

Note also that the term "exocentric" is not restricted to examples where the end user's viewpoint is fixed to gain a "bird's eye view" of a task or scenario. Exocentricity can also refer to tasks or part-tasks where the end user has to:

(a) maintain an awareness of the location and interrelationships of objects or subsystems whilst operating in a predominantly egocentric frame of reference. For example, a submariner working in a submarine's Forward Escape Compartment needs to know how the actuation of a specific high-pressure air valve affects, and is affected by, other components of the HP Air system, not to mention the overall effect on the submarine itself.

(b) maintain an awareness of a situation or process that may begin and/or extend beyond his or her immediate first-person location. A good example of this can be found in infection control training for hospital personnel. Observational analyses in British Hospitals (undertaken in support of the Technology Strategy Board-sponsored project mentioned at the beginning of this document) have shown that hygiene transgressions often occur on some other part of a ward, away from the end user's immediate viewpoint. Providing an exocentric view as part of a new serious games training package, it is hoped, will help train staff to understand how infection problems can evolve from areas not under their immediate supervision (see also Figure 31).

The submarine example in Figure 35 (left) relates to dockside vessel familiarisation tasks. Not only must students be able to name the services leading from the dock to the interior of the submarine, they have to be aware of where these services terminate within the vessel. They are also required to describe the external features of the vessel and how these link to interior components and systems. Officers of the Watch and remotely-operated systems controllers (middle and right of Figure 35) also have to maintain a form of exocentric awareness of the situation they are monitoring, even though their primary interface with deck- or console-based systems demands first-person activities.

Another highly safety critical example relates to Diving Supervisors, employed by offshore oil and gas exploration companies. From a first-person perspective, these personnel need to be able to monitor – from a single workstation (Figure 35, lower three images) – the status of life support resources being transferred from platform- or ship-borne assets to underwater habitats and diving bells. However, from an exocentric perspective, they also need to remain aware of other key activities, such as the deployment of free-swimming divers, remotely-operated and manned submersibles, the depositing of subsea pipeline components, the approach and docking of supply vessels, the current and near-term condition of the weather and its effect on (for instance) dynamic position-keeping systems, and so on.

Therefore, in some cases, it may be necessary to consider both ego- *and* exocentric frames of reference in the design of virtual training environments, depending on the spatial demands imposed at certain stages of the task.

Figure 35: Examples of egocentric *and* exocentric frames of reference – (clockwise) submarine dockside services awareness, bridge watchkeeping, UAV/UGV piloting, offshore diving supervision (lower three images).
Source: Author's Image Archive

In some military applications where multiple exocentric views are necessary, *coplanar* displays are also used, although this tends to be restricted to the navigation of manned and unmanned aircraft/submersible applications. Some coplanar displays also exploit exocentric 3D terrain representations, but their application to i3D and serious games-based simulations is very rare. A typical avionics coplanar display is shown in Figure 36. The display essentially combines 2D plan and elevation views (e.g. a map view and aircraft side elevation, or a *Vertical Situation Display* (VSD), showing symbolic and alphanumeric altitude and pitch cues[34]). Perceptual and interpretational evidence for and against the use of coplanar displays exists. Some researchers believe that the cognitive loading required to integrate the information in each 2D display may become too high at certain mission stages, especially if the VE user makes a movement that involves integration of display elements from each view. Because of their somewhat specific application field, coplanar displays are not discussed further in this edition of the guidelines.

Figure 36: Example of an avionics coplanar display (map Display on top, VSD Below).
Source: Prevot & Crane (1999)[34]

4.4 Task Coupling

"Task coupling" is a term used by the author[35] to describe how a user's performance is influenced by the features and qualities of his or her immediate working environment. Task elements relevant to coupling include components of the user's immediate working environment (including the close proximity of other team members and the effect of the environment on his or her working posture and motion envelopes) and special items of equipment and tools that physically link the user to his or her task.

When designing part-task training simulations, task coupling is an important issue to consider during early end user observations, as the extent of coupling – ranging from "loose", through "medium" to "close" (see examples in Figures 40 through 43 below) – will influence:

(a) decisions relating to those elements of the human's real working environment that should be implemented as real and/or virtual objects, together with appropriate levels of physical and psychological fidelity;

(b) decisions relating to whether or not the use of COTS interface devices (Section 5) and, in particular, *hybrid* devices (e.g. haptic feedback; see Section 5.3) are appropriate to enhance the interaction with, and "believability" of the virtual representations;

(c) the selection of appropriate non-COTS hardware for the physical interface to the simulation. Such hardware may vary from purpose-built mock-ups (e.g. seating "bucks" for automotive Human Factors research) to the integration of real equipment (e.g. inert weapons).

[34] Prevot, T. & Crane, B. (1999), "A Vertical Situation Display for Automated Aircraft – Design and Evaluation in Full Mission Simulation", in Bullinger, H-J., & Ziegler, J. (Eds.), *Human-Computer Interaction: Ergonomics and User Interfaces*, Lawrence Erlbaum Associates, pp. 1266-1270.

[35] Another human-centred use of the term *task coupling* relates to anatomical coupling in the design of hand controllers (e.g. for remote manipulator systems): Kern, P., Muntzinger, W.W. & Solf, J.J. (1982), "Development of Ergonomically Designed Control Elements – Final Report", NTIS HC AO9/MF A01, Fachinformationszentrum, Karlsruhe, West Germany.

Although Human Factors specialists would argue that elements that *constrain* performance should always be designed out of a working environment, this is not always possible. For example, items of equipment may be present throughout, or at different stages of a task that are critical to the success of that task. However, their presence may well have some modifying effect on the behaviour of the human ("task modifiers").

Surgical procedures provide good examples in this context – the introduction of X-Ray devices, special life support systems, even robotic support tools may be critical to the success of an operation. However, their introduction may constrain the surgeon in gaining access to the patient, attending to key system components and displays and interacting with his or her surgical support team (e.g. Figure 37).

There is an argument suggesting that, if constraints in the real world are excluded from the virtual training environment, then this might impact negatively on the transfer of skills from the virtual to the real. The simulation users' task performances in the real operational setting may be compromised if they have to modify behaviours they acquired during simulation-based training to cope with new or unfamiliar constraints.

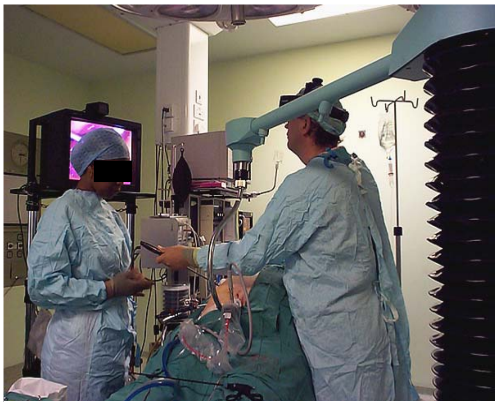

Figure 37: Head-controlled endoscopic camera robot affects "keyhole" surgeon's posture and medical instrument working envelope.
Source: Author's Image Archive

In some cases, implementing closely-coupled hardware elements as part of a distributable simulation package, through the use of real equipment or mock-ups, will not be feasible, due primarily to the cost of procuring and maintaining such elements. In these cases, exposure of the end user to actual, in-service equipment or environments becomes an essential component of the training programme. For example, training Royal Navy personnel to become familiar with the spatial layout of a submarine and the location of compartments, valves, life-saving equipment and so on does not require a simulator that features tightly-coupled hardware elements. A simple interface to the simulator – mouse and arrow keys, for example – should be all that is necessary to support deck-by-deck navigation (with some form of animation or transition effect to represent motion between decks).

However, training those same personnel to operate the numerous items of submarine equipment that are typically located behind panels, pipes or other obstructions, and are therefore difficult to access and handle manually, is a different matter (Figure 38).

Figure 38: Valves located behind panel within cramped bunk space onboard a *Trafalgar* class submarine.
Source*: Author's Image Archive*

Whilst basic operational procedures can be visualised using simulation techniques, their *actual* operation can only be trained realistically by providing access to a real submarine, or to specialised training facilities, such as the torpedo handling facility at HMS Raleigh, the Royal Navy's Submarine School (Figure 39).

Figure 39: Weapons handling facility at HMS Raleigh.
Source: Royal Navy Submarine School

Some of the key questions of relevance to task coupling to answer when provided with the opportunity to conduct early Human Factors observations are:

- Does the workspace dictate the posture and/or movements of the operators in any way (e.g. require or force the user to stand, stand constrained (e.g. with harness), sit, kneel, lay prone, etc.)?
- Do the users perform their tasks within a constrained or limited-volume workspace?
- If yes, over what proportion of the task do the workspace features have a *supportive* impact on the user's performance?
- If yes, over what proportion of the task do the workspace features have a *constraining* impact on the user's performance?
- Do the users interface with the task(s) using any special items of equipment or tools?
- If yes, over what proportion of the task are each of the items used?
- Do any of the items of equipment or tools constrain the user's task performance in any way (e.g. restrict the user's immediate field of view vis-à-vis other important task elements or his or her functional reach envelopes)?
- Do these items of equipment require special set-up procedures (e.g. pre- and post-usage settings, such as weapon arming or safeing)?
- Do these items of equipment constrain the posture and/or movements of the operators in any way (e.g. require or force the user to stand, stand constrained (e.g. with harness), sit, kneel, lay prone, etc.)?
- Do these items of equipment (or the task itself) require the user to wear any form of protective equipment?
- Do these items exhibit any special sensory qualities (or transmit specific sensory stimuli) that are relevant to the tasks being performed (e.g. haptic, vibratory, sound or thermal cues)?

Some of these issues will be illustrated in the following examples of differing degrees of coupling, each of which was accompanied by an early – and rapid – Human Factors analysis prior to developing the specifications for the final i3D simulation.

4.5 Other Task Coupling Examples

Figure 40: Examples of *close coupling* – RN weapons aimer and ear, nose & throat (ENT) Surgeon.
Source: Author's Image Archive

In Figure 40, the 20mm close-range weapons user (left) is closely coupled to the weapon by virtue of the shoulder stocks and a lumbar region strap, although his head is free to move to support scanning and search behaviours. Considerable physical effort on the part of the standing, harnessed aimer is necessary to slew the weapon in azimuth and elevation[36], including extreme knee-bending activities to lower the weapon barrel from its upper elevation limits. In addition, the firing and braking mechanisms required firm handgrips. The simulation solution for this application (middle image of Figure 40) exploited the availability from the RN of inert 20mm weapons. Head-mounted displays, designed to afford a degree of peripheral vision (thereby allowing the close-range weapons students to glance left and right and be aware of the position of their arms and hands vis-à-vis the firing and braking controls), were considered an appropriate form of interface technology on this occasion[36]. The HMD and inert weapon were independently equipped with spatial tracking devices.

The ENT surgeon in Figure 40 (right image) is closely coupled to his task by virtue of his seated posture, the microscope and the static location of the patient's head. The surgical process known as mastoidectomy also demands close coupling, as the surgeon needs to "feel" and "hear" the different skull bone densities as the drill penetration progresses (the simulation solution for this application was described earlier). In Figure 41, the Dillon Minigun operator (left image) is closely coupled to the weapon for the actual firing process, but is relatively free to move otherwise. Although the electrically-operated Minigun does not exhibit any significant recoil when fired, the torque induced by the rotating barrel, preceded by a brief delay between actuating the firing pushbutton and the first round of ammunition engaging, can cause an unanticipated "kick-down" effect for new trainee aimers. The aimers, who typically exhibit medium coupling to the weapon (by virtue of the design of the firing interface and the postural changes required to bring the Minigun's reflex sight closer to the face prior to target engagement), will attempt to recover control by pulling down on the Minigun spade grips in a reactionary fashion. The simulation solution for this application was also described earlier.

The helicopter rear-door marshal (middle image of Figure 41) exhibits varying levels of coupling with features of his workstation (handholds, winch controls, door, harness), but is relatively free to move and change posture within the confines of the cabin. The simulation solution for this application is shown in Figure 42[37]. The minimal access surgeon (right image of Figure 41) is closely coupled to his instruments for variable periods but is reasonably free to access other

[36] Stone, R.J. & Rees, J.B.M. (2002), "Application of Virtual Reality to the Development of Naval Weapons Simulators", *Proceedings of the Interservice/Industry Training, Simulation & Education Conference* (I/ITSEC; Orlando, Florida), December 2-6, 2002.
[37] Stone, R.J. & McDonagh, S. (2002), "Human-Centred Development and Evaluation of a Helicopter Voice Marshalling Simulator", *Proceedings of the Interservice/Industry Training, Simulation & Education Conference* (I/ITSEC; Orlando, Florida), December 2-6, 2002.

surgical facilities, including foot-operated equipment. The surgeon can also request additional manipulative support from other team members. The simulation solution for this application (MIST) was also described earlier.

Figure 41: Examples of *medium coupling* – Minigun operator, helicopter voice marshal and "keyhole" Surgeon.
Source: Author's Image Archive

Figure 42: Helicopter voice marshalling VR solution – simulator station (left); view from virtual cabin (right).
Source: Author's Image Archive

In Figure 43, the Officer of the Watch (left image), whilst constrained by his "enclosure", has full freedom of movement around the bridge and only engages with certain items of equipment and stations (binoculars, poloris, intercom, chart table, radar screen, etc.) for short time periods. The simulation solution for this application – developed to record Officer of the Watch performance, as opposed to train or select – was based on an abstracted part-task VE. This integrated on a single screen a series of subtasks designed to record a range of perceptual-motor and cognitive features, including tracking, threat detection, reaction time, prediction/anticipation, short-term memory and performance on secondary alphanumeric questions (Figure 43, right image). The Army route search team members (Figure 43, middle image) are loosely coupled to their task of searching for signs of explosive ordnance placement, although they will be provided with specialist detection equipment and will adopt pre-planned search procedures, based on the context in which they have been deployed. The simulation solution for this application was also described earlier.

Figure 43: Examples of *loose coupling* – bridge officers and EOD route search personnel. The right-hand image is a screen grab from the HFI DTC bridge officer performance capture tool.
Source: Author's Image Archive and DEMSS Image Database

Section 4.0
Task Design Issues & Task Fidelity
Key Points Summary

- **The results of an early task analysis can help define:**
  - **Whether the task to be trained is fundamentally perceptual-motor (e.g. skills-based) or cognitive (e.g. decision-based) in nature (or a combination of the two), and**
  - **Whether or not all or only a percentage of the members of a target audience possess pre-existing (task-relevant) perceptual-motor skills and domain knowledge.**
- **Perceptual-motor skills-based tasks may be trained using simplified, "abstracted" virtual environments, combined with realistic interactive devices.**
- **Cognitive, decision-making tasks may require higher physical fidelity in the virtual environment, but with a greater reliance on animation (especially for the representation of any manual skills already possessed by the end user). Conventional (off-the-shelf) interactive devices may suffice (as opposed to more realistic devices).**
- **For simulated perceptual-motor *and* cognitive tasks, content and interactivity decisions *must* be supported by Human Factors evidence that supports the fact that psychological fidelity is preserved in all cases (see also the Key Points Summary for Section 3.0, page 29).**
- **Do NOT assume that end users will *not* notice shortcomings in task and context fidelity and other aspects of game design.**
- **Games developers must avoid the drive to endow serious games products with unnecessary "special effects". These *hyper-fidelity* effects may not be representative of what happens in the real world and could produce distraction and frustration on the part of the end users.**
- **Similarly, when designing games-based or i3D skills trainers, ensure that the tasks and contexts are not oversimplified, or under-endowed with visual and behavioural features, as *hypo-fidelity* could promote negative training transfer.**
- **During task and observational analyses, it is important to establish how the human operator interfaces with his or her task and context, as this will dictate the most appropriate reference frame(s) and interactive styles for the simulation – *egocentric* ("first-person") or *exocentric* ("third-person").**
- **During task and observational analyses, it is also important to establish how *coupled* a user is to his or her immediate working environment, as this will influence decisions relating to physical fidelity (see also Key Points Summary for Section 3.0) and, thus, whether or not the exploitation of bespoke, real-world or off-the-shelf interactive hardware is appropriate.**

Section 4.0 – Main References

Ellis, .R., Kaiser, M., & Grunwald, M. (Eds.), *Pictorial Communication in Virtual and Real Environments* (2nd Edition), pp. 338-358, Taylor & Francis (London).

Shah, P. & Miyake, A. (Eds., 2005), "The Cambridge Handbook of Visuospatial Thinking", Cambridge University Press.

Stone, R.J. (2004), "Rapid Assessment of Tasks and Context (*RATaC*) for Technology-Based Training", *Proceedings of I/ITSEC 2004* (I/ITSEC; Orlando, Florida), 6-9 December, 2004.

Thomas, L.C., Wickens, C.D. & Merlo, J. (1999), "Immersion and Battlefield Visualization: Frame of Reference Effects on Navigation Tasks and Cognitive Tunneling", University of Illinois Institute of Aviation Final Technical Report (ARL-99-3/ARMY-FED-LAB-99-2), Savoy, IL: Aviation Research Lab.

5.0 Interactive Fidelity

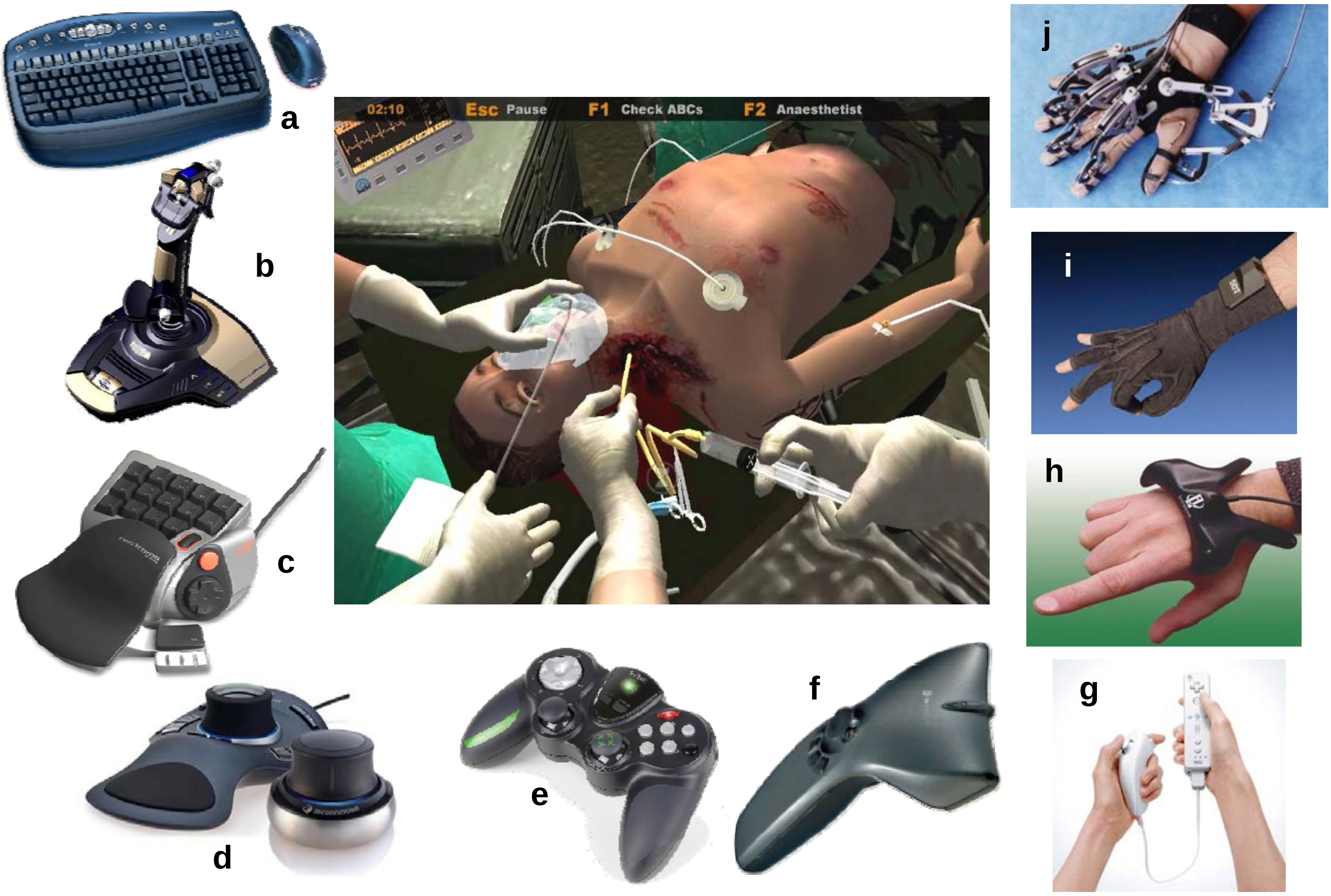

Figure 44: Which control device is appropriate for the task? A selection of interactive controllers.

a: Keyboard & Mouse
b: Multifunction Isotonic (Displacement) Joystick
c: Multifunction Keypad with Directional Controls (Belkin *Nostromo*)
d: Multi-Axis Isometric (Force-Torque) Controller ("3D Mouse" – *SpaceExplorer* & *SpaceNavigator*)
e: "Gamepad" (Saitek)
f: Spatially-Tracked "Wand"
g: *Wiimote* & *Nunchuk* Spatial and Input Controllers (Nintendo *Wii*)
h: "Hand-Worn Wand"
i: Virtual Reality or "Cyber" Glove
j: Glove With Exoskeleton

Source: Google Images

Closely related to the previous discussions relating to task fidelity and coupling in the previous section is the notion of *interactive fidelity*. For the purposes of this edition of the guidelines document, the term *interactive fidelity* relates to data input devices (hardware) only – a subsequent edition will also cover display hardware.

Earlier, whilst focusing on the topic of *task coupling*, it was stated that end user observational and task analyses will help support early design decisions relating to the appropriateness of selecting either COTS or non-COTS hardware for the physical interface to the simulation (where "non-COTS" refers to the exploitation of full-scale mock-ups or real equipment). Throughout this document, references have been made to various forms of input device, both COTS and bespoke in nature, how they map on to i3D or game-based simulation and why the need for early Human Factors input is essential to ensure the seamless integration within simulation-based training projects. This short section of the document seeks to reinforce the key Human Factors concerns and issues relating to interactive devices and will be expanded in future editions. In particular, this section considers the use of COTS hardware and seeks to draw the reader's attention to three key human-centred design questions:

- How appropriate is the interactive device selected in terms of how well it physically maps to the role and activities expected of the end user – navigation, object selection/interrogation, manipulation and relocation, function actuation, object construction and so on (see also Section 4.3)? For example, at a glance, would it appear obvious that the Belkin *Nostromo* shown in Figure 44 would be an appropriate method of controlling the virtual MIST laparoscopic instrument representations shown in Figure 20? Or that the spatially tracked wand would effectively control the Army personnel avatar movements in Figure 34?

- How well do discrete and dynamic input commands from the interactive device map onto the displayed function? How intuitive is the mapping between the human source of input (and this could range from basic keyboard inputs and mouse or joystick movements, to arm/head/eye tracking and direct voice input) and the on-screen activities? What if the Human Factors analysis of a particular application suggested that a multifunction controller like the Belkin *Nostromo* was appropriate for, say, the mastoidectomy procedure described in Section 4.1 (Figure 22)? Which of the controls on the *Nostromo* would best map on to the simulated functions, such as drill speed, drill movement (right-hand usage), irrigation and suction (left-hand usage), or display magnification? How would one compensate for the lack of haptic and haptic-related auditory feedback if one chose this controller?

- Are the ergonomic design features of the interactive device itself acceptable (wearability, short- or long-term use, layout of multifunction components, component coding, etc.)? With controllers like the Belkin *Nostromo*, is there too much redundancy in the controller that could lead to the actuation of inactive controls or confusion with which control element governs which function?

Figure 19, presented at the beginning of Section 4.1, is also highly relevant here. The continuum presented in that diagram suggested that many basic perceptual-motor skills trainers (such as the MIST keyhole surgery trainer; see Section 3) might well benefit from the presentation of simple, abstracted Virtual Environments, interfaced via data input controllers representative of real-world devices. In contrast, predominantly cognitive skills trainers (such as the Interactive Trauma Trainer, also mentioned in Section 3) appear to demand higher fidelity Virtual Environments but can "tolerate" much lower physical fidelity interface devices.

Whilst these observations have yet to be formalised through experimental studies, they are based on two decades of developing i3D solutions for real-world training applications and, as such, lend support to an important point of Human Factors concern. Namely, choose the wrong interactive device, or fail to pay attention to the mapping between that device and on-screen activities, and one runs the very real risk (as emphasised in Section 2.1) of forcing the end user to spend more time and effort interfacing with the i3D than actually assimilating the i3D content.

Unfortunately, there is no easy process by which interactive devices can be assessed from a human-centred design or commercial perspective, although a number of high-level guidance points can be put forward at this stage (some of these are mentioned further in subsequent sections of the document). Table 2 is part of a much larger matrix that has enabled the author to conduct a variety of *technology appropriateness* assessments since the publication of an extensive Human Factors review document of interface technologies for telerobotics and VR, for British Nuclear Fuels (BNFL) in 1992[38].

Table 2: Extracts from interactive technology "appropriateness matrix", originally developed for BNFL (Stone (1992)[38]).

Technology (Class/Type)	Relevance/ Comments (Y,FI,N)	Maturity (L,M,H)	Operational? (Y,Rs)	Usability Score (1-5)	Cost (Outlay) (L,M,H)	Cost (Ongoing/ Maintenance) (L,M,H)	Relevant HCD Standards? (Y,P,N)	Relevant HCD Knowledge? (Y,N)	Image
Head-Mounted Binocular/Biocular (Semi-Inclusive: affording the wearer peripheral visual access to the real world)									
Haptic Large Volume "Master"									
Multi-Function Isotonic Joystick									
"Gamepad"-like Controller									
Eye Tracking									

In essence, the selection or procurement of an item of interactive technology should be influenced by a range of factors (as presented in Table 2), including:

- "Relevance" and "Usability" – or "appropriateness" – a term that has been used throughout this document. Entries in these cells would be based on judgements made by Human Factors specialists following observational analyses of the tasks performed by the potential end user population and their contexts. Under "Relevance", the possible entries are "Yes" (Y), "Further Investigation Required" (FI), or "No" (N). In the original BNFL matrix, a simple 5-point Usability rating scale (or "score") was also provided:

    1. From an ergonomics design and system integration perspective, the interaction device possesses features highly likely to support the user in performing observation, exploration or modification activities (see Section 4.3) intuitively within the target application.
    2. The interaction device requires minor modification and/or integration with other device(s) to become suitable in the support of the user in performing observation, exploration or modification activities intuitively within the target application. In an unmodified form, the device will require some adaptation on the part of the user, making it appropriate for some tasks only (possibly excluding those of a safety critical nature).
    3. The interaction device requires significant modification and/or integration with other device(s) to become suitable in the support of the user in performing observation, exploration or modification activities within the target application.

38 Stone, R.J. (1992), "British Nuclear Fuels Limited Agreement No. A022595 (Schedule 2): Natural Man-Machine Interface Study Final Report: Volume 1 - Review and Requirements", UK National Advanced Robotics Research Centre Report No. ARRL.92 002, March, 1992.

4. The interaction device shows potential for supporting the user in performing observation, exploration or modification activities within the target application, but requires further research / experimental investigation in order to make confident recommendations.
5. The interaction device is totally unsuited to supporting the user in performing observation, exploration or modification activities within the target application.

- Evidence supporting the maturity ("Low" (L), "Medium" (M), or "High" (M)) of the device under consideration (including whether or not there is evidence that the device is already "in the field", or "operational", or confined to one or more research laboratories). *Technology Readiness Levels* (TRLs[39]) are also useful to mention in this column.

- Costs (not just from an initial outlay point of view, but from an annual maintenance/support and software development perspective as well). Defining "Low" (L), "Medium" (M) and High "H" costs is an exercise that needs to be performed with end users and their organisational representatives in order to review market trends and customer "tolerance" levels.

- Evidence (from Human Factors references and literature searches) that supports the application of the specific device to a specific i3D/serious games training, education or prototyping role (including any established guidelines or standards that may exist). One of the major problems with the Human Factors and i3D community generally is that, whilst it is possible to find isolated papers in conference proceedings and journals of relevance to a guidelines document such as this, there is (as yet) no single publication that attempts to collate the most relevant findings from the research community and publish them under a single cover.

At the outset of this document it was stated that, despite the claims of the immersive Virtual Reality "purists", today's simulation and games users are, in the main, mouse, keyboard and flat screen exploiters. Occasionally, other COTS devices (such as joysticks, steering wheels and aircraft yokes) are exploited for certain games, such as those offering simulated experiences in civilian and combat flight or in *Formula 1* racing.

Given the failure of the VR community to achieve its end-of-(20th) century human-system interface "domination", it is, perhaps, understandable that today's i3D end users – a good number of whom will have been "victims" of the 1990s VR "bursting bubble" – will be very sceptical about novel input devices such as those shown in Figure 44 and throughout these guidelines. Whilst this scepticism is understandable, it can actually cause its own Human Factors problems. In the recent experience of the author, there are groups of researchers who, whilst still recovering from their VR experiences of the late 20th Century, are restricting their outlook by only considering interface designs based on the basic mouse and keyboard. Their negative, historical experiences with novel interactive devices seem to be preventing them from devoting at least a small amount of attention – suitably underpinned by Human Factors principles, of course – to alternative solutions.

When this happens, there can be a tendency to expect too much of the mouse and keyboard …

[39] See also: http://en.wikipedia.org/wiki/Technology_Readiness_Level.

5.1 Don't Expect Too Much of the Mouse!

Figure 45: Variations on the mouse.

Central (Red-Framed) Image: Doug Engelbart's Original Wood-Enclosed Mouse (SRI, 1968*).* *Image Source: www.bootstrap.org*

a: A4 Tech Opto-Mechanical (Ball) Mouse
b: Logitech *Trackman* Trackball Mouse
c: Logitech *G9* Mouse
d: Logitech *MX* and *VX* Mice
e: Belkin *Nostromo n30* Game Mouse
f: Microsoft *SideWinder* Game Mouse
g: IOGEAR *Phaser* Mouse with Trackball (and Nano-Particle Anti-Bacterial Compound Surface)
h: Logitech *MX Air Mouse*
i: Sandio 3D *Game O' Mouse*
j: 3M *Renaissance Mouse*
k: *CyberGun* (Lower) and *PistolMouse* FPS (Upper)
l: Mini Trackball (Finger-Mounted)
m: *Ring Mouse*
n: Logysis Optical Finger Mouse
o: 3D Finger Optical Mouse
p: EzKEY Keypad Mouse

Other Image Sources: Google Images

Even in cases where the sceptical end user refuses to accept anything other than a mouse to work alongside the keyboard for the purpose of interacting with i3D simulations and serious games, it can be tempting to procure mouse-like devices that are endowed with additional data input functions, such as those COTS products shown in Figure 45. As of Summer 2008, the market for mouse-like devices, let alone interactive devices in general, was awash with all manner of futuristic concepts and designs and, as was mentioned earlier in this section, there is no easy (or rapid) process by which interactive devices of this nature can be assessed from a human-centred design perspective.

Certainly, it is unlikely that external Human Factors pressures (unless they are concerned with health and safety issues, such as Repetitive Strain Injury (RSI) or forearm/upper-arm injuries) will, for the foreseeable future, have any major influence on the key market players. Indeed, and with one or two exceptions relating to basic ergonomic requirements presented in ageing military standards, the lack of generic Human Factors guidelines for the design of mice with integrated multifunction controls is quite astonishing, given its decades of existence! Nevertheless, and as has been stressed throughout this document, the role of task analysis is crucial in helping ensure that the extent to which the end user is coupled to the task in the real world (Section 4.4) drives the selection of the most appropriate interface device (COTS or otherwise).

In the case of the mouse, this is not necessarily a straightforward process and, despite the fact that many mainstream entertainment games allow the end user to modify mouse functions, the allocation of those functions to activities in i3D simulations or serious games-based environments must be thought through carefully. For example, mouse movement in egocentric (first-person) games may well be different when using the same design of mouse in an exocentric (third-person) game, although some of the additional control functions may be identical to both frames of reference (e.g. Table 3, page 58). Observational analyses and end user interviews (possibly allowing a selection of end users to experience a range of candidate mouse designs) will also help establish how many – and what type of – integrated functions the device should possess, and how those functions map intuitively onto the on-screen activities.

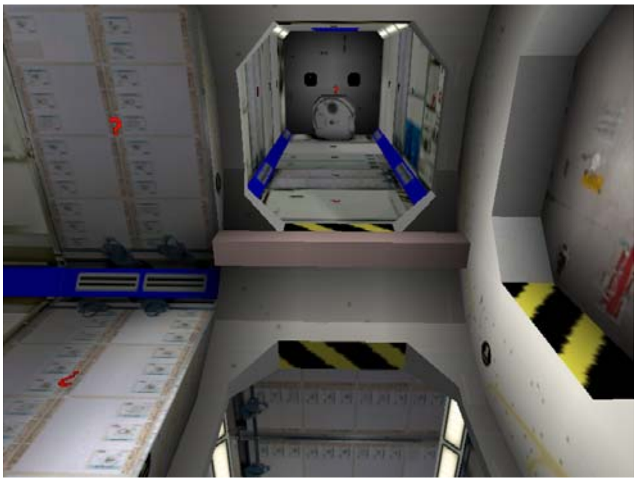

Figure 46: Interior of the *Unrealty* International Space Station model, showing "collidable trigger objects" in the form of 3D question mark characters.
Source: Author's Image Archive

Some of the items in parentheses in Table 3 suggest "secondary" functions that may not, at first glance, appear intuitive to some readers (note also that "DPI" in Table 3 refers to the resolution or sensitivity of the mouse which, with the Logitech *G7* example shown, can be selected by the user via the two DPI buttons below the scroll wheel). Take, for example, forward and backward movement using the left and right mouse buttons respectively. Normally, games players would expect to use specific keys on the keyboard to move in virtual space (such as the arrow keys or the W-A-S-D combination – see Section 5.2). However, there may be occasions where keyboard-based motion control is not available or desirable (at kiosks or exhibition stands, for example) and some other form of movement capability needs to be provided. In fact, for some applications demanding exploratory or navigation behaviours on the part of the end user, interactive ("point-and-click") demands on the mouse can be minimised by the use of other, on-screen cues and virtual "trigger objects". An excellent example of this was delivered by the developers of the original *Unrealty* Virtual International Space Station (based on the *Unreal*

Engine; see Figure 46[40]). Here, users could navigate both inside and outside the Space Station, simply by moving the mouse to change direction and by clicking the left and right keys to "fly" forwards and backwards, as if in conditions of artificial gravity. By entering new compartments or "colliding" with the 3D question mark icons (as can be seen in Figure 46), a voice would be triggered, providing the user with information relating to his or her location or an experimental module close by. As the virtual environment was designed from the outset to permit mouse-only interaction, the exploration experience was, in fact, quite intuitive.

5.1.1 Mouse Function Cueing

Mouse "function cueing" refers to the use of icons, symbols or small groups of alphanumeric characters to convey – on screen – how a particular mouse function works with a given task element or in a certain context. Typically cues are only displayed when an event is triggered, such as after an introductory animation, or if a specific object has been selected for inspection or manipulation. Function cueing is important, especially for early or infrequent users of an i3D/serious game-based simulation. In addition, experienced users should be given the opportunity to disable function cueing. Furthermore, the cues displayed must convey accurate information relating to the use of the mouse and should not obscure other task or context features.

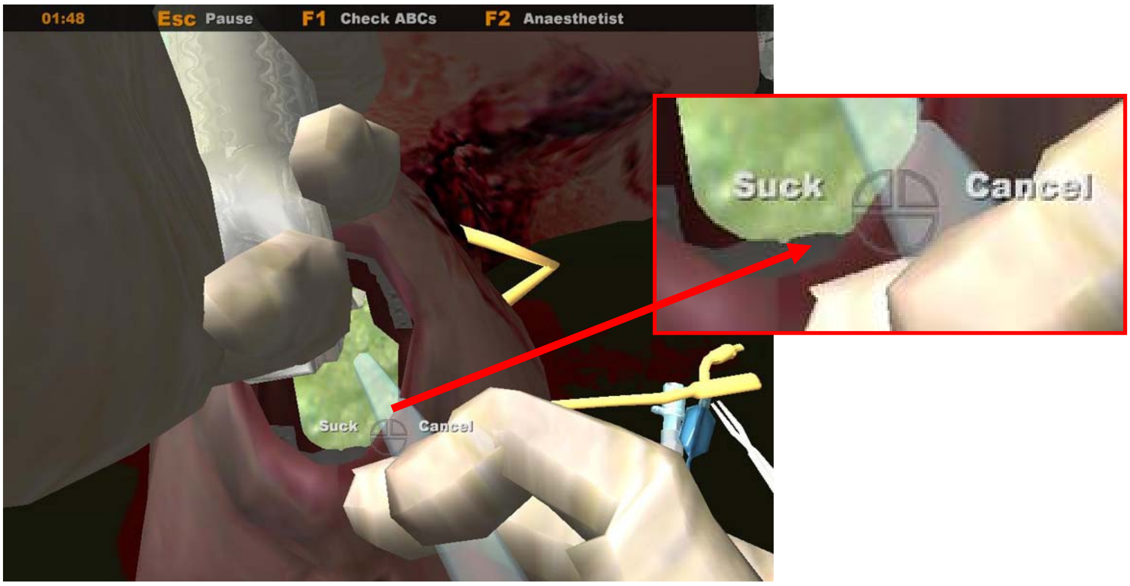

Figure 47: An example of simple but effective mouse function cueing (Interactive Trauma Trainer).
Source: Author's Image Archive

Examples of good and bad function cueing are illustrated in Figures 47 and 48. In Figure 47, the trachea suction cue ("suck-cancel") appears on-screen as the tube insertion animation sequence, previously triggered by the end user, comes to an end. The symbol is designed to show that suction is achieved by pressing the left mouse button. When complete, pressing the right mouse button triggers another animation – the tube is withdrawn and placed on a tray next to the trauma surgeon. The bad example of function cueing is shown in Figure 48. *SubSafe* trainees can click on extractable virtual objects in the scene (previously highlighted as "active" by the appearance of a label). As the object (the Hull Valve in Figure 48) "flies" toward the user's viewpoint, the mouse

---

[40] Unfortunately, references to the original *Unrealty* Virtual International Space Station project are limited on the Internet, although the demonstrator (*Unrealty* Client and Space Station files) can still be downloaded from http://iss.astronet.pl/virtualiss.htm (as of June 2008).

function cues appear, as shown in the red-bordered area. The cues consist of three sets of arrow icons (from left-to-right, these are: move extracted valve up and down, rotate valve in azimuth and elevation and zoom in and out). Underneath these arrow sets are further icons depicting relevant keyboard and mouse controls. Unfortunately, with the delivered version of *SubSafe*, the up-down function was actually redundant (as the virtual valve object should always be located in the centre of the screen), and rotation in elevation was not even enabled. In addition to these issues, the pre-rendered shadows of the extracted valve – virtual shadows that do not change as the object is manipulated – did not, it was felt, support the manipulation process either (see also Section 6.3).

Figure 48: An example of inappropriate cueing of mouse / keyboard functions, leading to possible end user confusion when trying to manipulate the "extracted" virtual valve.
Source: Author's Image Archive

In exocentric presentations, the cueing of mouse functions becomes even more important, as the amount of on-screen information can be more dense and dynamic than is often the case with egocentric presentations. This is partly as a result of the more distant presentation and will depend on the angle of exocentric presentation, as discussed earlier in this document. Consequently, care needs to be taken when relying on the mouse to govern such functions as:

- View rotation;
- Zoom-in and zoom-out limit cueing (particularly if there is a need to restrict the zoomed-in view with Low and High-Angle Projections to preserve believable levels of detail);
- Highlighting objects;
- Manipulating and operating objects;
- Directing individual or groups of avatars.

One entertainment game that demonstrated a reasonable attempt to achieve some of these features was *ER* – a hospital game based on the television programme of the same name (Figure 49).

Figure 49: Screenshot from ER – The Game.
Image Source: About.com: Computer Sim Games (http://compsimgames.about.com)

Table 3: Suggested Mouse Functions for Ego- and Exocentric i3D Reference Frames.
Based on Logitech *G7* Mouse.
Image Source: Google Images

Frame / → Activity	Egocentric (First-Person) Reference Frame				Exocentric (Third-Person) Reference Frame			
	Environment Navigation	Object Identification/ Select	Object Actuate	Special Functions	Environment Navigation	Object Identification/ Select	Object Actuate	Special Functions
Function ↓	Logitech *G7* "Primary" Controls							
Mouse Movement	"Look" Up, Down, Left, Right			Manipulate Object	Rotate About Fixed Point in Scene			Manipulate Object
Left Button (L)	(Move Forward)	Select or Highlight Object, Avatar, etc.	Actuate Object or Menu Item (Discrete)	Click to Allow Object Manipulation (Dynamic)	Select Next Waypoint for Avatar to Move To	Select or Highlight Object, Avatar, etc.	Actuate Object or Menu Item	Click to Allow Object Manipulation (Dynamic)
Right Button (R)	(Move Backwards)			Interrogate Object Selected (e.g. Call Up Drop-Down Menu)				Interrogate Object Selected (e.g. Call Up Drop-Down Menu)
Upper Wheel (UW) Rotate		Scroll Through Objects "Held"		Scroll Menu; Zoom View (e.g. Sight, Binoculars, etc.)	Zoom In / Out			
Upper Wheel Press		(Deactivate Mouse Look Functions and Activate Cursor)		(Screen Capture)				(Screen Capture)
Function ↓	Logitech *G7* "Secondary" Controls							
Upper Wheel Displace Left-Right	(Step Sideways)			Scroll Through Objects "Held"	(Fixed Rate Scroll; Left-Right)			
Thumb Button (TB)	Toggle Walk-Run							High-Level Menu Call-Up
DPI Button 1 (+)				Aiming Sensitivity				Mouse Sensitivity
DPI Button 2 (-)				Aiming Sensitivity				Mouse Sensitivity

5.1.2 Inappropriate Use of the Mouse

As well as attempting to exploit mice with multifunction qualities, there have been examples of designing i3D simulations where the essentially two-dimensional (planar) motion functions of the basic mouse are exploited inappropriately.

For example, research and development personnel involved with at least one medical games-based training system have contemplated slaving quite complicated movements of the user's virtual arm and hand to simple movements of the mouse, sometimes in conjunction with other function keys. This *must* be avoided, as achieving even simple arm-hand movement combinations and coordination requires the user to learn unintuitive mouse-and-keyboard data input combinations. In addition, unless the virtual arm and hand has been modelled accurately in 3D, with an appropriate underlying skeletal structure (similar to the complexity shown later for a virtual bomb disposal sniffer dog, for example – see Figure 71), then deformations in the real-time model can occur, as can "cross-talk" between limb axes, such that movement of one axis causes unwanted (and sometimes unnatural) movement in another.

An excellent example illustrating these problems was the game *Jurassic Park: Trespasser* (also the first game to exhibit "ragdoll physics" – see Section 6.5). In this game up to five keyboard buttons/mouse functions could be pressed to manipulate the arm and hand for certain functions (picking up, dropping, moving, swinging and rotation), sometimes resulting in a range of physically impossible (real-world) arm postures (Figure 50). These problems were exacerbated by the fact that the medium-fidelity graphics did not support shadowing or other strong monocular cues to depth of field, therefore accurate positioning of the hand was made even more difficult.

Figure 50: Mouse-controlled arm / hand movements in *Jurassic Park: Trespasser* (1998).
Source: Author's Image Archive

Clearly, this form of interaction, whilst just tolerable for a game (where it undoubtedly added to the overall amusement value), would very likely compromise performance and skill acquisition if adopted for a serious application of games-based technology. Indeed, for simulations where time is of the essence (trauma or life-saving interventional scenarios, for example), then it is of vital importance that end users focus on the simulation content, as opposed to the hardware or software technique used to interface to that content (e.g. Barnett et al., 2000; *op cit*. – see Section 2, Key Points Summary).

For real-time applications, and until master-slave-type technologies (such as exoskeletons, instrumented gloves, motion capture devices, etc.) become unintrusive, reliable and affordable, arm-hand *animation* should always be preferred over direct slaving between input device and virtual limbs.

5.2 Don't Expect Too Much of the Keyboard!

Turning now to the keyboard, and despite its long history, there is much controversy about which keyboard functions to choose when interacting with a simulation or serious game. For example, games developers and experienced games players are content to use the W-A-S-D keys to control movement functions (forward - sidestep left – backward – sidestep right) in conjunction with mouse control of viewing direction. Some keyboard users prefer W-A-X-D, E-S-D-F, R-D-F-G and many other combinations[41]; others prefer the arrow keys (either the isolated arrow set or those located on the numeric keypad).

Although, at first glance (especially for Human Factors specialists and newcomers to gaming), using keys whose letters (and to some extent location on the keyboard) bear little or no relevance to on-screen navigational directions, there are some well-established arguments in favour of using these. For instance (and for right-handed mouse users), it is sometimes claimed by proponents of the W-A-S-D layout that this option best serves the seated posture in that it keeps the display, keyboard and mouse positions roughly symmetrical about the left and right "halves" of the human torso (the *midsagittal* plane in anatomical terminology). Such a layout, it is also claimed, puts a number of other important gaming keys within reach of the fingers and thumb (e.g. space bar, function (F) keys, shift key, etc.).

Those in favour of the arrow keys (which are, after all, more intuitive when it comes to governing on-screen movements, especially for naïve users) claim that moving the keyboard a few centimetres to the left would have little impact on their seated gaming posture. Indeed, some of the more important activity keys would still be within reach of their left hand (including spacebar = jump, 'c' = crouch, shift key = toggle "run", +/- = zoom in, zoom out, etc.).

In essence, and whilst the keyboard-mouse combination remains the most commonplace of human-computer interfaces, the argument as to their appropriateness in i3D and games applications will continue. Fortunately, most game editors support control options that enable the end user to change the key selection to meet his or her preferences. One general caution to mention with regard with keyboards is that i3D designers should avoid integral touch pads or mini cursor controls embedded within keyboards. A combination of such factors as sensitivity, size, the proximity of other keys and the need for finger control make them non-ideal devices for interacting with i3D or serious games-based simulations. This is especially the case when controlling first person views, for tracking dynamic elements in the virtual scene, or for highlighting and directing (for example) avatars when in an exocentric reference frame.

[41] A *Wikipedia* entry on this subject makes for very interesting reading: http://en.wikipedia.org/wiki/WASD.

Figure 51: Art.Lebedev Studio's *Optimus Maximus* (Upper) and *Tactus* (Lower) programmable keyboards (note that the keys on the *Maximus* have been programmed to support the game *Half-Life*).
Source: www.artlebedev.com

A final important issue with regard to keyboard usage in i3D or games-based simulations is to consider the question: should a keyboard be used at all? Requiring the end user to learn which function is governed by which key (and it is not always possible to select a letter key that has some relevance to the function, such as 'c' for crouch, or 'p' for prone) adds an element of cognitive complexity that is best avoided in most educational or training simulations, unless, of course, keyboard training is part of that simulation.

Keyboards with programmable display keys, capable of displaying user-customised icons, are becoming more available, such as Art.Lebedev Studio's *Optimus Maximus* OLED and *Tactus* keyboards (see Figure 51). These keyboards offer the potential of removing the cognitive load on the end user when he or she has to search for specific alphanumeric keys during a simulation. As can be seen in Figure 51, non-essential keys can effectively be "switched off", and others can be endowed with application-specific icons or symbology.

However, at the time of writing, these devices cost considerably more than a conventional keyboard (e.g. around £UK 940 for the *Optimus Maximus*, as of June 2008!) and suffer from certain basic ergonomic problems, such as the pressure needed to actuate the keys. Each key consists of an OLED (Organic Light-Emitting Diode) unit, together with a mechanical switching component, which renders touch-typing quite difficult. Applications that require discrete or momentary, as opposed to dynamic or continuous key pressing, may be better suited to these keyboards (in their current technological state). Gaming is a good example of just such an application.

In the meantime, then, one should still question the need for the presence of a full QWERTY keyboard from the outset of an i3D/serious game design project. If multifunction key presses are required, then an alternative might be to consider exploiting a smaller programmable keypad. Note that the Interactive Trauma Trainer, shown in Figures 9, 25, 26 and 29, with the exception of one function key press (which could have been allocated to pressing the mouse wheel), requires no keyboard input at all on the part of the end user. Medical device selection, test, application and operation are all achieved by left or right mouse clicks and, as emphasised earlier (Section 3), complex arm and hand movements are all committed to animation sequences.

5.3 Novel Commercial Off-The-Shelf (COTS) Interactive Hardware

The COTS computer peripherals depicted in Figures 44 and 45 represent just a small selection of available control or data input devices (as of January 2008). As with the Virtual Reality era, there is already evidence that many of the control devices available from today's COTS market are beginning to feature in i3D and serious games research projects across the globe (see also Figure 5 in Section 2.1). The Nintendo *Wiimote* and *Nunchuk* controllers are good examples of this (Figure 44, bottom right-hand corner and earlier in Figure 7). The current *Wii* "pandemic" shows how developers assume that, because a device finds positive statements about usability in one market (i.e. the home entertainment arena), that same acceptance will automatically become evident when the device is used for more serious applications of games-based technologies. The number of Internet news items proclaiming the *Wii* controller as a serious data input device (for example, to improve surgical dexterity, support exercise régimes, even foster food preparation skills!) is very much on the increase. No doubt, as competitors to the *Wii* controllers emerge, such as the Motus *Darwin* (a *Wii*-like controller for other games consoles and PCs), other so-called "serious applications" will be reported. However, as hinted in Section 2.4, just assuming an input device with novel (and "wow") design features will, in isolation, bring intuitive control features to an otherwise contemporary (some might even say "boring") human-system interface is not recommended, as is relying on the results of small end user sample studies in high-profile application domains, such as defence and surgery.

Unfortunately, the problem does not simply stop at exploiting the out-of-the-box control device. Images and videos are now appearing on the Internet showing data input devices from today's market being used to add functionality to the somewhat experimental and hastily-marketed devices of yesteryear. One good example is the use, by a Japanese gamer, of (yet again) the Nintendo *Wiimote* controller to endow an old Mattel *Power Glove* with spatial tracking capability (Figure 52).

Figure 52: Mattel *Power Glove*, modified using a Nintendo *Wiimote*.
Source: sygg.web.infoseek.co.jp/neta/061206.html

The *Power Glove* product was never provided with a reliable form of hand/arm tracking, the ultrasonic system only providing limited hand translation and rotation sensing. However, these outlandish creations are often the creation of academic laboratories and "garage" technology developers. Their true value as reliable and ergonomically acceptable interactive devices for specific training purposes is highly questionable. The same concern is true of the myriad of current COTS devices, just a small sample of which appears in Figure 44. Another trend evident in the interactive device and gaming market relates to the development of haptic feedback systems. As mentioned earlier, the term "haptics" refers to the "science of touch" and is considered by many to be crucial for human exploration and manipulation of the world, be that world real or virtual. It is not the intention to deliver a comprehensive review of haptic feedback technologies, as such reviews are available elsewhere[42;]

[42] Stone, R.J. (2000), "Haptic Feedback: A Brief History from Telepresence to Virtual Reality", in Brewster, S. and Murray-Smith, R. (Eds.), *Haptic Human-Computer Interaction* (Proceedings of the First International Workshop, Glasgow, 31 August to 01 September, 2000), *Lecture Notes in Computer Science* No. 2058, Springer-Verlag, 2001, pp. 1-16.

[43] and the Internet is awash with good sites detailing new research developments and listing proprietary products.

However, it is important to understand that, at the time of writing, there is no one haptic feedback system that is capable of delivering a completely realistic, universal tactile or force sensation that is freely wearable and unintrusive. Even considering human tactile sensing mechanisms alone, the multiplicity of cutaneous and subcutaneous sensory systems[44] cannot be served by any one current generation tactile transducer. Some of the haptic feedback scenarios one sees on the Internet and in marketing material – for example, showing gloved hands interacting with apparently solid virtual steering wheels and other equipment – are cases of "wishful thinking". In addition, the very complex and costly arm-hand exoskeleton-glove combinations (e.g. Figure 53) are still unproven from a real-world application perspective and remain interesting devices for research within academic and government research laboratories.

Figure 53: "Haptic Workstation".
Source: vrlab.epfl.ch

Having said that, there are some excellent haptic devices on the market that lend themselves very well to certain applications, such as specific surgical interventions – laparoscopy and mastoidectomy, for example (see Sections 3 and 4.1). Indeed, nearly any surgical procedure where there is an intermediate structure coupling the surgeon to the patient that is in some way "fixed", either to the wall, ceiling or operating table, or to a penetration node on the human body[45]. This fixing point enables the haptic feedback system to generate realistic simulations of forces and torques, by exploiting a dependency on physical structures, rather than attempting to reproduce the effects of gravity and forces experienced during free-space manipulation (e.g. when trying to handle objects that are not immediately connected to physical features in the real world).

If the Human Factors observations or task analyses isolate interactive events that might benefit from the implementation of a structurally-supported haptic feedback system, then haptic feedback technologies are worth reviewing, especially with regard to the three key human-centred design issues listed at the start of Section 5 and the headings shown in Table 2. However, designers must be certain from the outset that implementing complex haptic feedback within an i3D simulation or serious game adds value and does not compromise the end user's performance. Designers must also be sure that what is actually needed is haptic feedback as opposed to *haptic cueing*, where simple tactile stimuli (e.g. "rumble" or vibrotactile functions in mice and gamepads) are used to cue features of the Virtual Environment that are either invisible to the end user or cannot be adequately displayed using the visual and auditory senses alone.

---

[43] Burdea, G.C. (1996), *Force and Touch Feedback for Virtual Reality*, John Wiley & Sons.
[44] For example, *Ruffini Endings* (Skin Pressure), Hair Follicle Endings (Hair Displacement), Free Nerve Endings (Mechanical, Thermal, Chemical), *Meissner Corpuscles* (20-40Hz Vibration), *Pacinian Corpuscles* (150-300Hz Vibration), *Krause Corpuscles* and *Merkel Cells* (Pressure), to mention but a few.
[45] For example, in laparoscopic surgery, *trochars* penetrate through the abdominal wall to provide a physical conduit and point of rotation for any laparoscopic instrument being inserted into the abdominal cavity. When the surgeon moves his/her instrument, s/he will see a reversal of that movement on the endoscopic camera display.

Section 5.0
Interactive Fidelity
Key Points Summary

- **Interactive fidelity is closely related to task fidelity and task coupling (see Key Points Summary for Section 4.0 – page 45), especially when considering the adoption of off-the-shelf human-computer interface technologies and the degree to which they support the end user's performance with the simulated tasks.**
- **Human Factors consideration must be given the appropriateness of the interactive device selected, how well that device supports the end user's virtual activities (navigation, manipulation, and so on), how well discrete and dynamic input commands map onto displayed functions and how usable – from an ergonomics perspective – the device actually is.**
- **When selecting a novel interactive device for use in serious games or i3D applications, always seek Human Factors advice and conduct a literature search to establish whether or not that (or a similar) device has been used to good effect in other similar applications.**
- **Avoid the temptation to integrate a novel interactive device simply because it would become an attractive and attention-grabbing "gimmick", or because it receives considerable coverage and acclaim from the gaming media and from online review sources.**
- **Novel interactive technologies used for mainstream entertainment gaming platforms may not be appropriate for their serious gaming counterparts.**
- **If the Human Factors analysis suggests that the serious game or i3D simulation does not require an innovative off-the-shelf interactive device, one should pay as much attention to the implementation of appropriate keyboard and mouse functions as one would to the exploitation of a less conventional technology.**
- **Do NOT demand too much of the keyboard and mouse when designing serious games or i3D simulations. Question whether or not a full QWERTY keyboard should be used at all, or whether a programmable keypad would deliver the required level of interactivity.**
- **Avoid using the mouse to control multi-axis functions, such as virtual arm and hand motions.**

Section 5.0 – Main References

Stone, R.J. (1992), "British Nuclear Fuels Limited Agreement No. A022595 (Schedule 2): Natural Man-Machine Interface Study Final Report: Volume 1 - Review and Requirements", UK National Advanced Robotics Research Centre Report No. ARRL.92 002, March, 1992.

6.0 Context Fidelity

Earlier in the document the term "context" was used to refer to the design of appropriate "background" sensory and behavioural detail in i3D or serious games systems. It was stressed that background effects and scenarios should complement – and not interfere with – the task being performed and, therefore, the learning outcomes. Unfortunately, the design of contexts in simulations often leaves a lot to be desired from a Human Factors perspective. It is evident that, on occasions, simulation and game designers adopt an attitude that their end users are "blinkered" and somewhat naïve individuals who are likely to be so engrossed with the task that cutting corners during the design of scenarios will be tolerated or missed altogether. In other cases, examples of hyper-fidelity abound in background contexts and serve only to distract the end user considerably from his or her task.

It has already been shown that errors in the design of task elements can be detected by end users – some of whom are not games players from the outset. A good example is the "impossible reflection" in the virtual laryngoscope mentioned in Section 4.2 (reference the Interactive Trauma Trainer).

Figure 54: Context fidelity issues in early triage training game-based scenario.
Source: Author's Image Archive

A context-related example is shown in Figure 54 (expanded upon in Section 6.5 relating to "Context Fidelity – Special Case: Avatars, NPCs and Virtual Agents"). Note here the fact that the paving stones around the incident victim are covered with shards of glass, yet the exposed parts of the victim's body, not to mention his clothing, are cut-free, despite his very close proximity to the blown-out windows. Also note the lack of blood on the floor and clothing, despite the obviously serious injury to the victim's leg. Other context-related examples are given below. It may well be that many end users will be so engaged with the task in hand that some of these omissions will go unnoticed. However, as the end user community becomes more informed and more critical (from a gaming perspective[46]), these kinds of omissions could possibly lead to criticism, distraction and/or an absence of believability or engagement. In the final triage training demonstrator, some (but not all) of these omissions were corrected.

In general, then, as much Human Factors attention needs to be given to the content and fidelity of the scenario as to the design of the simulated tasks themselves, and the issues covered in Section 4.2 relating to hypo- and hyper-fidelity are just as important[47]. Furthermore, as the simulated context will feature heavily in the end user's navigation, exploration and event recall behaviours,

---

[46] Games magazines, Web features and television programmes such as *Gamer TV* may have considerable influence on how perceptive and critical gamers can become when evaluating new games for the first time.

[47] Tversky (2005) distinguishes between the space of the body, the space around the body, the space of navigation and the space of external representation; these issues are central to the issues of task and context design as presented in this document and how design in i3D simulations or serious games influences the development of spatial cognition (Tversky, B. (2005), "Functional Significance of Visuospatial Representations", in Shah, P., & Miyake, A. (Eds., 2005), *The Cambridge Handbook of Visuospatial* Thinking, Cambridge University Press).

close attention to issues such as believable content, fidelity and consistency (see below) is of crucial importance. From a Human Factors observational perspective, the following basic issues need to be addressed.

6.1 Task-Supportive Context Elements

Are there elements of the context(s) that directly support the performance of the task?

These might include:

- Features of the immediate workspace or bodyspace[47];
- Features of the immediate workplace – internal and/or external scenarios (the space around the body[47]);
- Features of the navigation space[47];
- Presence of other actors (e.g. team members – see also Section 6.5);
- Normal or special environmental conditions (relevance of sensory cues – including sound – plus physically constraining features);
- Health and safety issues.

Examples related to many of these points have been described earlier in this document.

6.2 Task-Hindering Context Elements

Are there elements of the context(s) that may adversely affect or hinder the performance (or believability) of the task?

Areas of concern here include:

- Background/ambient sound;
- Ambient visual conditions;
- Features of the navigation space;
- The degree of environmental "clutter" (natural or man-made);
- The behaviours of other actors (see Section 6.5).

One example of how features of the navigation space can hinder the performance of the end user is the humble ladder! In many First-Person Shooter games at the time of writing, ladders are essential parts of gameplay and present "obstacles" that contribute to the time pressure and overall enjoyment of the action. However, there are often certain interactive issues with how one ascends and descends a virtual ladder that would hinder performance in a serious game and result in end user frustration.

Figure 55: Ladder scenes from *Half-Life 2*, *Episode 2*.
Source: Author's Image Archive

Using the game *Half-Life 2* as an example (Figure 55), to overcome this obstacle, one has to approach the ladder (whereupon there is an automatic registration of one's "desire" to ascend the ladder), look upwards and move forwards. On ascending the ladder there is sometimes a tendency to "stick" to the topmost rung. One then has to use another function key (e.g. "jump", via the spacebar, for instance) to detach from ladder – this can result in falling to the bottom if the angle of one's immediate view is incorrect. When wishing to descend a ladder, it is sometimes difficult to register the position of one's virtual body with the top of ladder – sometimes falling is inevitable (and highly frustrating).

For these reasons, it may be necessary to implement some other form of ladder or staircase "navigation" (and, indeed, to *train* safe ladder negotiation using real facilities!). In the submarine safety game *SubSafe*, for example, 3D arrows appear on approach to ladders between decks (Figure 56). Mouse-clicking an arrow actuates a "teleport" function, making the transition between decks potentially less frustrating than negotiating 3D ladder models. However, in cases such as this where the recording of task time is important for performance evaluation, the simulation "clock" needs to be incremented automatically to represent the time taken to ascend or descend a real ladder.

Figure 56: Use of ladder ("deck transition") arrow cues in *SubSafe*.
Source: Author's Image Archive

6.3 Inappropriate Context Elements & Distraction

Are there elements of the context(s) which, if implemented inappropriately in an i3D or game-based simulation, would distract the end user during performance of the task(s)?

Areas of concern here include:

- Local or remote environmental features;
- The degree of environmental "clutter";
- Actor interactivity.

Local or remote environmental features may well present distraction opportunities. For example, the application of spot, diffuse lighting and specular bump-mapping effects to the field hospital tent canvas surface in the Interactive Trauma Trainer serious game (Figure 57 shows the effect next to an image of an actual tent interior). This effect gives a visual look similar to the silver paper once included with cigarette cartons. This is very evident during the animated tent entry sequence at start-up, but becomes distracting as the end user looks around his or her immediate first-person location in the scenario (a simplified canvas material/texture finish would appear less dramatic).

Figure 57: Lighting effects in virtual field hospital tent (left) in contrast with real tent environment.
Source: Author's Image Archive
and Defence Image Database (CROWN COPYRIGHT)

Another issue noted by nearly all Interactive Trauma Trainer (ITT) test users was the extent of the development company's "advertising" – not only showing the development company's logo on the screen, but on the virtual screens in the far right-hand corner of the field hospital tent. In fairness, this latter effect was only slightly evident during the animated tent "walk-in" sequence at the start (see Figure 57, left image, indicated by the red arrow), but could, if the ITT was developed with more freedom of movement within the tent, become quite distracting.

Grass textures can also provide a source of disruption to the end users of i3D or game-based simulations. Take for example the EOD application described earlier. The need for high-fidelity context modelling and visual effects was central to the success of the development of this early prototype. If, as was the case with legacy simulators (some of which are still in existence today), *flat* grass textures were applied in the fields shown earlier in Figure 34, then this would have provided for a totally unrealistic virtual training scenario. Figure 58 shows the problem. The left-hand image of Figure 58 is based on a flat grass texture and the explosive ordnance command wire is, as a result, visually prominent. The right-hand image of Figure 58 exploits a pseudo-3D virtual grass effect based on multiple texture layers, each layer boasting a different level of transparency. Here the command wire is more concealed and the EOD search task more realistic as a consequence.

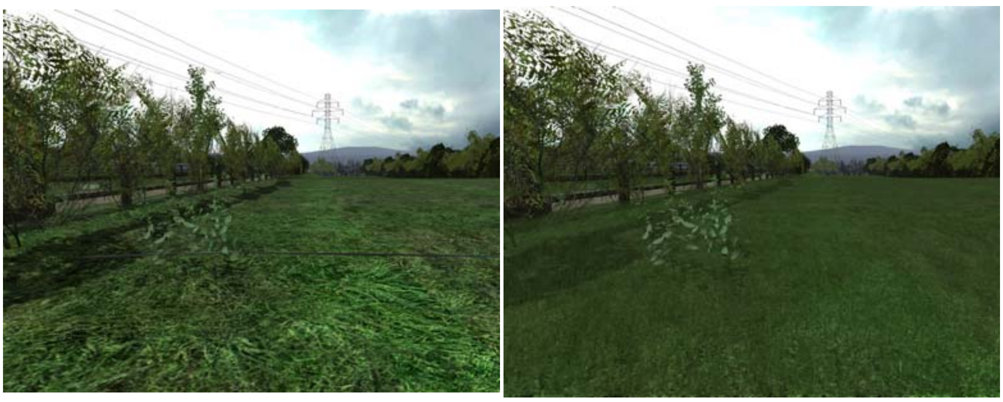

Figure 58: Grass textures (flat – left image; pseudo-3D – right image) and perceptual effects on "concealed" objects.
Source: Author's Image Archive

Pre-Rendered shadows also have to be implemented with care. Shadow pre-rendering is a process normally applied to objects whose positions are fixed within a virtual environment. The shadows do not move relative to any changes in the location of ambient or point light sources (such as a torch) and, as a result, distraction and/or disbelief in the simulation can readily occur. Distractive effects can be kept to a minimum either by surrounding or partially obscuring the object with a degree of "clutter", or by using subtle shading to convey just enough of a shadow effect to achieve an acceptable degree of contextual realism.

However, problems can occur if there is a need to access the object in question for inspection or manipulation. A good example of this is shown in Figure 59 (upper image pair). When in situ, the pre-rendered shadows applied to the submarine Forward Escape Compartment Main Valve are appropriate. However, when that valve is removed for inspection (upper right image), the pre-rendered shadows are inappropriate and may additionally obscure features of the valve or text on labels.

In contrast, the Line Replaceable Units delivered with the *Tornado* ATF maintenance trainer (mentioned in Section 4.1) were not subjected to any form of pre-rendering. So, when extracted (Figure 59, lower image pair), realistic shadows were not cast by or onto the LRUs. However, there was, in fact, no need to do this, as the method of extraction and manipulation was intentionally designed *not* to reflect what actually happens in the real world (as explained earlier in this document).

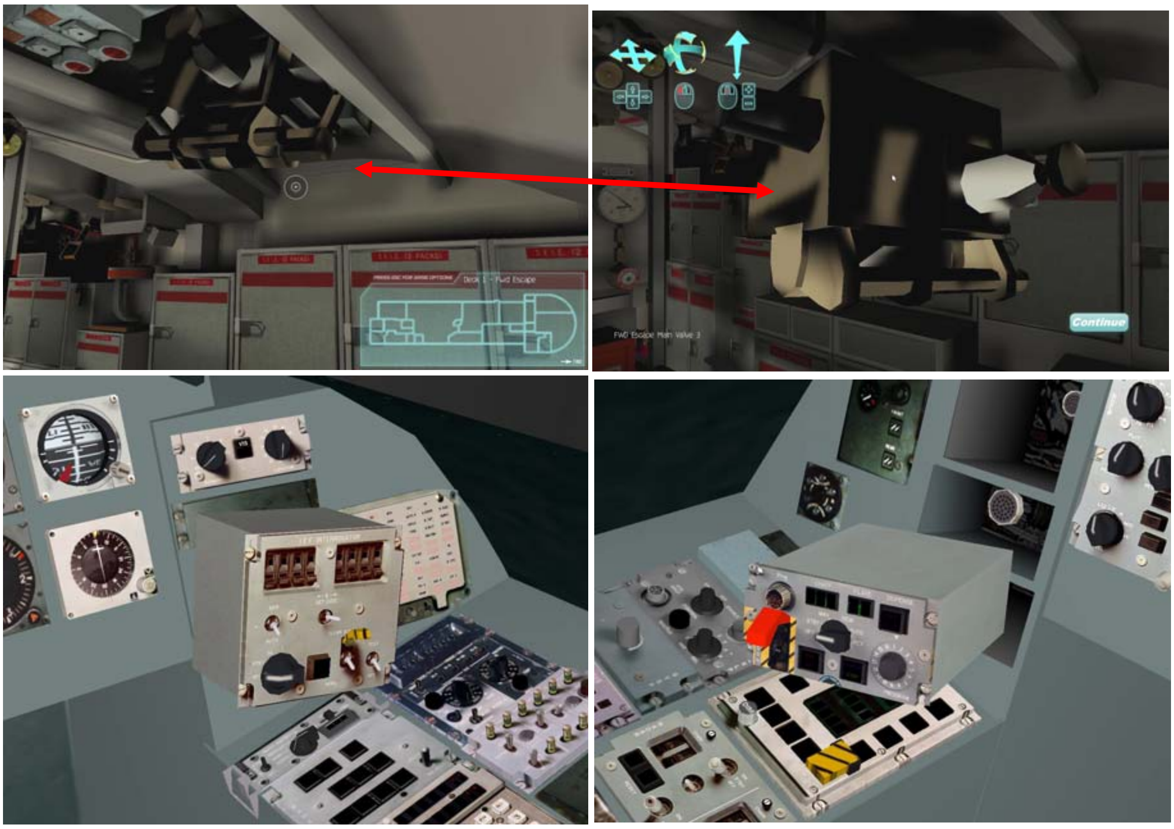

Figure 59: Examples of objects extracted from their context and (uppity image pair) the inappropriateness of pre-rendered shadowing.
Source: Author's Image Archive

Other context effects employed by i3D and games developers can also produce distraction if they are implemented to an extreme level. Such techniques include *zone culling* and *level of detail* (l.o.d.) *management*, and support the gradual and selective removal of graphical features of the 3D environment, either when they are at a great distance from the observer or outside of his or her immediate viewpoint. For example, if one is inside one of many compartments making up a virtual ship, the other compartments need not be drawn, or *rendered*. Therefore they are *culled* from the end user's immediate view of the virtual scene. If one is, say, 10 metres away from a virtual control panel, it need only be displayed as a simple cuboid. As one moves closer and the panel's displays and controls gradually become the centre of visual attraction, the culling of objects outside one's field of view frees up computer processing power, thereby enabling the displays and controls to be drawn at increasing *levels of detail* (by gradually increasing geometric and/or texture complexity – "fading l.o.d."). These and other processes maximise the VR system's real-time performance by concentrating the computer's rendering power on the scene being displayed.

On occasions these effects can be quite drastic. The level of detail in the rail track in Figure 60 (right image) degrades far too quickly, from a combination of geometric rails and a medium-resolution gravel texture in the foreground to a simple blurred flat texture in the distance. In some circumstances, such a dramatic l.o.d effect could compromise two of the strongest monocular visual cues to depth and distance – linear perspective and texture gradient. Other techniques that help to minimise the computational loading on real-time graphics processors include *billboarding*. Distant buildings can be represented as flat geometric surfaces with simple frontage textures, as opposed to complex 3D entities.

Figure 60: Examples of *billboarding* (left image - *Half-Life 2, Episode 2*: the trees behind the detailed models left of centre are simple textured billboards) and *level of detail* effects (right image - *Half-Life 2*: the railway track changes from a model comprising 3D features and textures to simple textures of decreasing resolution as the distance from the end user's viewpoint increases).
Source: Author's Image Archive

Distant trees can be designed in a similar fashion, or as intersecting 2D planes, each with flat tree textures (Figure 60, left image). In older i3D simulations (and many legacy military simulations even today), this "cardboard cutout" effect was acceptable. However, today's games-based engines (notably *CryEngines* 1 and 2) are highly capable of rendering quite detailed dynamic foliage and billboarded trees and bushes should be avoided, except at long viewing distances and when fronted by more detailed models. Figure 61 shows a scenario from *Half-Life 2*, where textures of trees, landscape features and clouds have been pasted onto a distant "skydome". Note the repeated tree textures along the base of the sky dome and also the texture *tessellation* (regular patterning) of the polluted river under the road bridge.

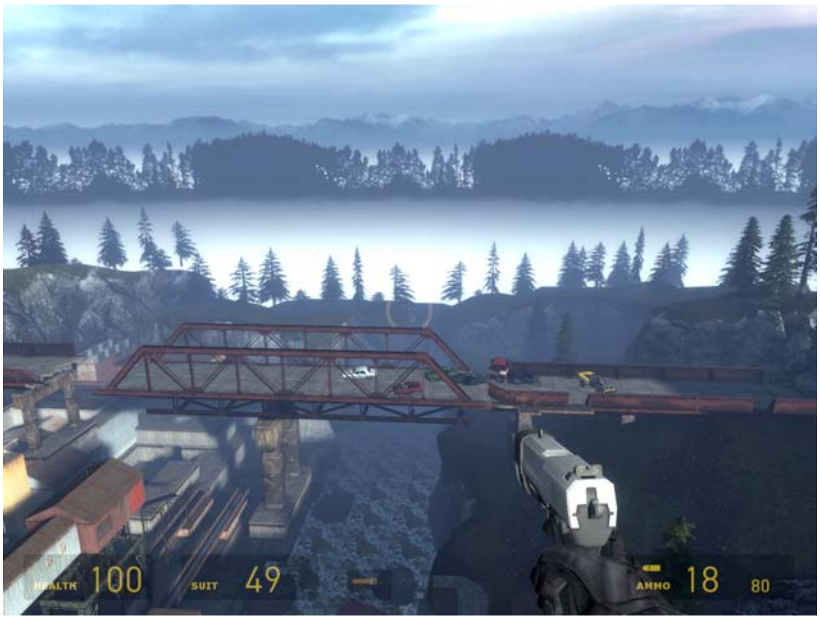

Figure 61: A non-gameplay view of one of the *Half-Life 2 Episode 2* scenarios using the "noclip" function, showing "edge of world", sky / horizon dome and tessellation effects (see repeated tree pattern on horizon and pollution pattern under bridge).
Source: Author's Image Archive

Tessellation can be a particularly distracting and annoying effect in present-day simulations and games-based environments. Although a certain amount of tessellation can be tolerated, especially in First Person (egocentric) visual frames (see Section 4.3), exocentric presentations such as that shown earlier in Figure 34 (EOD Search & Disposal Scenario) need to be designed with care as different amounts of the Virtual Environment surrounding the focal avatar(s) become visible depending on what angle of viewing projection is adopted. The higher the angle, the more of the virtual world is seen by the end user and the more exposed tessellation, billboarding and skydome implementations become.

In general, and from a context design perspective, considerable care must be taken when including l.o.d., billboarding, edge-of-world and sky or horizon dome effects, texture tessellation, or partial model fascia to represent buildings. If applied without reference to the end user's task, they can be distractive and trivialise the simulation.

A final example of a context-distractive element is "environmental clutter". For example, in real-world settings, the existence of litter (trash) or other forms of clutter often goes unnoticed in most cases. However, when implemented in an i3D or serious game simulation (e.g. Figure 62, left image), such features can distract the "impressed-with-the-detail" end user from his or her main task and encourage inappropriate interaction, such as picking up objects or trying to destroy them. The opening sequences to the game *Half-Life 2* are a good example of this. The train station scenario is littered with discarded items (cartons, bottles, suitcases), many of which can be picked up, thrown and broken. None of these features are actually relevant to the task (which is, simply, leaving the train station without "antagonising" the military police).

Returning to Figure 62 (left image), if the main i3D task requires the military user (for example) to be vigilant for snipers in nearby buildings, then distraction caused by inappropriate context elements, such as litter, could result in poor training outcomes. If, on the other hand, the task of the user is to be alert for potential explosive ordnance, then the presence of litter and other objects may well be appropriate.

Figure 62: Potentially distracting (hyper-fidelity) examples – litter in a road-and-building search scenario and overly-detailed posters and pamphlets in a trauma hospital corridor.
Source: Author's Image Archive

Similarly, the existence of features such as non-task specific information bulletins, posters or leaflet racks in virtual hospital settings (Figure 62, right image) has been shown to distract nurses from their primary task of patient care – something that would probably not happen in real-world contexts. The right-hand image of Figure 62 is from an early iteration of the US Virtual Healthcare Project *Pulse!!* [48]. Interestingly, an Internet-hosted review of *Pulse!!* (*Business Week*, 10 April 2006) had the following to say about the fidelity of the hospital context (which is modeled accurately on one of the departments at Bethesda Naval Hospital near Washington DC):

> "Some of the design details are uncannily precise. A nurse who saw the graphics told us she was embarrassed because she recognized the old bulletin boards. She realized that the staff hadn't changed some of what's been posted for something like 10 years …".

One has to question whether or not the simulation was designed to foster healthcare skills for the care of traumatised patients or perceptual skills supporting aesthetic reviews of building information boards!

6.4 Consistency of Context Fidelity

Are there any specific context features that, if not implemented consistently within or across a scenario, may present inappropriate cues and, thus, confound the end user's task performance?

Some training applications may well demand that context fidelity is consistent across a given scene, such as in a complex control room, where the task being trained includes the location and operation of safety- or mission-critical controls and displays. In such a task, the use of prominent control geometries, or high-resolution textures depicting items the end user must locate "framed" within lower-resolution context textures, may artificially focus the end user's attention on the target item(s). The upper left image of Figure 63 shows this with respect to the Emergency Blow Valve pair on a submarine control panel (just left of centre). Here, high resolution texture and geometric models of the valves have been inserted into an otherwise low-resolution panel texture. In the case of the *Tornado* F3 Avionics Maintenance Trainer (Figure 63, upper right image), described in Section 4.1 and shown additionally in Figure 23, creating a believable virtual cockpit context required careful

[48] http://www.sp.tamucc.edu/pulse/home.asp

attention to the use of high-quality digital textures mapped on to simple flat surfaces, interspersed between the functional (active) 3D models of display and control components. Distractive effects can also be brought about by oversimplifying natural effects (Figure 63, lower image pair). Here, the Virtual Environment on the left is of general high fidelity, but on close inspection, the puddles appear to resemble transparent blue sheets of Perspex laid onto the ground. Real-time water effects, along with other natural features, demand care when implemented in a Virtual Environment. Otherwise they can stand out from the otherwise high quality images, thereby leading to task distraction.

Figure 63: Appropriateness and consistency in context design elements.
Source: Author's Image Archive

6.5 Context Fidelity – Special Case: Avatars, "Non-Playable Characters" and Virtual Agents

Of the issues listed throughout Sections 6.1, 6.2 and 6.3, the presence of, and interaction with, other "actors", is one of particular Human Factors interest. Whilst task and context fidelity play a key role in both engaging the end user and in supporting his or her effective learning uptake from Virtual Environment or game-based training technologies, the visual and dynamic qualities of actors or *agents* within those contexts – specifically virtual humans and animals – can make or break the acceptance and credibility of the simulation at a very early stage.

Of particular interest are "NPCs", or non-playable (non-player) characters, as these tend to be the more prevalent in First-Person games at the present time (although networked versions of FP games enable players to control their own avatars and view the avatars controlled by other players). In mainstream games, NPCs can be adversaries, allies, or simply bystanders, their behaviours typically triggered by specific events throughout the game or by the actions of the player. The extent to which those behaviours are scripted (i.e. pre-programmed procedural actions) or based on

Artificial Intelligence (AI) depends on the complexity of the game design (Figure 64). In parts of the game *FarCry*, for example, small groups of NPCs were programmed with two basic levels of AI, such that their retaliatory behaviour when attacked depended on whether or not their "leader" had been terminated at the outset. Without a leader, NPCs would exhibit more unfocused and uncoordinated retaliation strategies than was the case when the leader was still present in the game. In *Assassin's Creed*, and despite the mixed reviews of the game's AI, the NPCs in crowds react to the player's in-game behaviour – the more extreme the behaviour, the more members of the crowd exhibit fear or intolerance; the more "acceptable" the behaviour, the more the crowd supports the player's attempts to "blend in" ("social stealth").

Figure 64: NPCs in *FarCry* (left) and *Assassin's Creed* (right).
Source: media.teamxbox.com and insidegamer.nl

Sometimes, the behaviour of NPCs can be very frustrating indeed and some examples of avatar AI have even been referred to as Awesomely Incompetent[49]! In *Half-Life 2*, for example (Figure 65), there are occasions where the avatars are actually obstructive, due to the fact that they move aimlessly around the player's viewpoint, avoiding contact if possible, when all the player requires is to get the group to "bond" and follow him/her on to the next objective.

Figure 65: "Loitering" avatars in *Half-Life 2* – when approached (i.e. player tries to pass through), each agent responds by executing an avoidance movement, often "colliding" with other avatars.
Source: Author's Image Archive

[49] A phrase coined by reviewer Gregory Thompson when reviewing the game *SOCOM 3: US Navy Seals* on videogames.lovetoknow.com.

The visual detail of avatars, regardless of their player-controlled or NPC status, must be given adequate and early Human Factors attention. For example, unless the simulation has been intentionally designed using a low physical fidelity approach (such that agents in the virtual scenario can be represented by simplified human representations without compromising the psychological fidelity) and/or a high- (and distant) projection exocentric frame of reference frame has been adopted (see Section 4.3), avatars with identical features should be avoided (Figure 66). Low-fidelity avatars for online community applications, such as *Second Life*, are acceptable (at the time of writing), as the myriad of activities one can experience in that environment outweighs the shortcomings of the task and context fidelities. However, in more serious applications, both task and context fidelities become more important and warrant close Human Factors attention. The inclusion of identically-featured avatars in a medical training scenario runs the risk of the end user experiencing recency conflicts in short-term if interaction with avatars is sequential (as in the Triage Trainer example shown in Figure 66)[50]. Having evaluated the health of one avatar in this triage scenario, there could be a risk of confusing and misreporting the condition of the next avatar (a “haven’t I seen you before?”, or “weren’t you just suffering with …?” effect).

Figure 66: Identical “persona” avatars in a triage trainer serious game.
Source: Author’s Image Archive

An exception to this rule applies to some defence i3D environments involving groups of NPCs where, even in First-Person or egocentric frames, identically-faced NPCs may be acceptable when designed wearing significant headgear (such as combat helmets with goggles, radio microphones), thereby obscuring facial details. However, care must be taken to ensure that, in cases where team command structure is important, then the role/status of NPCs is made clearly visible, either by obvious clothing or weapon differences or through the markings on, around or above each avatar (as in the multiplayer version of *Call of Duty 4 – Modern Warfare*, for example; Figure 67).

[50] It has been theorised that specialised memory processes may store information about elementary features of the visual world, such as the orientation, colour, motion and texture of visual patterns, assimilated across fairly short time spans (hence “recency”) to help construct more permanent object representations (e.g. Magnussen, S. & Greenlee, M. (1999), “The Psychophysics of Visual Memory”, *Psychological Research*, 62, 81-92).

Figure 67: Screenshot from *Call of Duty 4* showing basic avatar labelling.
Source: barelylethal.com

As a general rule, if the chosen modelling tools or simulation/games engines are incapable of supporting an acceptable level of visual and dynamic detail for human or animal avatars, then, to preserve the engagement of the end user, one should consider either static avatars ("placeholders") or symbolic representations of human and animals (e.g. flat shaded models, even billboards). "Blending" static, billboarded characters with dynamic avatars in a scene is also acceptable, as long as those characters display context-appropriate background static poses (e.g. waiting in a queue, making a mobile 'phone call, standing in front of a shop window or kiosk, etc.). Static, billboarded representations of avatars with context-inappropriate or an "on-the-move" pose can be distractive and will do little to enhance the believability of the simulation. From a Human Factors perspective, it is far better to introduce very low physical fidelity representations from the outset, rather than risk early disengagement on the part of the end user because the avatars are "not quite right".

Furthermore, the i3D designer should not rule out the use of other media if it is felt that the most appropriate level of avatar fidelity for the task cannot be achieved, for whatever reason. In simulated scenarios where the majority of activities involve interaction between the end user and the virtual actor(s) – an interview scenario, for example – then it might be more appropriate and cost effective to exploit *video* as the media of choice, whereby the responses of real actors can be integrated into branching virtual interview sessions, with i3D vignettes inserted at appropriate stages. This is especially important if the i3D designer is unable to spend time achieving realism, particularly in modelling detailed facial characteristics of avatars (e.g. as can be seen in Figure 68[51]) or, worse still, cannot preserve those modelled features in the real-time environment due to the choice of a particular simulation or games engine.

Of particular interest are the eyes of avatars. "Dead Eye Syndrome" is a common problem inherent with some avatar designs and will most certainly result in issues of acceptability and believability on the part of the observer, especially in real-time interaction applications. With Dead Eye Syndrome, the eyes of the avatar are inappropriately animated and may appear fixed and dilated, even though

[51] The facial models depicted in Figure 68 were developed by TruSim (www.trusim.com) for the TSB project addressing video games to create serious training applications, mentioned at the outset of this document.

other facial components have been endowed with movement patterns – cheek muscles, eyelids and eyebrows, for example. As a result, the virtual characters take on a "doll-like" quality and often elicit feelings of "eeriness" in those individuals who have to observe or interact with them. One often-quoted example of where Dead Eye Syndrome was very noticeable was in the computer-animated film *Polar Express* (Figure 69). Some critics lay the blame for the extent of the effect firmly on an exploitation of whole-body motion capture technologies, often to the exclusion of more subtle, yet as-important forms of human non-verbal communication[52].

Figure 68: Examples of high-fidelity facial models (TruSim).
Source: Author's Image Archive

Figure 69: Images from the 2004 Film *Polar Express*, showing examples of "Dead Eye Syndrome".
Source: Google Images and Frame Grabs From Promotional Video Trailers

Even with low-fidelity avatars, accurate movement patterns (especially when distant from the end user's viewpoint) are as important as (and sometimes more important than) the visual features of the avatar itself. One application where the movement patterns of avatars were judged to be inappropriate to the particular context was a games-based demonstrator designed to investigate how the technology might support therapeutic programmes associated with mental health issues in defence. This *CryEngine*-based project consisted of a number of short scenarios relating to urban patrol and attendance at an incident in a Middle East-like setting. For example, the user could be confronted with an empty street, containing some burned-out and abandoned vehicles and background distant noise. A *Warrior* Armoured Fighting Vehicle (AFV) together with a small Army

[52] http://wikidumper.blogspot.com/2007/04/dead-eye-syndrome.html

contingent was visible around 400-500 yards from the user's "start" position and he or she had to walk towards the vehicle and climb inside. Another scenario included a combination of elements, such as overhead helicopter activity, *Adhan* chants emanating from a nearby virtual mosque, a crowd in the vicinity of the AFV, with accompanying shouts, screams, local gunfire and an explosion during the early part of the *Warrior* approach (Figure 70).

Unfortunately, the size and (rather simplistic hand-waving) visual behaviour of the crowd in the vicinity of the *Warrior* AFV did not match the level of crowd activity suggested by the scenario sound effects. Whilst the early part of the AFV approach routine was very engaging, the scenario was let down by the avatar hypo-fidelity in the latter stages of the demonstration. Another issue related to the use of (or reliance on) pre-preprogrammed avatar behaviours to create "realistic" loitering behaviours. Whilst some of the *CryEngine* loitering behaviours were acceptable in this context (glancing, turning on the spot, even neck scratching!), others were not, such as shoelace tying whilst the avatar was positioned with his back to the crowd!

Figure 70: Small visual crowd accompanying large crowd sound effects in early defence mental health therapy serious games demonstrator (HFI DTC).
Source: Author's Image Archive

Another lesson to be learned here is that, if other sensory channels are to be stimulated in an i3D or serious games environment, such as sound, then the extent of the auditory effect must match the visual image presented to the end user. If there is a mismatch between sensory cues, then the credibility of the simulation will be compromised.

Another example of avatar motion fidelity relates not to human avatars, but to animal representations. In general, animal representations have, to date, been somewhat unimpressive, even in games where considerable effort has been expended in the design of human characters, natural terrains and so on. For instance, during the game *FarCry* there is the occasional appearance of a wild boar. As well as the fact that the three-dimensional representation of the creature was actually quite poor, its style of motion across the terrain was both comical and distracting. The movement effect can only be described as a combination of simplistic leg motion whilst hovering just above the ground! Whilst these limitations may be acceptable in games where animal representations provide a simple context or background feature, their incorporation into other simulations and serious games cannot be treated as lightly. Figure 71 shows a 3D model of a Springer Spaniel "sniffer" dog, as deployed by British Army patrols whilst conducting early route searches for explosive ordnance. To achieve the 3D representation in Figure 71 took some considerable time, experimenting with hair effects and differing complexities of "boning" or "rigging" (the process by which the 3D model is endowed with a virtual "skeleton" – links and joints that define the level of detail achievable for animation purposes – Figure 71, insert). Unfortunately, even with the extent of rigging achieved, the animal's motion patterns – based on video footage of a dog participating in a mock explosive ordnance location exercise – were not of an acceptable quality. Consequently, it was decided to render the dog in a static pose (albeit with moving tail!), some distance away from the main part of the simulation. In this way, the credibility of the game-based simulation was preserved from the outset, the static dog being less likely to distract the end user or damage the credibility of the simulation by virtue of some rather comical movement patterns.

Figure 71: Virtual Springer Spaniel developed for an explosive ordnance search and disposal planning / training serious game demonstrator (HFI DTC). Insert image shows complexity of underlying "boning" or "rigging" to make the dog animation as realistic as possible.
Source: Author's Image Archive

A final note on the subject of avatar motion fidelity relates to one of the gaming community's most exploited effects, *ragdoll physics*. Ragdoll physics is a special form of procedural animation for avatar motion, typically used to simulate the absence of muscular control when, for example, the avatar is "killed" in an action game sequence (Figure 72, insert). Ragdoll physics exploits the hierarchical structure of rigged avatar bone structures, as described above.

Although ragdoll physics support reasonably accurate interactions ("collisions") between the avatar and its immediate environment, the flexible nature of the rigging underlying the 3D representation (i.e. the absence of stiffness between joints) means that, for certain actions and events, there is a distinct lack or realism in the animation. This is most noticeable if the avatar falls from height or is close to an explosion. In the latter case, the virtual body – which is frequently intact after the blast – flails through the air and hits the ground in an often comical or compromising pose (Figure 72, outer images).

This can be quite a distracting, hyper-fidelity effect for the observer and, as a consequence, the use of ragdoll physics should be given careful consideration before implementation in a serious game. The effects should be used sparingly and only when they closely approximate their real-life counterparts. For serious games applications, ragdoll physics should **not** trivialise the effects of explosions or other weapons effects on the human body.

Figure 72: Extracts From a short video sequence showing typical ragdoll animations. Middle image shows a ragdoll effect in the game *Call of Duty 4*.
Source: Video Screen Captures – http://www.youtube.com/JerezJulio and Call of Duty 4 (In-Game)

Section 6.0
Context Fidelity
Key Points Summary

- **Effective serious games / interactive 3D systems design demands attention to context as well as task fidelity – end users can be highly critical of inaccuracies or "cut corners" in Virtual Environments.**
- **Hypo- and hyper-fidelity effects are as important in the design of contexts as they are in the design of tasks.**
- **When undertaking an early Human Factors task analysis or end user observation, record elements of the real context that support the execution of tasks or could potentially hinder the execution of tasks or distract the end user if implemented inappropriately in the Virtual Environment.**
- **Ensure that context features are implemented with a degree of consistency across a Virtual Environment, in order to avoid inappropriate masking or exposure of key task elements.**
- **The use of virtual characters (*avatars*) in serious games or i3D simulations demands special care and attention. The visual and dynamic qualities of avatars can, if implemented inappropriately, destroy the "believability" of a simulation from the start.**
- **With particular reference to *non-playable characters* (NPCs), ensure that their behaviours (scripted or Artificial Intelligence-based) are relevant to the context or scenario and that they do not impede the performance of the task in any way (unless the simulation design demands some form of impedance, as may the case in close combat or crowd scenarios).**
- **If the gaming or simulation engine is incapable of supporting realistic avatar representations and behaviours, or the application does not require the identification of individual entities, use simple representations, such as billboarded (2D) characters or simple flat-shaded 3D human forms. Billboarded characters can be "blended" with dynamic avatars, as long as the billboarded representations depict context-appropriate, static, background behaviours.**
- **For task sequences involving close-up interaction between the end user and avatar, pay careful attention to non-verbal characteristics and features, in particular gestures, eye movement and eye quality. Consider using video sequences with live actors if there is any possibility of losing the end user's believability in the simulation.**
- **Avatars that are not central to the task and cannot be animated with a reasonable degree of lifelike movement should be relegated to distant locations within the virtual world.**
- **Ensure context consistency when implementing avatars. For example, avoid large crowd sounds when only a small crowd is visibly present in the Virtual Environment.**
- **Avoid entertainment gaming effects that impart an unnecessary comical element to a simulation, or may trivialise an otherwise serious application (e.g. *ragdoll physics*).**

Section 6.0 – Main References

Magnussen, S. & Greenlee, M. (1999), "The Psychophysics of Visual Memory", *Psychological Research*, 62, 81-92.

Tversky, B. (2005), "Functional Significance of Visuospatial Representations", in Shah, P., & Miyake, A. (Eds., 2005), *The Cambridge Handbook of Visuospatial* Thinking, Cambridge University Press.

7.0 Concluding Comments

If one actually believed the claims of the “purists” throughout the 1990s, Virtual Reality was, by the end of the 20th Century, destined to have helped computer users abandon the keyboard, mouse, joystick and computer display in favour of interfaces exploiting a wide range of natural human skills and sensory characteristics. They would be able to interact intuitively with virtual objects, virtual worlds and virtual actors whilst “immersed” within a multi-sensory, 3D computer-generated world. As is evident today, this brave new world simply did not happen. Despite sizeable early investments, national initiatives, expensive (and unexploited) international collaborative projects and the proliferation of hardware-heavy, so-called centres of “academic excellence”, VR delivered very little of use to the global IT community. A handful of organisations actually adopted VR, but most were deterred from doing so by its complexity and cost. Today’s VR supply companies have either passed away or are hanging on by a commercial thread. The academic centres have closed, or have been re-branded to fall in line with current research funding initiatives, or have simply become expensive technological museums. And the biggest mistake made by the VR community was that it ignored the human factor.

Over a decade on and there is little doubt that games-based learning technologies have the potential to deliver much more than the promises and hype of their VR predecessors – affordability and accessibility in particular. However, to do this, human-centred lessons must be learned. Interactive 3D media has to be designed in conjunction with its end users, identifying the skills that need to be trained or the knowledge that has to be imparted and then delivering a solution based on appropriate content, fidelity and interactive technologies. Furthermore, the training solutions must be packaged in a form that can be delivered to the end users in the their own working environments, as opposed to expecting them to exploit the technology in isolated and restricted laboratory environments. The solutions must be developed so that the end users can understand and benefit from their contents immediately, supporting *their own* modifications through simple-to-use shape, texture and behavioural editors. This is where yesterday’s VR failed. This is where today’s games-based interactive technologies have the potential to give the i3D community a second chance.

This document and its subsequent editions aspire to be an integral part of the second chance scenario. As stressed at the outset, this is the first of what will hopefully become a series of updated guidelines that are designed to expose Human Factors, games development and end user communities to basic issues relating to human-centred design in games-based training (and other forms of media based on interactive 3D) to ensure that “human pull” prevails over “technology push”.

7.1 Future Editions

It was also stressed at the outset of this document that a sizeable proportion of the comments and recommendations presented herein have been based on many years of involvement on the part of the author with the i3D community. It was stated that “evidence” underlying the recommendations comes from the results of applying i3D technologies to a range of real-world domains, primarily (but not exclusively) in the field of defence part-task training. With this in mind, and as well as informing the i3D and serious gaming communities about basic HF issues that warrant early consideration in VE/SE training design processes, another aim of this document is to challenge the international research community to undertake meaningful experimental programmes and produce results that can be used to support or refute these experiential recommendations. It is the intention of the HFI DTC to publish subsequent editions of these guidelines as additional data become available, both via application and experiment. Future editions will also expand the sections dealing with interactive devices to include specific guidelines relating to display technologies and novel input/control systems. Comments and contributions to subsequent editions – even requests for guidelines for specific issues not yet covered – are most welcome and can be sent to the author using the contact details given below. All contributions will be fully acknowledged.

Another point to emphasise is that the present document has focused mainly on the exploitation of games-based technologies for applications in specific areas of part-task training for sectors including defence, aerospace, emergency services, medicine and surgery. There are those "purists" in the gaming community who would consider many of the examples contained herein *not* to be representative of gaming, but more relevant to the real-time simulation or VE community. It was not the aim of this document to enter into a debate about what does or does not constitute a games-based simulation. Rather, the document set out to raise the awareness of the importance of considering HF issues throughout the i3D design process, irrespective of whether the system is a game or simulation, 2D or 3D in nature, first-person or third-person and so on. Indeed, the terms i3D, serious game and VE have been used interchangeably throughout this document. As experience with other games-based formats evolves, HF issues relevant to these will be included in future editions of the guidelines.

Prof. Bob Stone

Human Interface Technologies Team
Department of Electronic, Electrical & Computer Engineering
University of Birmingham
Gisbert Kapp Building, Pritchatts Road
Edgbaston
Birmingham, B15 2TT
United Kingdom

Tel. (Office): (+44) (0)121-414-7395
Tel. (Mobile/Cell): (+44) (0)7740-858901
Fax: (+44) (0)121-414-4291
E-Mail 1: r.j.stone@bham.ac.uk
E-Mail 2: profbobstone@aol.com

Abbreviations

2D	Two Dimensions (or Two Dimensional)
3D	Three Dimensions (or Three Dimensional)
ABC	Airway-Breathing-Circulation
AFV	Armoured Fighting Vehicle
BERR	Department for Business, Enterprise & Regulatory Reform
CAD	Computer-Aided Design
CAVE	Cave Automatic Virtual Environment
CD	Compact Disk
CGI	Computer-Generated Imagery
COTS	Commercial Off-The-Shelf
CRW	Close-Range Weapons
DEMSS	Defence Explosives, Munitions & Search School
DIUS	Department for Innovation, Universities and Skills
DPI	Dots Per Inch
DPM	Disruptive Pattern Material
DTC	Defence Technology Centre
DTI	Department of Trade & Industry (now BERR)
DVD	Digital Video (Versatile) Disk
ENT	Ear, Nose & Throat
EOD	Explosive Ordnance Disposal
FP(S)	First-Person (Shooter)
HAP	High-Angle (Exocentric) Projection
HCI	Human Computer Interaction
HF(I)	Human Factors (Integration)
HFI DTC	Human Factors Integration Defence Technology Centre
HMD	Head-Mounted Display
HP(A)	High-Pressure (Air)
i3D	Interactive 3D
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
IT	Information Technology
ITT	Interactive Trauma Trainer
JSF	Joint Strike Fighter
LAP	Low-Angle (Exocentric) Projection
l.o.d.	Level of Detail
LRU	Line-Replaceable Unit
MIST	Minimally Invasive Surgical Trainer
MMI	Man-Machine Interface
MMO	Massively Multiplayer Online
MMVR	Medicine Meets Virtual Reality
NPC	Non-Playable (or Non-Player) Character

OLED	Organic Light-Emitting Diode
OTS	Over-The-Shoulder
RAF	Royal Air Force
RN	Royal Navy
RPG	Role-Playing Game
RSI	Repetitive Strain Injury
SE	Synthetic Environment(s)
SG	Serious Games
SG ETS	Serious Games – Engaging Training Solutions (Technology Strategy Board-sponsored SG project (UK) – see Preface)
SME	Subject Matter Expert
TPS	Third-Person Shooter
TRL	Technology Readiness Level
TV	Television
UAV	Unmanned (Uninhabited) Air Vehicle
UK	United Kingdom
US	United States (of America)
VE	Virtual Environment
VR	Virtual Reality
VSD	Vertical Situation Display
VSMM	Virtual Systems and Multi-Media

Bibliography

Anon. (2007), "A Generic Process for the Verification & Validation of Modelling and Simulation & Synthetic Environments Systems"; Interim Defence Standard 03-44, Issue 1; Publication Date: 31 January 2007.

Brooks, T.L., and Bejczy, A.K. (1985), "Hand Controllers for Teleoperation; a State of the Art Technology Survey and Evaluation"; JPL Publication 85-11; Jet Propulsion Laboratory; Ellson, D.C.

Bergeron, B. (2006), "Developing Serious Games"; Charles River Media Inc.

Farrell, R.J., and Booth, J.M. (1984), "Handbook for Imagery Interpretation Equipment"; Boeing Aerospace Company (Seattle, Washington 98124), Report No. D 180-19063-1.

Gee, J.P. (2003), "What Video Games have to Teach Us About Learning and Literacy"; Palgrave Macmillan.

Gee, J.P. (2007), "Good Video Games + Good Learning"; Peter Lang Publishing Inc.

Michael, D., & Chen, S. (2006), "Serious Games: Games That Educate, Train and Inform"; Thomson Course Technology.

Novak, J. (2008), "Game Development Essentials"; Thomson Delmar Learning.

Schiflett, S.G., Elliott, L.R., Salas, E., & Coovert, M.D. (Eds., 2004), "Scaled Worlds: Development, validation and Applications"; Ashgate Publishing.

Shah, P., & Miyake, A. (Eds., 2005), "The Cambridge Handbook of Visuospatial Thinking"; Cambridge University Press.

Stone, R.J. (1997), "Report on 3D Representations for Tactical Displays"; DERA (Portsdown) Centre for Human Sciences; Project No. CHS0/5002S; performed under subcontract to Gregory Harland Ltd (Windsor).

Wickens, C., Todd, S., and Seidler, K. (1989), "Three-Dimensional Displays: Perception, Implementation, and Applications"; (CSERIAC-SOAR-89-001). Wright-Patterson Air Force Base, AAMRL.