ENABLING EXPLORATORY LEARNING THROUGH VIRTUAL FIELDWORK

Kristoffer Marc Getchell

A Thesis Submitted for the Degree of PhD
at the
University of St. Andrews

2010

Enabling Exploratory Learning Through Virtual Fieldwork

Kristoffer Marc Getchell

A dissertation submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

of the

University of St Andrews

May 2009

School of Computer Science

University of St Andrews

St Andrews, FIFE

KY16 9SX

Abstract

This dissertation presents a framework which supports a group-based exploratory approach to learning and integrates 3D gaming methods and technologies with an institutional learning environment. This provides learners with anytime-anywhere access to interactive learning materials, thereby supporting a self paced and personalised approach to learning.

A simulation environment based on real world data has been developed, with a computer games methodology adopted as the means by which users are able to progress through the system. Within a virtual setting users, or groups of users, are faced with a series of dynamic challenges with which they engage until such time as they have shown a certain level of competence. Once a series of domain specific objectives have been met, users are able to progress forward to the next level of the simulation.

Through the use of Internet and 3D visualisation technologies, an excavation simulator has been developed which provides the opportunity for students to engage in a virtual excavation project, applying their knowledge and reflecting on the outcomes of their decisions. The excavation simulator enhances the student learning experience by providing opportunities for students to engage with the archaeological excavation process in a customisable, virtual environment. Not only does this provide students with an opportunity to put some of the theories they are familiar with into practice, but it also allows for archaeology courses to place a greater emphasis on the practical application of knowledge that occurs during the excavation process.

Laconia Acropolis Virtual Archaeology (LAVA) is a co-operative exploratory learning environment that addresses the need for students to engage with archaeological excavation scenarios. By leveraging the immersive nature of gaming technologies and 3D multi-user virtual environments (MUVEs), LAVA facilitates the adoption of exploratory learning practices in environments which have previously been inaccessible due to barriers of space, time or cost.

Acknowledgements

I would never have completed this work, and the dissertation chronicling it without the help, support and guidance of many people. Amongst the masses, the following people deserve a special mention:

- Dr Alan Miller and Dr Colin Allison, my supervisors. Your assistance throughout this PhD has been invaluable. Without your advice, support and encouragement I would not have got this far. Thank you for your willingness read my work right down to the last minute.

- Dr Alan Miller and Dr Rebecca Sweetman for coming up with the idea for this work and providing the enthusiasm and resources required to make it possible.

- Everyone who has been involved in LAVA: Ross, Sarah, Jeremy, Vicky, Ruth, and Clare.

- My current and past office mates: Tommy, Iain, Ying, Ittipong, and David. You have put up with a lot and always with good grace. I was certainly kept entertained and I hope you were too…though I don't think I'll play backgammon again!

- My friends, both here and over there. You have offered light relief and many a distraction when one was called for. You all know who you are, but Richard, David, Alan and Andy deserve a special mention.

- My family who've put up with the perpetual excuses for having not yet submitted and given me perfect opportunities to escape for a breather every now and then.

- Wendy, my mum, for her unfailing support and encouragement when I've needed it most…even if I have rung during tea or when it's otherwise inconvenient. Thanks for being there.

- Finally, and most of all, I would like to thank Rachel. You have been wonderful. You've kept me going and had faith in me throughout this process. Your proof reading and crash courses in the use of colons and semicolons in the final hours was invaluable. You've taken my mind off things and put up with a lot. Thank you!

Without all of these people this dissertation, funded by an EPSRC Studentship grant would not have been written.

Note on References

Due to the nature of the gaming industry and computing community in general, several of the sources referred to in this dissertation exist only on the World Wide Web. All Universal Resource Identifiers (URIs) have been checked, but their longevity cannot be guaranteed. Where appropriate the bibliographic references contain a date of citation (As recommended by BS ISO standard 690-2 [1]) that indicates when the URI of the source in question was checked and found to be functioning correctly. Where appropriate and allowed by copyright laws, PDF copies of all URIs referenced have been produced and are available for public download from: http://phdlinks.getchell.co.uk/.

Declarations

I, Kristoffer Marc Getchell, hereby certify that this thesis, which is approximately 79,995 words in length, has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

I was admitted as a research student in September 2004 and as a candidate for the degree of Doctor of Philosophy in September 2005; the higher study for which this is a record was carried out in the University of St Andrews between 2004 and 2009.

Date _____ Signature of Candidate _____

I hereby certify that the candidate has fulfilled the conditions of the Resolution and Regulations appropriate for the degree of Doctor of Philosophy in the University of St Andrews and that the candidate is qualified to submit this thesis in application for that degree.

Date _____ Signature of Supervisor _____

In submitting this thesis to the University of St Andrews I understand that I am giving permission for it to be made available for use in accordance with the regulations of the University Library for the time being in force, subject to any copyright vested in the work not being affected thereby. I also understand that the title and the abstract will be published, and that a copy of the work may be made and supplied to any bona fide library or research worker, that my thesis will be electronically accessible for personal or research use unless exempt by award of an embargo as requested below, and that the library has the right to migrate my thesis into new electronic forms as required to ensure continued access to the thesis. I have obtained any third-party copyright permissions that may be required in order to allow such access and migration, or have requested the appropriate embargo below.

The following is an agreed request by candidate and supervisor regarding the electronic publication of this thesis:

(i) Access to printed copy and electronic publication of thesis through the University of St Andrews.

Date _____ Signature of Candidate _____

Date _____ Signature of Supervisor _____

Contents

Chapter 1 – Introduction **1**
1.1 Introduction 1
1.2 Overview of LAVA 2
1.2.1 Introduction 2
1.2.2 The Student Experience 3
1.2.3 System Architecture 7
1.2.4 The 3D Environment 8
1.3 Dissertation Roadmap 11
1.4 Chapter Summary 13
Chapter 2 – Research Context and Design Motivation **14**
2.1 Introduction 14
2.2 Learning as a Process 16
2.2.1 Bloom's Taxonomy of Learning; Encouraging Educationally Positive Behaviours 19
2.2.2 Anderson's Updates to Bloom's Taxonomy; Relevance for the 21st Century 21
2.2.3 Impact on LAVA Development 23
2.3 The Role of Pedagogy in Shaping Learning Design 24
2.3.1 Established Models of Learning 25
2.3.2 Constructivism and Constructivist Approaches to Education 28
2.3.3 The Influence of Computer Game Methods 29
2.3.4 Summary 30
2.4 The Impact of Technology and Technological Enhancement 32
2.4.1 The Effect of Technological Innovation 35
2.4.2 Software in the Educational Sector 37
2.5 Applying New Technologies in the Educational Sector 40
2.5.1 Presentation of Learning Materials 42
2.5.2 Engagement, Presence and Interactivity 44
2.5.3 Learner Differences, Learning Styles and Cooperative Working Arrangements 46
2.5.4 Summary 47
2.6 Chapter Summary 48
Chapter 3 – Design Process and Development Methodology **50**
3.1 Introduction 50
3.2 The User Environment 50
3.3 The Development Process 51
3.3.1 Scale Within the 3D Environment 52
3.3.2 Concurrency, Coordination and Synchronisation 52
3.3.3 Managing the Software Lifecycle 54
3.4 Chapter Summary 55
Chapter 4 – Case Study **56**

4.1 Introduction 56
4.2 The LAVA Case Study 57
4.2.1 Learner Engagement 57
4.2.2 Personalisation 57
4.2.3 Groupwork and Collaborative Working 57
4.2.4 Realism 58
4.2.5 Accessibility 59
4.3 Challenges Associated with Teaching Archaeology 59
4.4 Case Study Aims and Objectives 61
4.4.1 Teaching and Learning Objectives 61
4.4.2 Research Objectives 65
4.5 The Excavation of the Sparta Basilica 66
4.5.1 Historical Significance of the Excavation Site 66
4.5.2 Excavation Timeline 66
4.5.3 Analysis of Excavation Findings 67
4.5.4 Scope for Future Excavation and Research on the Site 70
4.6 Design of the Excavation Simulator 71
4.7 User Perspective 72
4.7.1 Accessing the System and Resource Organisation 72
4.7.2 Progression Through an Excavation 73
4.7.3 Summary 85
4.8 System Structure 85
4.8.1 LAVA Excavation Logic 87
4.8.2 Integration with Existing Institutional Infrastructure 88
4.8.3 Integration with Multi-User Virtual Environments 90
4.8.4 Conclusion 90
4.9 Design Decisions 91
4.9.1 Educational Design Decisions 92
4.9.2 System Structure and Design 95
4.9.3 Technological Decisions 100
4.10 Implementation 103
4.10.1 Simulation Logic 103
4.10.2 Data Layer 106
4.10.3 Second Life Development 107
4.11 Chapter Summary 112
Chapter 5 – Evaluation 114
5.1 Introduction 114
5.2 Research Methods 115
5.2.1 Qualitative Research Methods 116
5.2.2 Quantitative Research Methods 116

5.2.3 Qualitative versus Quantitative Research Methods 117
5.3 Methodology 118
5.3.1 Aspects and Metrics 119
5.3.2 Evaluation Techniques 120
5.3.3 User Evaluation 123
5.3.4 System Evaluation 130
5.4 Analysis of Subject Demographic 136
5.5 Analysis of Results 138
5.5.1 Year 1 139
5.5.2 Year 2 142
5.5.3 Year 3 146
5.5.4 Summary 149
5.5.5 Implications with Respect to LAVA Framework 152
5.6 Chapter Summary 154
Chapter 6 – Related Work 156
6.1 Introduction 156
6.2 Web-Based Virtual Learning Environments 157
6.2.1 Objectives and Functionality Provided 157
6.2.2 Specific Implementations 158
6.2.3 Relevance to LAVA 167
6.3 e-Learning Standards 168
6.3.1 Objectives and Functionality Provided 169
6.3.2 Specific Standards Bodies 170
6.3.3 Relevance to LAVA 172
6.4 Edutainment 173
6.4.1 Objectives and Functionality Provided 174
6.4.2 Relevance to LAVA 175
6.5 Gaming and Serious Games 175
6.5.1 Objectives and Functionality Provided 177
6.5.2 Specific Implementations 179
6.5.3 Relevance to LAVA 186
6.6 Multi-User Virtual Environments (MUVEs) 188
6.6.1 Objectives and Functionality Provided 189
6.6.2 Specific Implementations 190
6.6.3 Relevance to LAVA 192
6.7 Chapter Summary 194
Chapter 7 – Summary and Conclusions 196
7.1 Introduction 196
7.2 Summary of Argument 196
7.3 Summary of Contributions 198

7.4 Thesis Statement 201
7.4 Conclusion 201
Appendix A – Published Work 202
Appendix B – Interface Design Process 204
B.1 The 2D Environment 204
B.2 The 3D Environment 205
Appendix C – Pre-session Questionnaire 209
Appendix D – Post-session Questionnaire 210
Appendix E – Post-task Questionnaire 212
Appendix F – Semi-structured Interview Questions 213
Appendix G – Properties of Investigative Techniques 214
G.1 Questionnaires 214
G.2 Interviews 215
G.3 Individual and Group Observation 216
G.4 Co-participation 217
References 218

List of Figures

Figure 1 – Photographs of the Excavated Basilica Site 3
Figure 2 – Screenshots of 2D Excavation Management Interface 4
Figure 3 – 3D Studio Max Models of the Basilica 5
Figure 4 – The Second Life Reconstruction of the Basilica 6
Figure 5 – The Second Life LAVA Visitor Centre 6
Figure 6 – LAVA Integration with Existing Institutional Infrastructure 7
Figure 7 – The Internal Excavation Model maintained by the LAVA Excavation Logic 8
Figure 8 – The Knowledge Life Cycle 17
Figure 9 – The Development of Competence for a given Competency 18
Figure 10 – Hierarchical View of Bloom's Six Levels of Cognitive Learning Behaviour 20
Figure 11 – Anderson's Updates to Bloom's Levels of Cognitive Learning Behaviour 22
Figure 12 – 2 Dimensional Version of Bloom's Taxonomy following Anderson's Changes 23
Figure 13 – Problem Based Learning - Guidance Levels Progressively Fading 26
Figure 14 – Evolution of a Learner's Zone of Proximal Development 28
Figure 15 – The Exponential Increases in CPU Transistor Count between 1971 and 2008 32
Figure 16 – The Exponential Increases in Hard Drive Capacity between 1956 and 2008 32
Figure 17 – Timeline of Computer Classes as described by Bell's Law 33
Figure 18 – University of St Andrews Website circa 1997 35
Figure 19 – University of St Andrews Website circa 2009 36
Figure 20 – Second Life Reconstruction of Sistine Chapel 43
Figure 21 – Photograph of Sistine Chapel 43
Figure 22 – 2D Map Interface Depicting the Excavation Site 51
Figure 23 – Photograph of Area of Excavation Site 51
Figure 24 – Second Life Reconstruction of the Sparta Acropolis 51
Figure 25 – Boehm's Spiral Model of Software Development 54
Figure 26 – The MMS Users, Groups and Resources Model 58
Figure 27 – Byzantine Basilica with Domed Roofing 66
Figure 28 – Byzantine Basilica with Pitched Roofing 66
Figure 29 – A Plan of the Excavated Sparta Basilica 69
Figure 30 – The MMS Personalised Portal Page 72
Figure 31 – The Excavation Process as Modelled in LAVA 73
Figure 32 – Various examples of LAVA *Virtual Visit* Clickable Region Maps 74
Figure 33 – LAVA Virtual Visit Apple QuickTime Photo Based Panoramas 75
Figure 34 – LAVA Region in Second Life Showing a Reconstruction of the Basilica 75
Figure 35 – Student Personnel and Equipment Selection Page 76
Figure 36 – Student General Equipment Selection Page 76
Figure 37 – Tutor Personnel Administration Page 76
Figure 38 – Tutor Budget Administration Page 76

Figure 39 – Student View of Excavation Stage 1 Map....79
Figure 40 – Student View of Excavation Stage 2 Map....79
Figure 41 – Student View of Excavation Stage 3 Map....79
Figure 42 – Student View of Excavation Stage 4 Map....79
Figure 43 – Student View of Excavation Stage 5 Map....79
Figure 44 – Student View of Excavation Stage 6 Map....79
Figure 45 – Hotspots to Enable Student Exploration; Red for Artefacts, Blue for Contexts....81
Figure 46 – Context Information Page giving the option to Investigate or Close the Context....81
Figure 47 – Artefact Information and Context Sheet to allow Groups to Maintain Site Records....81
Figure 48 – Personnel Assignment Page, allowing Staff to be Assigned to Specific Contexts....81
Figure 49 – LAVA Stage Administration Interface....82
Figure 50 – LAVA Stage Administration Details Page....82
Figure 51 – External View of the Reconstructed Basilica....83
Figure 52 – Internal View of the Reconstructed Basilica....83
Figure 53 – The LAVA Visitor Centre within Second Life....84
Figure 54 – Exhibition Space inside the LAVA Visitor Centre....84
Figure 55 – LAVA Integration with Existing Institutional Infrastructure....85
Figure 56 – The Excavation Overview Page in MMS....86
Figure 57 – The Personalised Module Portal Page in MMS....86
Figure 58 – First Person Perspective View from Basilica Roof....87
Figure 59 – First Person Perspective View of Artefacts in the Second Life Visitor Centre....87
Figure 60 – The Internal Excavation Model maintained by the LAVA Excavation Logic....88
Figure 61 – 2D Management Interface used by Championship Manager 2007....99
Figure 62 – 3D First Person Perspective Interface used by FIFA 2008....99
Figure 63 – Flowchart of LAVA Artefact Discovery Process....104
Figure 64 – LAVA Database Entity-Relationship Diagram....106
Figure 65 – Content Stream used for Communication between MMS and Second Life....111
Figure 66 – MMS and Second Life Communication Process....111
Figure 67 – PlanetLab Round Trip Time Distribution....133
Figure 68 – PlanetLab Node Types....134
Figure 69 – Sample PlanetLab Round Trip Times between Europe, North America and Asia....135
Figure 70 – Self-Assessed IT Competency of Participants....137
Figure 71 – Relationship between Fieldwork Experience and Expedition Training....137
Figure 72 – Year 1 System Usability Scale Scores....140
Figure 73 – Year 1 Educational Value Scores....140
Figure 74 – Year 2 System Usability Scale Scores....144
Figure 75 – Year 2 Educational Value Scores....144
Figure 76 – Year 3 Task Completion Rate....148
Figure 77 – Ease with which Year 3 Users were able to Complete The Tasks Set....148
Figure 78 – User Opinion of LAVA Progress Reporting....148

Figure 79 – User Opinion of LAVA Progress Management 148
Figure 80 – Comparison between 2006/7 and 2007/8 SUS Results Returned..... 150
Figure 81 – Comparison between 2006/7 and 2007/8 Educational Value Results Returned..... 150
Figure 82 – Moodle Interface with Interactivity (Activities and Blogging) Tools Highlighted 159
Figure 83 - New Moodle Registrations per Month (2007/8/9) 159
Figure 84 – LAMS Authoring Area Interface 161
Figure 85 – LAMS Learning Area Interface 162
Figure 86 – The MMS Module Listing Page..... 163
Figure 87 – MMS Integration with Existing Institutional Infrastructure..... 163
Figure 88 – eCollege Class Live Pro Whiteboard and Video Conferencing Tool..... 165
Figure 89 – Comparison between TCP/IP and ISO OSI 172
Figure 90 – Exemplar Modular Game Engine Structure 177
Figure 91 – 2D Management Interface used by Championship Manager 2007 180
Figure 92 – The Isometric 3D Interface Presented by Civilization III 182
Figure 93 – Civilization III Menu System for Controlling a Town's Economic Growth..... 182
Figure 94 – Gates of Horus 3D Perspective Showing Temple Entrance 183
Figure 95 – High Priest..... 183
Figure 96 – Gates of Horus Zone Map 184
Figure 97 – The 2D Interface Showing the Campaign Map for Medieval: Total War 185
Figure 98 – A Real Time 3D Battle Under Way in Medieval: Total War 185
Figure 99 – The River City Project MUVE Interface..... 192

List of Tables

Table 1 – Description of the Behaviours Found at each of Bloom's Levels of Learning.....20
Table 2 – Definitions of Anderson's Updated Terminology 22
Table 3 - Computer Classes as Defined by Bell's Law.....34
Table 4 – Portal Features and Characteristics.....39
Table 5 – The Roles of Different Technologies in the Learning Process 42
Table 6 – Summary of Educational Design Decisions 93
Table 7 – Summary of System Structure and Design Decisions 96
Table 8 – Summary of System Structure and Design Decisions relating to Modes of Interaction.....97
Table 9 – Summary of Technological Decisions.....101
Table 10 – Group Evaluation Session Timetable 124
Table 11 – CURL Constituent Timings in Seconds for Single Client Access.....131
Table 12 – Summary Statistics for Second Life Traffic Trace 132
Table 13 – Evaluation Exercise Age Distribution 137
Table 14 – Year 1 Participant SUS and Educational Value Scores.....140
Table 15 - Year 2 Participant SUS and Educational Value Scores.....144
Table 16 – Individual Evaluation Session Focus Topics.....147
Table 17 – Individual Evaluation Session Responses 148
Table 18 – Summary of Key Features of Serious Games Examples 186
Table 19 – 3D Technologies, Their Capabilities and Suitability for LAVA 3D Recreations.....208

Chapter 1 – Introduction

1.1 Introduction

Up until now, there have been significant barriers to learners moving beyond comprehension through application to analysis in subject areas where real world application of knowledge and skills is difficult or expensive to facilitate. Recent advances in technology have facilitated richer Internet applications and accessible realistic 3D environments. This dissertation examines how these can be leveraged to support learners in constructing their understanding of a subject to become active inquirers rather than passive recipients of knowledge.

The application of concepts is an important part of the learning process [2]. By interacting with systems that support the application of knowledge, learners are able to engage in higher order learning behaviours. This allows them to progress further up Bloom's taxonomy of learning behaviours. This is beneficial from an educational perspective as it provides opportunities for students to engage in application, evaluation and reflection activities; all of which feature towards the top of Bloom's taxonomy.

When considering traditional approaches to learning, support for these types of interactions is generally limited, with most systems favouring a didactic approach which sees the transferral of knowledge from teacher to the student. Technological advancement [3] offers a real opportunity for these existing approaches to be enhanced or replaced, with 3D game [4] and multi-user virtual environment (MUVE) [5] technologies becoming increasingly accessible. With the learner at the centre of an interactive, mutable and collaborative environment, the possibilities for developing learning scenarios which encourage exploration, application and evaluation of knowledge, and reflection of performance are significant.

Using a bottom up approach, this dissertation examines the technical feasibility of such a system, with a concrete educational scenario being developed as a case study. By combining 3D and existing learning technologies, this work addresses a real world challenge experienced by educators responsible for teaching archaeology and provides an environment in which students are faced with a series of challenges which they need to apply their knowledge to solving. This solution provides a framework which supports a learning process where the learner is able to explore a subject interactively in collaboration with their peers, with the case study and subsequent evaluation work confirming the validity of our approach

The proof of concept instantiation of the framework delivers a learning scenario which is based on the archaeological excavation of a Byzantine basilica [6] in the Sparta region of Greece [7, 8]. Initially excavated by the British School of Athens during 2000-1, students undertake and manage their own virtual excavation project which features many artefacts and architectural details discovered during the real world excavation work.

The framework discussed in this dissertation has particular relevance to subjects that have scope for a significant practical element, but which in practice often go unexploited owing to the problems and costs associated with arranging practical experience for large numbers of students: archaeology, geography and architecture are all examples of such subjects.

The benefits of allowing students to collaboratively manage and participate in a virtual excavation of the Sparta basilica are considered, with domain experts considering the implications such a system could have on the teaching of highly tactile subjects, whilst the case study highlights how technology and real world data can be used to provide authentic learning experiences. An evaluation of the supporting framework is undertaken, with the opinions of students and tutors sought.

Structured into two sections, this chapter acts as an introduction to the work described by this dissertation:

- An **Overview of Laconia Acropolis Virtual Archaeology (LAVA)** is presented. LAVA is both the instantiation of the framework and a case study in its use. Whilst different aspects of the work are discussed in more detail in future chapters, a summary is provided here to allow the reader to obtain an overview of the core practical work that supports this dissertation.

- A **road map** of the different chapters in the dissertation is provided, along with a short summary of their content.

1.2 Overview of LAVA

1.2.1 Introduction

Archaeology is a naturally engaging subject which has, at its core, a process of exploration that leads to the uncovering of the past. As such it would seem to be a subject which is particularly suited to the application of exploratory learning. As can be seen with the continued popularity of films and television programmes dedicated to archaeological discovery, people are genuinely intrigued by the past, how our ancestors lived and the process of detective work that goes in to uncovering archaeological sites. However, the mass audience appeal of archaeology, through mediums such as film [9], television [10] and books [11], does not automatically translate into educational contexts. Indeed, faculty and students are faced with a number of barriers to applying exploratory learning within the context of archaeology.

The archaeological process is naturally destructive and unrepeatable, so the opportunities for students to learn within the context of real archaeological excavations are naturally limited. In addition, there are significant financial and temporal costs associated with such involvement. Even when access to an excavation site is granted, student participation is limited to undertaking prescribed activities, with few opportunities to experiment with alternative techniques and working practices. From an educational

Figure 1 – Photographs of the Excavated Basilica Site

perspective it is desirable for the excavation process to be opened to a wider audience, with students empowered to assume roles of higher authority so that they can experiment with working practices in order to more readily understand how archaeological processes impact the environment of the excavation site.

In much the same way as the World Wide Web (WWW) [12] opened up access to information through intuitive point and click graphical user interfaces, multi-user virtual environments (MUVEs) [13] such as Second Life [5] and first person shooter games [14] like Quake [4] offer new and innovative opportunities for the development of realistic and engaging educational scenarios based in previously inaccessible environments. They both provide a rich multimedia environment where interactions between learners can take place and can be used to develop groupwork and social interaction. In this way they can provide support for exploratory learning scenarios. Consequently these technologies offer an environment that is rich in the potential for developing multimedia content, which can be used to support the development of realistic models of otherwise inaccessible environments to be examined and explored by students.

An important component of the learning process facilitated by MUVEs is the ability to learn through doing. To support this type of experiential learning, a virtual excavation has been developed which is based upon the excavation of a Byzantine basilica explored by the British School of Athens [15, 16]. Realistic learning scenarios containing real world excavation data (as shown in Figure 1) are presented to students. Using management interfaces delivered through an institutional learning environment, the Module Management system (MMS) [17-19] (as shown in Figure 2), and the basilica reconstruction and visitor centre in the MUVE (as shown in Figure 3, Figure 4 and Figure 5), students can manage their excavation work and present their findings in an intuitive and creative way.

1.2.2 The Student Experience

The aim of LAVA is to allow students to engage with archaeology and practice archaeological research methods, with students progressively moving through the system as they develop their skills and understanding.

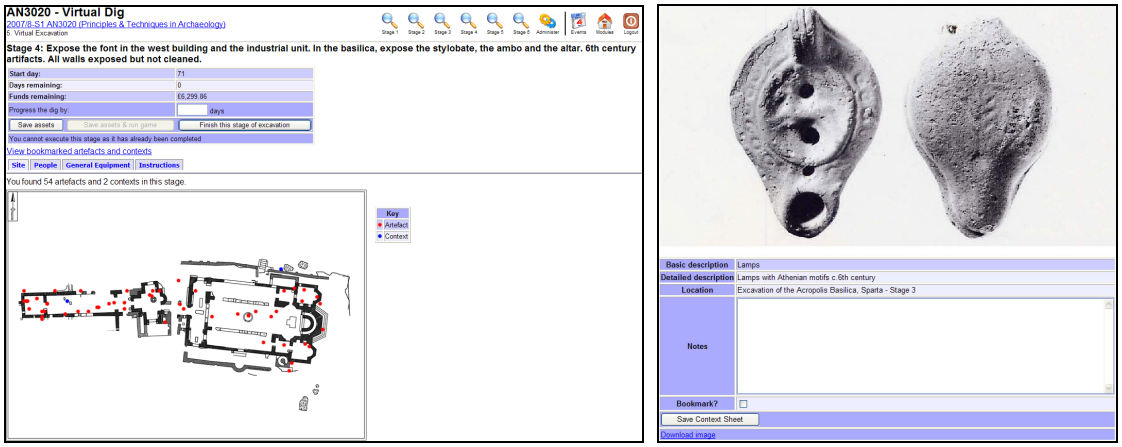

Figure 2 – Screenshots of 2D Excavation Management Interface

Initially students are introduced to the Sparta region of Greece and asked to explore the acropolis upon which the Byzantine basilica, which they will later excavate, is located. With the basilica in ruins, and the acropolis covered in deep overgrowth, finding the basilica is not straightforward. Student teams need to look for archaeological clues whilst reviewing a variety of 3D panoramas in order to locate sites upon which the basilica may be located. Following an inconclusive initial search, the teams are faced with a number of possible sites. In order to determine the location of the basilica, they must interpret geophysical data and use other surveying techniques to refine their shortlist. Once they are happy that the location of the basilica has been identified, each team needs to submit a proposal to obtain an agreement from a virtual research council to provide funding for a virtual excavation of the site. When this agreement, facilitated by the module coordinator, has been achieved, teams must develop a detailed budget and excavation plan which outlines the type of excavation work they wish to undertake.

Using knowledge gained from lectures, the LAVA case study, and third party sources, teams collaboratively draft an excavation plan and budget. With only finite funding available from the virtual research council, the teams compete for funding, with the strength and validity of their applications having an impact on the level of funding they receive. Applications are only accepted by the research council during a 2 week period. During this time, teams are given access to a consultant (the module coordinator), who is able to provide advice on constructing a funding application. Teams are free to use this advice as they wish. However, they must submit their applications within the application period if they wish to be considered for a funding award.

Once the application period has closed, the virtual research council assesses the value of each application, considering its strength and likelihood of success. Funding is then awarded to each team, and their excavation work can begin.

Using a variety of techniques borrowed from the gaming world, the excavation process is broken down into a series of contiguous stages, with teams progressing to the next level only once they have shown a certain level of competence at the current activity being attempted [20].

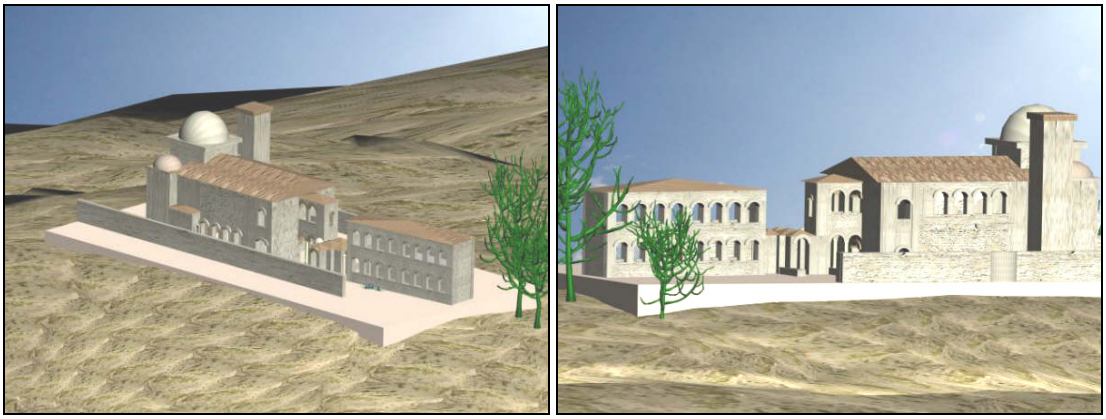

Figure 3 – 3D Studio Max Models of the Basilica

During the excavation work, teams must manage their finances carefully, ensuring that they employ people with the correct skills, provide them with the correct equipment and give them enough time in order to successfully carry out their excavation activities on different areas of the site. Throughout the excavation, the teams are able to adjust the levels of resources that they apply in order to maximise the quantity and quality of material that they discover. Remembering that excavation work is destructive in nature, teams initially draw on knowledge gained from lectures and other sources to manage their excavation plan, using increasing amounts of their own judgement as they become more familiar with the site and build up an understanding of the effect that different excavation techniques will have on it.

In the real world, applying the same excavation technique is not guaranteed to lead to the same result each time; sometimes a technique will be successful, and sometimes not. To address this issue within LAVA a degree of non-deterministic behaviour is introduced. Initially chance plays a relatively large role in determining the success of a team's efforts as they experiment with how best to organise their team in order to discover artefacts. As they become more adept at fine tuning the personnel, equipment and time allocated to each excavation activity, the impact of chance is reduced. However, there is always an element of chance influencing the outcome of each activity, so even with perfectly configured parameters each excavation will provide a different set of outcomes. This helps to differentiate each excavation and encourages engagement as teams cannot reliably predict the outcome of their efforts ahead of time.

Throughout the excavation process, teams uncover a rich variety of material which they must examine. Some of the artefacts found will be of archaeological significance, and some not. Depending on the resources allocated to each activity, teams will be given one of three levels of information, with the full information about an artefact only being revealed if the team has allocated the correct archaeological expert to the activity:

1. **No information**, just a photograph of the artefact.

2. **Basic information** accompanied by a photograph of the artefact.

3. **Full information** accompanied by a photograph of the artefact.

Figure 4 – The Second Life Reconstruction of the Basilica

Figure 5 – The Second Life LAVA Visitor Centre

Throughout the excavation process teams are free to consult external sources of information when identifying artefacts and can allocate specialists to examine previously found items in order to reveal the full information relating to a specific item.

As the excavation progresses, teams need to maintain accurate context sheets and site logs, just as they would do on a real excavation project, if they wish to make use of any of the information they reveal about an artefact. Should teams neglect to maintain this information, when they come to analyse and prepare their findings for presentation, the team will quickly realise that they have lost all contextual information associated with each of the items they failed to accurately record. This forces them to rely on external sources of information in order to determine the significance of their findings, just as they would do in a real excavation scenario. Whilst this process can be successful, it is likely to take longer and require more effort than maintaining the original contextual information gained during the excavation work.

Once the team has finished excavating the site and cataloguing the finds that they have made, they will present their research in a public forum. To do this, they curate an exhibition of their excavation work in the Second Life Basilica Visitor Centre shown in Figure 5. The inputs for this exhibition are sourced directly from the finds discovered during the excavation process. Consequently, for each team, different sets of artefacts will be available. To enable this, state from the excavation game is made available to Second Life. The architecture used to achieve this is discussed in Chapter 4.

The exhibition is made up of photographs and 3D models of artefacts, maps and drawings of the site, videos of the site pre- and post-excavation, and other multimedia resources. Each exhibition is visited by a representative from the virtual research council (the module coordinator), students from other excavation teams and members of the public. During the unveiling of a team's exhibition, the team guide their guests around the exhibits in the visitor centre and reconstructed basilica, answering questions from the audience as required.

To accompany the public exhibition, an excavation report is published which describes the findings of the excavation work and highlights the successes of the approaches adopted. Following the completion of the exhibition in Second Life, each team submits an excavation report for final assessment.

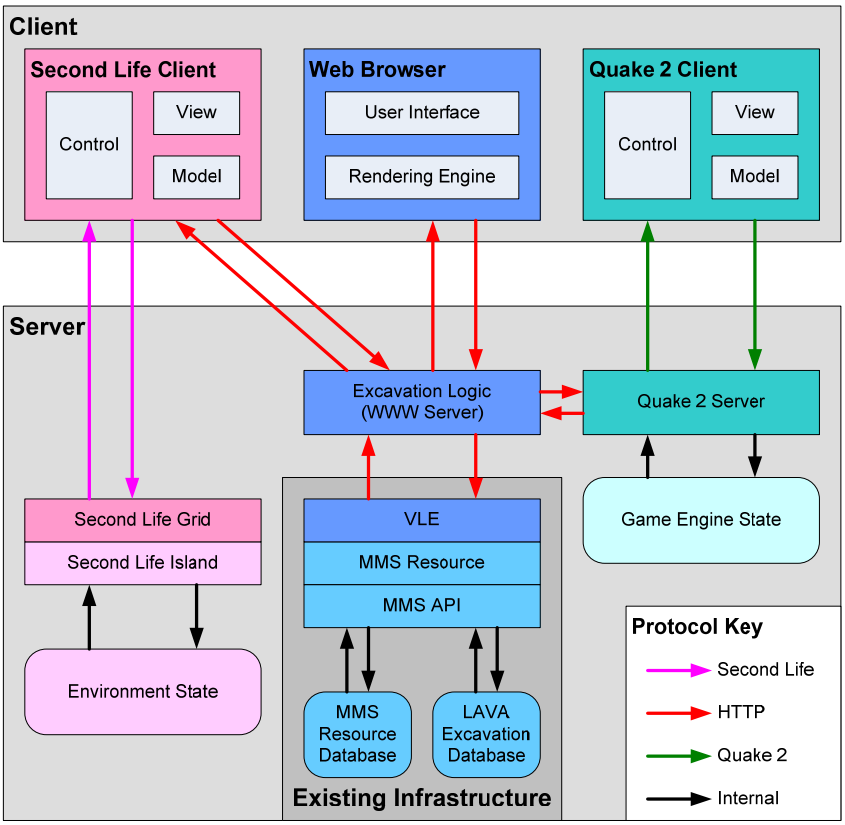

Figure 6 – LAVA Integration with Existing Institutional Infrastructure

1.2.3 System Architecture

LAVA uses a number of technologies to meet the educational goal of supporting exploratory learning within the context of archaeological excavation. The architecture presented here makes it possible to integrate these technologies so that each is cognisant of the relevant actions undertaken by learners in other parts of the system. In particular, borrowing from the model-view-controller architecture [21] makes it possible to maintain a single consistent state, with multiple views of that state accessed through different interfaces. Thus, the learner will interact with 2D maps of the excavation site, applying resources and undertaking management functions, with the results of these activities made available to Second Life for the creation of the virtual exhibition. This architecture is flexible and has allowed investigation into the use other technologies, including first person shooter games (i.e. Quake) and MUVEs (i.e. Second Life and Open Simulator [22]).

Figure 6 provides an overview of how LAVA integrates with existing institutional infrastructure, utilising resources and services provided by the institution (i.e. The Open Simulator grid and the institutional learning environment) and external organisations (i.e. The Second Life grid provided by Linden Labs). By integrating with services both internal and external to the host organisation, LAVA provides a varied interface to students. Not only does this offer students the opportunity to choose their preferred method of interaction with the system, but it also allows services from other systems to be used in the framework; for example authentication through the institutional learning environment allows individual students to be identified so that excavations can be tailored specifically for each individual or team.

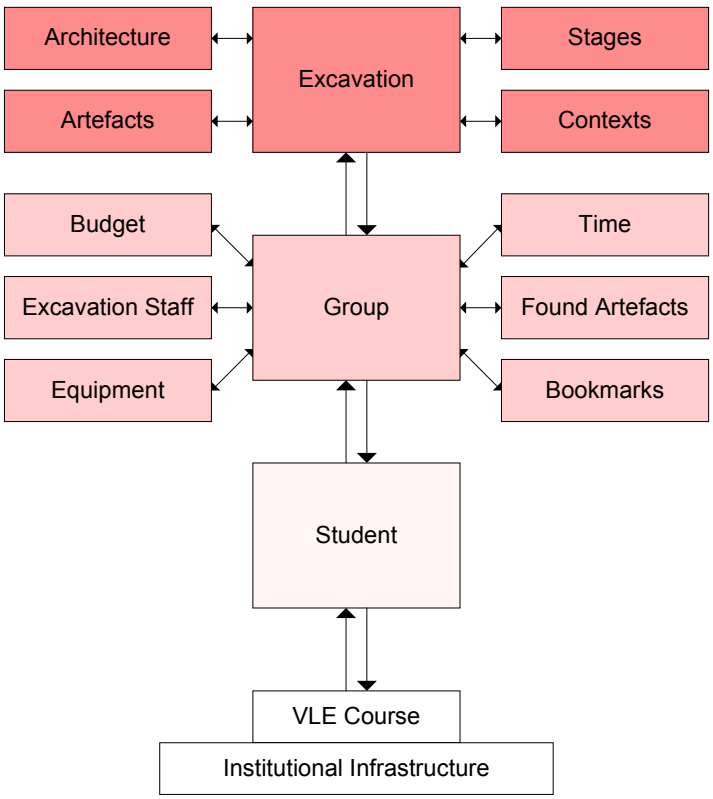

Figure 7 – The Internal Excavation Model maintained by the LAVA Excavation Logic

From a student's perspective, the framework supports three modes of interaction, with teams able to manage their excavation using a Web interface containing a variety of textual, graphical and audio resources delivered through the learning environment as previously shown in Figure 2. The 3D interactive environments offered by the Open Simulator and Second Life grids allow students to undertake an exploratory role, examining the excavation site from a variety of 3D perspectives similar to those in Figure 3, Figure 4, and Figure 5.

Although each mode of interaction is managed by separate systems, a shared model is maintained by a centralised component, the excavation logic, which ensures consistency throughout the framework. Within the excavation logic, each instantiation of an excavation is maintained using a series of database tables as shown by the model in Figure 7. By maintaining a centralised excavation state, coordinating changes to it and providing timely propagation of state changes, the excavation logic ensures that a consistent view of the excavation is presented across a variety of systems which may span multiple administrative boundaries.

1.2.4 The 3D Environment

In order to enable students to explore and understand the excavation site it is important that they are able to access realistic materials in an environment that encourages self-motivated discovery. When developing the excavation simulator, several types of 3D environment were considered:

- **First person shooter games**, e.g. Quake, Unreal Tournament [23].

- **MUVEs**, e.g. Second Life, Open Simulator, Active Worlds [24].

- **Photo based reconstructions** and **panoramas**, e.g. Apple QuickTime movies [25], panoramic photographs.

Each category of 3D environment was evaluated against five key requirements:

- **Learner Engagement.**

- **Personalisation.**

- **Groupwork and Collaborative Working Practices.**

- **Realism.**

- **Accessibility.**

When considering the functionality supported by each class of 3D environment, it quickly becomes apparent that photo based reconstructions and panoramas do not meet all of LAVA's requirements. Owing to their static nature, photo based reconstructions provide only limited viewpoints and cannot support student interaction with the underlying environment presented. However, these technologies can provide useful background knowledge to learners, and as such are used for the purpose of presenting an overview of the site using a variety of panoramas and static photographs.

In contrast, both first person shooter games and MUVEs are able to fulfil each of the key requirements. Both provide a first person perspective of a virtual environment that supports interactions between users and the environment itself. Both allow for undirected exploration, thereby encouraging student engagement and stimulating interest in the information provided. Both allow multiple students to simultaneously access a shared environment, with tools to enable synchronous communication and group collaboration. However, there are some important differences to consider between first person shooter games and MUVEs

- **Environment:** First person shooter games assume a closed, carefully controlled world which consists entirely of the game map in question (in this case an excavation site). Multiple game maps can be instantiated simultaneously, with users deciding which map to enter when they connect to the game server. Once in a game map, players cannot seamlessly move to other maps. As such it is possible for them to be constrained to a pre-determined environment which does not alter the state of any other game maps which have been simultaneously instantiated. In contrast, MUVEs consist of a single environment, hosted on multiple servers, which is shared with all users, regardless of which server they connect to. As such, users of a

MUVE are able to leave their designated area and explore other regions at their discretion. They can also interact with other MUVE users which could, in this situation, involve members of other excavation teams who are using the MUVE.

- **Administration and Access:** MUVEs are generally hosted on multiple servers. Users are able to connect, explore and shape the shared environment, modifying it (where allowed) using tools provided by the MUVE client. Individuals and institutions can obtain areas of the shared environment to build upon. This often confers additional rights and powers, for example allowing the new land owner to control access, edit and otherwise maintain his property. The control model in first person shooter games is substantially different. There is no concept of land ownership and as such no hierarchy of ownership – all users in the environment are treated equally. Unlike MUVEs, if a user is unhappy with the maps on offer or rules enforced on one server, a different first person shooter game server can be used.

Although significant, these differences are not inherent in the technologies, but are instead a manifestation of the way in which they are deployed and administered. As MUVEs are generally hosted by external entities, users are not able to customise the behaviour of the environment outwith the normal scope of service. However, the same is not true of first person shooter games which are generally licensed for hosting on a local system, with local administrative staff able to customise the operation of the game servers as required. This means that it is possible to add a third type of 3D environment into the selection, with MUVEs licensed for localised usage making it possible for the MUVE environment to be hosted and administered by the organisation within which they are deployed. This allows the limitations associated with the shared environment of a traditional MUVE to be removed, thereby enabling MUVE technology to be used to provide multiple isolated environments in a similar way to a first person shooter game server. This walled garden approach in locally licensed MUVEs makes it possible for student teams to explore whilst isolated from each other, thus mirroring the behaviour of first person shooter games.

When considering the differences between first person shooter games and MUVEs, it becomes clear that each technology is suited to different aspects of an excavation simulation:

- The first person shooter game and licensed MUVE model fit closely with the need to allow many simultaneous excavations to be undertaken independently, thus working well as the basis for the excavation activities undertaken in LAVA. The separation enforced by the walled garden ensures that students do not cross over into another team's excavation and also constrains a team's focus to the site of interest, thus making it more difficult for students to get off course and excavate an entirely wrong region!

- When intra-team cooperation is required (and possibly input from the wider community) the wider audience model of a traditional MUVE model works well. When considering the

reflection process undertaken after completing an excavation in LAVA, the ability for multiple teams to review a reconstruction of an archaeological site is beneficial – teams will be able to share ideas, critique the reconstruction of the basilica and reflect on how successful their excavation work and subsequent publications were at identifying features of the archaeological site.

Whilst this discussion shows that there is a degree of correlation between the functionality provided by MUVE and first person shooter game technologies, and the requirements of LAVA learning scenarios, it is important to remember that the choice of technology platform used to deliver the 3D environments to students is of less importance than the innovation that it can provide in the context of learning. From this perspective, there is significant value attached to allowing tutors to develop an environment which can be explored and modified by students from a familiar first person perspective. The coordination of activities amongst student groups is also worthy of merit, as is the ability for the environment to be updated and customised based on the abilities of the students exploring it. For each of these requirements, MUVEs and first person shooter games show promise as discussed in more detail in Chapter 4.

1.3 Dissertation Roadmap

Chapter 2 establishes a basic frame of reference for the dissertation, providing contextual background and a summary of work in the educational domain which has relevance to the areas of importance in this dissertation. As established educational theory has largely informed the approach adopted by this work, the chapter provides an overview of the educational theories that have influenced the development of the framework, and the corresponding archaeology case study implementation, as well as offering a rationale for their adoption. Through a discussion of competing educational theories, Chapter 2 builds an argument to support the adoption of the constructivist, learner-centric approaches used by this work to support the delivery of explorative, tailored learning experiences to users. In addition to considering learning from the perspective of educational theory, the chapter also considers the applicability of gaming methodologies to a number of common learning scenarios.

After discussing the theories supporting the framework discussed in this dissertation, Chapter 2 progresses to consider the technical issues relating to the development of such a framework, with the strengths of different types of learning technologies being considered. The chapter identifies the type and style of learning interactions supported by each technology as well as its ability to support extensions offering additional learning interactions. Separated into a number of categories based on the levels of learner interaction and customisation supported, each product is considered from the constructivist approach that has influenced this work, with the aspects that apply to the virtual fieldwork setting, and can be used to encourage and develop user engagement, highlighted.

Chapter 3 introduces the methodology and design process adopted by this work. Acting as a chronology to the development process, Chapter 3 identifies the problems that were uncovered when

developing learning resources and adapting technologies to LAVA's needs, as well as the solutions and working processes devised in order to overcome them. A significant contribution of Chapter 3 is the work undertaken to determine the ways in which various technologies can be used within the framework to provide visualisations of learning scenarios and opportunities for learner interactivity. By comparing and contrasting the different properties offered by first person shooter games, MUVEs, massively multiplayer online games (MMOGs) [26] and photo based reconstructions and panoramas, the applicability of each technology to the virtual fieldwork setting is considered. A summary of each technology is presented, with the relative merits and demerits of each, from the virtual fieldwork perspective, being highlighted.

During the development process discussed in Chapter 3, two significant questions were raised relating to perception within the 3D environment. The issue of scale became apparent when constructing reconstructions of real-world environments, the techniques used to investigate the manifestations of such issues are discussed in the chapter, as are the conclusions drawn from this investigative work. In addition, significant differences were found between the way in which spatial relationships were interpreted by individuals viewing static 3D models and dynamic 3D environments.

Chapter 4 presents a case study based on an archaeological excavation project, in the Sparta region of Greece, which is sympathetic to the educational theories discussed in Chapter 2. By considering the processes used to organise an archaeological excavation into a series of activities designed to engage and direct the learner, whilst at the same time managing the pace of their progression through the system, Chapter 4 draws on the outcomes of earlier chapters to bring together a complete organisational model of an archaeology fieldwork project. Dealing with implementation level details, Chapter 4 focuses on the design and integration of each component of the system and gives an overview of the system, as well as the modes of learner interaction it supports. User interactions are characterised through a walkthrough of the system, with both learner and tutor perspectives presented. At each stage, the learning aims and objectives are identified, as are the technologies and techniques used to deliver them.

The case study is followed by an evaluation in Chapter 5 which focuses on evaluating the implemented system in terms of operational suitability, educational value and user perception. By examining how the system is used by learners, as well as the value they attach to it (individually, and in groups), Chapter 5 offers an assessment of the impact that the framework has on user motivation and the delivery of learning outcomes.

A review of the relevant literature and work which relates to LAVA is presented in Chapter 6. Given the treatment of educational theory in Chapter 2, Chapter 6 focuses on the technological aspects of the work, in particular considering the use of MUVEs and gaming in educational contexts, with work which relates to, and which has informed the development of LAVA, identified.

Concluding the dissertation, Chapter 7 summarises the argument put forward and considers the work carried out to support it. In summarising the contributions made, this chapter situates the work in a wider educational and technological context. In reviewing the thesis statement guiding the work Chapter 7 considers the strengths of the dissertation in respect to the requirements of a PhD.

1.4 Chapter Summary

This chapter has introduced to the reader the problem space under consideration by this work. Through the summary of LAVA given in section 1.2, a case study is introduced which provides a documentary to the instantiation, use and evaluation of the framework proposed by this work, so that the benefits of the approach proposed can be readily visualised by the reader.

In concluding the chapter, section 1.3 provides a road map to the reader. This outlines the organisation of the argument put forward by this dissertation and summarises the content of subsequent chapters to enable the reader with specific interests to identify areas of the dissertation of most interest.

Chapter 2 – Research Context and Design Motivation

2.1 Introduction

This chapter considers the issues which affect the design and use of educational learning materials. By considering the process of learning, as well as the factors which can affect it, this chapter outlines the motivation behind the design and development of the case study discussed in Chapters 1 and 4.

This chapter situates our work within the context of learning theories. In particular we look at Bloom's widely accepted hierarchical taxonomy of learning [2] and identify that, for a significant class of disciplines, there are significant barriers for learners to be able to apply the knowledge and comprehension which they have gained through didactic learning processes in realistic scenarios. Consequently, achieving higher levels of learning behaviours, such as analysing and reflecting upon the application of knowledge, and synthesising the understanding which comes out of such application, with their existing body of knowledge is made more difficult.

This challenge is most relevant in disciplines where abstract ideas and theories need to be applied to concrete or physical environments, for example:

- In **archaeology** where methodologies of investigation are applied in physical excavations and social theories are tested against the discovery of artefacts and architecture.

- In **architecture** where theories are applied to develop plans for buildings designed to meet the needs of future generations.

- In **geography** where surveys of physical locations are undertaken in order to enhance our understanding of physical and social phenomenon.

We relate this challenge to the pedagogical approaches that are available to learners and educators, and consider the potential that exists for current and future technological innovations to improve the learning landscape. In particular we contrast didactic and constructivist approaches to teaching and learning and in doing so suggest that the constructivist approach enables learners to move beyond the basic learning behaviours of knowledge acquisition and comprehension to more complex learning exchanges which enable the analysis, synthesis and evaluation of knowledge.

The challenge is also considered from a technological perspective, with the impact of the continuing enhancement of computer processing power and networking infrastructure analysed. These advances, which have seen the Web transition from being a place where information is published for users to access to an environment which is dynamically created, have brought with them significant changes to the way in which users interact with the Web. Instead of simply browsing pages, users are now able to

create their own profiles, project their personalities and broadcast their blogs; in essence becoming a source of content as well as a consumer of it. Furthermore we consider the emerging class of 3D applications which are increasingly accessible through the use of non-specialised computers such as those found in the home, classrooms, offices etc. The use of these applications, which are capable of supporting new modes of interactivity, is steadily becoming more widespread, with significant numbers of users already spending large amounts of time engaged in the virtual environments that they provide.

These technologies, which can be summed up as Web 2.0 [27] and 3D MUVEs, when brought together offer the potential for educators to radically alter the way in which computers are used to support the learning process by creating realistic learning environments within which learners can not only acquire and comprehend new knowledge, but also apply, synthesise and evaluate it. Chapter 4 discusses the creation, use and evaluation of a virtual archaeological excavation site which makes use of such technologies. This case study relates directly to the high level discussions that follow in this chapter and acts as an example of how these discussions inform the creation of a learning environment which can extend and enhance the learning process.

Section 2.2 begins by dissecting the learning process and examining the types of behaviour that can lead to learning, before progressing to consider how learners can be motivated to engage in these educationally positive behaviours. By considering learning as an active process involving both learners and educators, the section examines the roles which are assumed by learners and educators as well as the ways in which educators dissect the learning process and develop strategies to maximise learner participation. Through the introduction and discussion of Bloom's taxonomy of learning, in section 2.2.1 and section 2.2.2 the chapter considers the ways in which different learning behaviours can be encouraged by learning resources, thereby considering the impact of the decisions that educators make during the design and development of learning materials. Following this, section 2.3 assesses the suitability of different pedagogical approaches to learning design, with the significance of constructivism examined in the context of the development of interactive and collaborative learning scenarios in section 2.3.2, before the influence of gaming methods are considered in section 2.3.3.

Section 2.4 continues the chapter by focusing on the role that technology plays in the delivery of learning scenarios. Initially examining the way in which technological capabilities increase over time, the section introduces Moore's Law and relates the technological advancement that it predicts to the evolving ways in which we use computers. By examining the previous progression from textual to graphical interfaces and the impact that this has had on end users, section 2.4.1 considers the impact that future technological innovation may have and the new classes of 3D applications that it may support. Section 2.4.2 continues the chapter by focusing on existing software deployments within the education sector. Beginning by classifying the types of software in routine use, the section examines the types of learning behaviours which are already well supported before highlighting possible enhancements to the learning process that the introduction of new 3D technologies can provide.

Within this discussion, specific attention is paid to the development of interactive, collaborative learning scenarios of the type discussed in Chapter 1 and Chapter 4 of this dissertation.

The chapter continues with section 2.5 considering the emerging applications that 3D multi-user virtual environments can provide. Focusing specifically on encouraging higher order learning behaviours, the chapter is split into three subsections, with each focusing on enhancements that can be applied to the educational process, with specific reference to: the different types of presentation of learning materials that can be achieved through the use of different technologies (section 2.5.1), the ways in which engagement, enhanced presence and interactivity with learning resources can be used to construct pedagogically sound learning exchanges (section 2.5.2), and the ways in which technological enhancements can provide support for tailoring learning scenarios to meet the needs of different types of learners and their learning styles whether working independently or as part of a larger group (section 2.5.3). Having considered the overall changes to the learning process, section 2.5.4 concludes by considering the overall impact that such techniques can have on the learning process as well as the steps that can be taken to maximise the possible benefits of presenting learning materials using the alternative technologies and design paradigms discussed.

Concluding the chapter, section 2.6 provides a brief summary of the discussion and outlines its implications with respect to the development of the LAVA archaeology case study presented, discussed and evaluated in Chapter 1, Chapter 4 and Chapter 5.

2.2 Learning as a Process

Learning is referred to by Piaget as:

> "a process of discovery." [28-30]

However, the process of learning is often abstract in its nature and varies from person to person. As such it is difficult to accurately describe. At its most basic, learning is concerned with the development of competencies, skills or knowledge [31, 32]. These competencies are usually developed over a period of time, with learners becoming more adept as their competency in a specific area grows. Educators play a significant role in the process and become more effective when they understand the process through which learning occurs and can develop learning materials and scenarios which are sympathetic to it.

Historically the information transfer paradigm has been used as a way of imparting knowledge to learners. In this arrangement, the educator assumes a central role within the learning process, gathering and presenting knowledge which the learner is expected to consume. Learner progress is determined through monitoring, with the capability of the educator having a direct impact on the success or failure of the approach. However, the capabilities of the educator alone cannot deliver a successful learning outcome; the role of the learner is central to the exchange. In this vein, whilst better teaching is important, indeed some may argue necessary [33], it is not the sole factor to be considered when

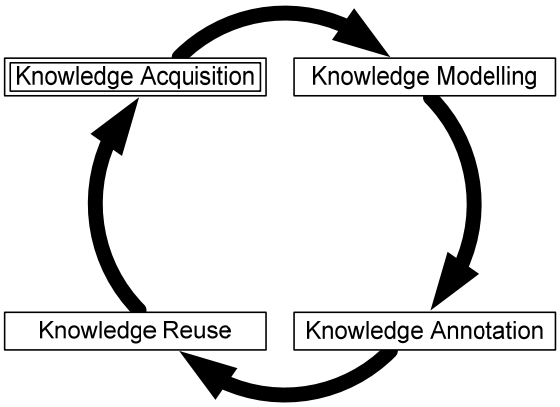

Figure 8 – The Knowledge Life Cycle

encouraging better learning. Instead, a shift in paradigm is required, with knowledge viewed not as something transmitted by an educator, but as something acquired, understood and reused by the learner as shown by the knowledge life cycle depicted in Figure 8.

- **Knowledge Acquisition:** The first stage of the process is for learners to acquire knowledge from domain experts, provided learning resources and external sources. Behaviours which enable knowledge acquisition generally occur at an early stage in the learning process and are usually fairly straightforward in their nature: reading a book for example.

- **Knowledge Modelling and Knowledge Annotation:** Once knowledge has been acquired or gathered, it needs to be formalised by the learner. For this to happen, learners need to break down the knowledge they have gathered in order to understand its meaning, how it can be applied and how it may affect their pre-existing knowledge. Behaviours which enable learners to undertake these activities can only occur once knowledge has been acquired. As such learners must be able to acquire knowledge before they can begin to understand it. Examples of this type of behaviour include questioning and the repeated practicing of a specific activity.

- **Knowledge Reuse:** Once familiar with their newly found knowledge, learners begin to reuse the knowledge in alternative scenarios and evaluate it against alternative options in order to understand different scenarios as and when they are presented. In this way learners are able to develop a deep understanding of unfamiliar scenarios presented to them. The types of behaviour which enable learners to achieve this level of understanding are often complicated in nature and can only occur once knowledge has been acquired and understood by a learner. Examples of this type of behaviour include the ability to construct a coherent argument and discuss the relative pros and cons of competing concepts and ideas.

For the knowledge life cycle approach to be realised, it is important that the role of the learner is central to the learning process, with the learning process focusing on the development of not only

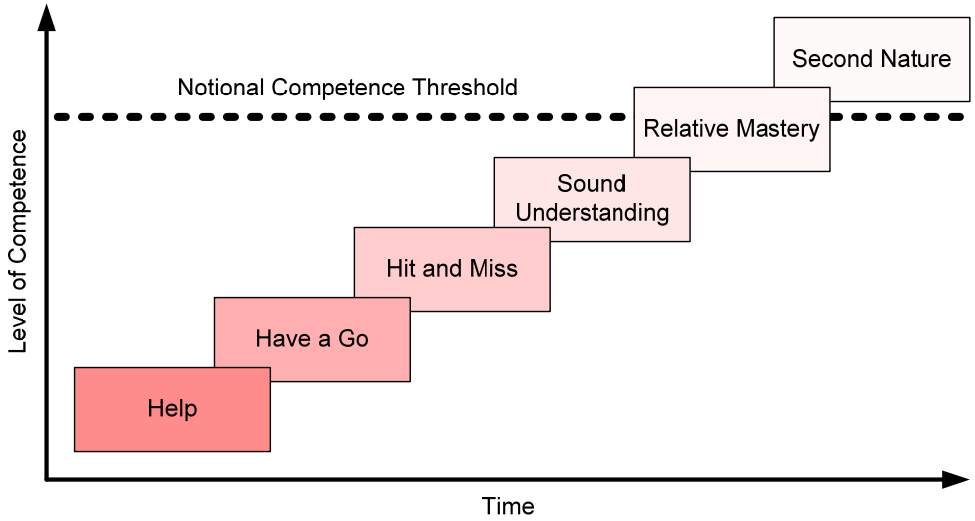

Figure 9 – The Development of Competence for a given Competency

knowledge, but also skills and competencies. In this way learners are required to assume an active role in the learning process, controlling the speed at which their learning progresses.

During the development of competencies, learners progress through many stages as shown in Figure 9 [34]. Initially requiring significant assistance to achieve any progress, learners slowly build up the confidence required to have a go at a specific problem or activity. As a learner's competence develops they are likely to experience a mixture of occasional success and failure, before eventually becoming adept at a given competency. Once a sound understanding has been achieved, learners become able to apply their knowledge consistently and, over time, develop a mastery of it. In this way learning can be seen as an ongoing process of improvement, with learners playing an important and active role.

Learning may take many forms, occurring both consciously: for example learning the process by which one can solve quadratic equations, or without any conscious awareness: for example learning not to scald oneself with hot water. Regardless of the type of learning, all processes involve a series of exchanges between learners and sources of information.

From the point of view of the learner, the process of learning is naturally disruptive, with learners having to make sense of new information by connecting it to what they already know. Any conflicts between existing and newly gained knowledge which occur during the learning process must be dealt with and resolved, possibly through reference to further sources of information, before the learner can draw conclusions based on the new information with which they are presented [31, 32]. Thus, it is important that learners assume an active role for the learning process to prove effective. However, such a role requires motivation and commitment from the learner, thus there is often a natural resistance to learning within a formalised educational setting. This must be overcome if learners are to participate in, and fully benefit from, the learning process.

Without the careful planning and design of learning resources, it is conceivable that the effort required will discourage learners from active participation in the process. Thus, educators also play an important role in the learning process, being tasked with developing scenarios which not only facilitate knowledge development, but which also encourage and motivate learner involvement. It is therefore important that educators consider the desirable outcomes of the learning process, for example developing the skills and knowledge required to allow a learner to construct bar graphs or pie charts, as well as the ways in which humans learn, i.e. by undertaking educationally positive behaviours, thereby reducing the factors which can have a negative impact on the learning process.

2.2.1 Bloom's Taxonomy of Learning; Encouraging Educationally Positive Behaviours

In an effort to more readily understand the complexities of the learning process, it is beneficial to first dissect learning into a series of stages which consider different aspects of the process. Work of this nature has been undertaken by many educators and is frequently summarised in educational literature [35-37]. As one of the most widely recognised works in the field, Bloom's Taxonomy of Educational Objectives [2] is often referenced as an exemplar model for describing and classifying levels of intellectual behaviour deemed important to the learning process.

In Bloom's analysis, three domains of learning are identified, with each relating to a different set of learning skills:

- **Cognitive:** Referring to knowledge structures and intellectual behaviour, the cognitive domain has the most relevance to educators when developing educational resources and as such is the most referred to of the three areas identified by Bloom. Traditional approaches to education typically tend to emphasise the skills found in this domain, particularly at the lower levels (for example knowledge acquisition is directly related to the information transfer paradigm often used in e-learning and classroom environments).

- **Affective:** Less intuitive than the cognitive domain, the affective domain is concerned with values and the perception of value issues. In this way the affective domain considers issues relating to emotion, morality, etc.

- **Psychomotor:** Skills in the psychomotor domain relate to the development of skills and physical abilities, for example the ability to manipulate a tool or instrument in order to induce a change in the physical environment. Unlike the other two domains, Bloom did not complete his work in this area and as such failed to provide any subcategories through which psychomotor behaviours can be classified.

  In an effort to complete Bloom's taxonomy, several psychomotor taxonomies have been suggested, with the approach adopted by Dave [38] being widely accepted. In addition to fitting with the model of developing skill put forward by Reynolds [34], Dave's model draws

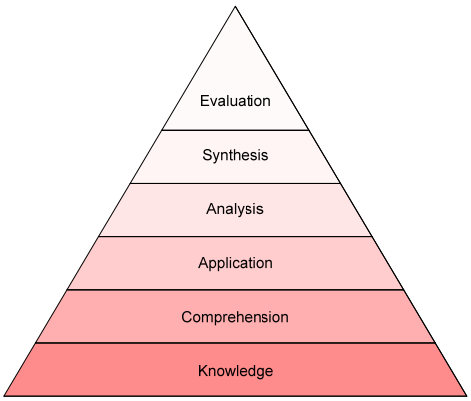

Figure 10 – Hierarchical View of Bloom's Six Levels of Cognitive Learning Behaviour

Category	Description	Examples
Knowledge	Simple recall data of information previously presented.	Ability for learners to be able to recite the stages of an archaeological excavation from memory.
Comprehension	Understand the meaning, translation, interpolation, and interpretation of instructions and problems. Being able to re-state a problem in one's own words.	Explaining in one's own words the steps required to perform a complex excavation activity.
Application	Use of a concept in a novel situation or the application of what was learned in the classroom to alternative scenarios.	Application of the laws of physics to evaluate the reliability and effectiveness of a specific technique in the reconstruction of an archaeological structure.
Analysis	Separation of material or concepts into component parts so that the organisation and structure may be understood. Ability to distinguish between facts and inferences.	Troubleshooting of technical equipment using logical deduction. Recognition of logical fallacies in reasoning.
Synthesis	Building of a structure or pattern from diverse elements. Collection of component parts to form a whole, with emphasis on creating new meaning or structure.	Writing an excavation manual with which to manage the excavation of a site of archaeological significance.
Evaluation	Ability to make judgements about the value and/or reliability of ideas and/or materials.	Selecting the most effective tool from a range of possibilities, ability to explain and justify decisions.

Table 1 – Description of the Behaviours Found at each of Bloom's Levels of Learning

attention to the fundamental role that imitation plays in skill acquisition, and as such bares a strong resemblance to Bloom's work in the cognitive domain which also considers the importance of basic learning behaviours (which, in the cognitive domain, relate to the recall and recognition of facts and information).

Within the cognitive domain, Bloom identifies six distinct levels of behaviour as shown in Figure 10. Starting with the simplest type of intellectual behaviour: the recall or recognition of facts, Bloom creates a pyramid hierarchy which progresses through increasingly more complex and abstract learning behaviours until the highest order of intellectual behaviour, evaluation, is reached. Accompanying Figure 10, Table 1 provides a short description of the meaning of each level of the hierarchy, as well as examples of the type and nature of behaviour expected of learners at each level [2, 39].

Within the hierarchy, lower levels are subsumed by those above, thus, if a learner is operating at the application level, then they must also be undertaking (or have undertaken) learning behaviours which are found in the knowledge and comprehension levels of the pyramid. In this way, levels of learning behaviour are often referred to as a stairway, with learners encouraged to progress upwards as their capabilities develop.

Progression up the hierarchy of behaviours requires learners to adapt their engagement with the learning process and materials presented. Whilst it is entirely possible at the lowest level (knowledge) for learners to simply repeat previously imparted knowledge without attaching any understanding or meaning to it, this becomes more problematic the further up the hierarchy they go. In order to exhibit behaviour befitting of the comprehension, application, analysis, synthesis and evaluation levels, learners need to be able to, as a minimum, exhibit behaviours which indicate an understanding of the meaning of the previously imparted knowledge. Without understanding the meaning of something, it is simply not possible for learners to be able to apply, analyse, adapt (synthesise) or evaluate said knowledge and apply it to alternative contexts. Thus, for learners to progress up the hierarchy they need to be able to show increasing levels of mastery of the subject matter so that they are not only able to merely remember the knowledge being acquired, but also to consider and reflect on it in a wider context which sees new knowledge and pre-existing knowledge assimilated to form a coherent model of the wider world. In this way, it is desirable to have learning materials which enable students to move up the hierarchy of educational behaviours. This implies that it is beneficial to have learning resources which go beyond simply making educational materials available, instead supporting active learning with students positioned at the centre of the process.

2.2.2 Anderson's Updates to Bloom's Taxonomy; Relevance for the 21st Century

In an effort to add relevance for 21st century learners and educators, Anderson et al [37] suggested some amendments to the original taxonomy which not only provide greater clarity by changing some of the terminology used, but which also extend the applicability of Bloom's taxonomy by introducing structural changes which see knowledge being broken down into a number of subcategories based on the type of knowledge being acquired.

As shown in Figure 11, the changes in terminology introduced by Anderson are the most noticeable of the revisions to the basic structure of the taxonomy, with the majority of the original categories being changed from noun to verb form as shown in the diagram. In addition, in an effort to more clearly convey the intended meaning, the original knowledge category was renamed 'remembering', whilst the original evaluation category became 'creating'. As outlined in Table 2, the meanings of the revised terms remain broadly similar to those originally devised by Bloom and as such examples of the type of behaviour remain the same as those listed in Table 1 and have therefore not been repeated in Table 2.

Figure 12 presents the high level structural changes introduced by Anderson's work. As can be see in the diagram, knowledge is transformed into a number of subcategories, which are defined as:

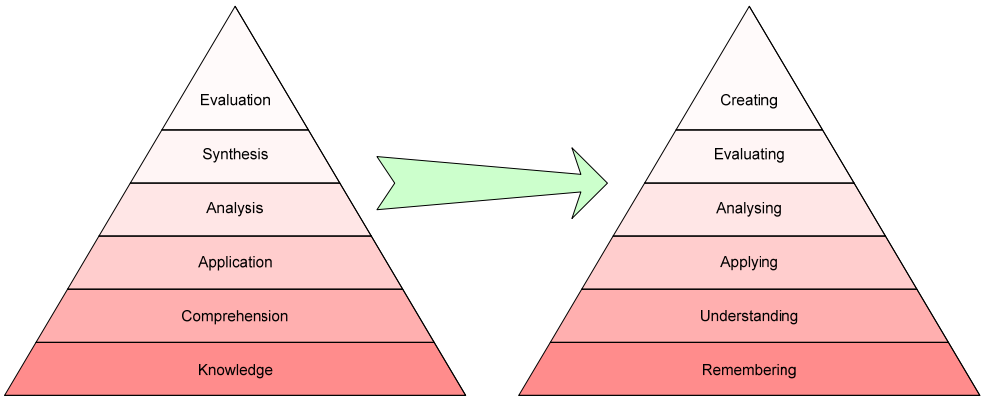

Figure 11 – Anderson's Updates to Bloom's Levels of Cognitive Learning Behaviour

New Term	Original Term	Description
Remembering	Knowledge	Retrieving, recognising and recalling relevant knowledge stored in long term memory.
Understanding	Comprehension	Constructing meaning from oral, written and graphic messages through interpretation, exemplifying, classifying, summarising, inferring, comparing and explaining.
Applying	Application	Carrying out or using a procedure through execution or implementation.
Analysing	Analysis	Breaking material into constituent parts, determining how the parts relate to each other and to an overall structure or purpose through differentiating, organising and attributing.
Evaluating	Synthesis	Making judgements based on criteria and standards through checking and critiquing.
Creating	Evaluation	Putting elements together to form a coherent or functional whole; reorganising elements into a new pattern or structure through generating, planning or producing.

Table 2 – Definitions of Anderson's Updated Terminology

- **Factual:** The basic elements learners must know in order to be familiar with a discipline and able to solve problems in it. Factual knowledge includes knowledge of domain specific terminology (for example logic symbols, technical vocabulary, etc.) as well as knowledge of specific details and elements (for example major natural resources, reliable sources of information, dates of historical events, etc.)

- **Conceptual:** Details of the relationships between the basic elements within the domain as well as knowledge of any classifications or categorisations used (for example periods of time in history, etc.), principles applied (for example Pythagoras' theorem, etc.) or theories and models of structures (for example the survival of the fittest, structure of parliament etc.).

- **Procedural:** An understanding of how to do something, methods of enquiry and the ability to appropriately apply skills, algorithms, techniques and methods. Procedural knowledge also requires learners to have an understanding of subject specific skills and algorithms (for example geophysical exploration in archaeology, long division in mathematics, etc.) as well as techniques and methods (for example interviewing techniques, scientific method, etc.). In addition, learners should also be able to determine when it is appropriate to apply this subject specific knowledge.

The Knowledge Dimension	The Cognitive Process Dimension					
	Remember	Understand	Apply	Analyse	Evaluate	Create
Factual Knowledge	List	Summarise	Classify	Order	Rank	Combine
Conceptual Knowledge	Describe	Interpret	Experiment	Explain	Assess	Plan
Procedural Knowledge	Tabulate	Predict	Calculate	Differentiate	Conclude	Compose
Meta-Cognitive Knowledge	Appropriate Use	Execute	Construct	Achieve	Action	Actualise

Figure 12 – 2 Dimensional Version of Bloom's Taxonomy following Anderson's Changes

- **Meta-Cognitive:** A higher level understanding and awareness of cognition in general as well as awareness and knowledge of one's own cognition. Meta-cognitive knowledge focuses on a learner's ability to determine the structure of knowledge, the types of tests which can be used to evaluate knowledge and the cognitive demands of difference activities. As part of meta-cognitive knowledge, learners will develop knowledge of their strengths and weaknesses (for example applying mathematical theories may be a personal strength, whilst writing essays a weakness, etc.) and overall knowledge level.

With the introduction of the knowledge dimension, Bloom's taxonomy is transformed from a one-dimensional definition into a two-dimensional entity. This makes it possible for each type of knowledge to be considered separately and also allows for more tailored and specific descriptions of relevant educational behaviours to be included in each of the intersections as shown in Figure 12. In this way, the alterations suggested by Anderson also make Bloom's taxonomy directly relevant to educators looking to understand and encourage the types of behaviour and interactions most likely to yield an educationally positive result.

2.2.3 Impact on LAVA Development

With reference to Figure 10 and Figure 11, when considering archaeology it is relatively easy to design educational resources to encourage learners to acquire and comprehend basic knowledge, i.e. engage in behaviours at levels 1 and 2 of the hierarchy. Indeed, this is exactly what the information transfer paradigm serves to do. As such, these are activities which are readily accommodated by existing classroom or lecture theatre teaching arrangements.

However, when developing learning scenarios which allow learners to apply and analyse their knowledge (i.e. engage in behaviours at levels 3 and 4 of the hierarchy), designing the learning process becomes more difficult, with traditional classroom and lecture theatre teaching arrangements often failing to meet the needs of learners. It is here where Anderson's extensions to Bloom's work are most useful.

In breaking the knowledge domain down into a series of sub-sections (see Figure 12), Anderson's work is helpful in identifying the types of application and analysis behaviours which are sometimes difficult to achieve within the classroom environment, namely those involving the experimentation and calculation of applied knowledge. As such, it is these behaviours which need to be more readily addressed by learning technologies.

When considering the application of conceptual and procedural knowledge, many learning activities are domain specific, with physics experiments, geography fieldwork and mathematical calculations all requiring learners to engage in different types of learning scenarios, all of which feature elements of experimentation and explorative work within some type of organisational structure. Whilst it is true that many subject domains are already well supported, with physics experiments and mathematic calculations being readily recreated in classroom environments, there still exists a large subset of disciplines (archaeology included) for which real world re-enactment of activities is not possible on a large scale due to limitations of time and space or due to inherent dangers and risks. Activities which are naturally limited in the application owing to their dealings with dangerous or inhospitable environments, scarcely available resources or limited amounts of time are all examples of such scenarios.

For these activities to be included en-masse in the curriculum there is a need for additional technological support to be provided. It is for this reason that we contend that a need exists for additional technological support to be provided within existing virtual learning frameworks to enable the application of conceptual and procedural knowledge. Furthermore, we suggest that archaeology is one such discipline which could directly benefit from enhancements and extensions to the type of technological support available, with Chapter 3 and Chapter 4 identifying the design methodology and implementation of such a framework.

2.3 The Role of Pedagogy in Shaping Learning Design

Pedagogy is a word which is frequently used and often misunderstood. According to the Oxford English Dictionary, pedagogy is simply:

> The art, occupation, or practice of teaching [40]

Pedagogy plays a key role in the learning process, encompassing many aspects of the teaching and learning process by shaping not only the interactions themselves, but also the roles that educators play within them.

At the heart of every pedagogical approach is a didactic arrangement in which learners acquire a base level of knowledge through a process of information transfer, of the type seen in many traditional classroom and lecture theatre environments. In this arrangement, the teacher assumes an authoritative position as a source of knowledge, with the learner acting as a recipient of said knowledge. The

relationship between learner and teacher is broadly one way, with the teacher in control of the learning environment. On occasion, learners are given the opportunity to pose and respond to questions in order to allow them to solidify their understanding etc. However these interactions are at the behest of the teacher and as such do not signify a transferral of control to the student.

In terms of learning behaviours, the didactic arrangement is primarily concerned with knowledge acquisition and is therefore situated at the bottom of Bloom's hierarchy of learning behaviours. Given that a base level of knowledge needs to be obtained before more complex and higher order learning behaviours can be undertaken, this is understandable.

2.3.1 Established Models of Learning

When considering pedagogy there is an emphasis on encouraging good practice in teaching, as such didactic approaches are often employed as part of a wider programme of teaching and learning. These programmes, which feature a range of activities designed to develop effective learning scenarios, are designed to encourage learners to engage in higher order learning behaviours, for example:

Interactive Learning

As the name would suggest, interactive learning encourages learner involvement with learning materials, with learners directed by, and able to refer to an instructor or teacher as required throughout their interactions. In contrast to didactic learning, interactive learning sees a degree of control over the learning process pass to the learner, with the instructor managing the overall flow of a session. Within classroom environments, interactive learning is sometimes difficult to achieve owing to a reliance on learner engagement. If learners fail to engage with the materials and resources presented, progress throughout a session will be difficult, if not impossible, to achieve.

Collaborative Learning

Collaborative learning is not limited to a specific pedagogy or approach to instruction, but is instead a generic term to refer to any learning process which involves the joint intellectual effort of more than one learner or instructor. Collaborative learning practices are frequently found in learning environments [18, 24, 41] as well as classroom environments, with learners forming groups to work towards specific goals or objectives. Through a collaborative approach, learners are able to gain access to experience, expertise and knowledge that they themselves may not have. In this way collaborative approaches to learning can be particularly useful in encouraging weaker learners to engage with challenging learning materials.

Experiential Learning

Experiential learning is the process of learning or forming knowledge from direct experience [42, 43]. Focussing on an individual throughout the learning process, experiential learning places the learner at the heart of the knowledge development process. Requiring no instructor or teacher figure, the

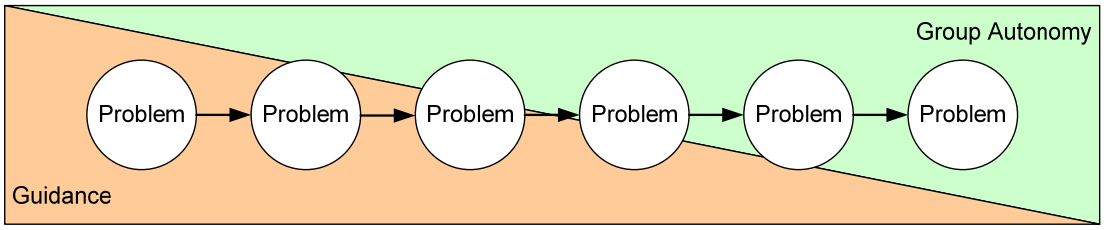

Figure 13 – Problem Based Learning - Guidance Levels Progressively Fading

experiential learning process is highly personal and specific to each individual, with no two learners sharing the same experiential learning experience. Whilst knowledge formation is an inherent process that occurs naturally, for a genuine experiential learning process to occur, certain elements must exist [44]:

1. The learner must be willing to be actively involved in the experience.

2. The learner must be able to reflect on the experience.

3. The learner must possess and use analytical skills to conceptualise the experience.

4. The learner must possess decision making and problem solving skills in order to use the new ideas gained from the experience.

As experiential learning is essentially a personal process, learners must be self motivated and prepared to use their own initiative. Given this, experiential learning is not necessarily always appropriate, especially in scenarios which may lead to the learner requiring additional support and assistance.

Problem Based Learning

Enabling learners to collaboratively solve problems and reflect on their experience, problem based learning was developed and has been used extensively at McMaster University in Hamilton, ON, Canada [45]. By presenting learners with challenging, open ended problems, problem based learning encourages learners to take responsibility for, organise and direct the learning process. During the early stages of problem based learning, learning groups receive significant guidance from a tutor and/or instructor responsible for managing the learning session. As group members develop confidence and gain expertise this guidance is reduced, with learners eventually acting as an autonomous group [46] as shown in Figure 13.

To aid progress, problem based learning often begins with simplified examples of real world problems which are used to encourage learners to understand the basics of the theories or concepts being taught. Whilst these early examples run the risk of being negatively affected by reductive bias [47], as the problem based learning scenarios develop the simplification is reduced, with later problems increasingly reflecting wider aspects of the real world, thus countering the reductive bias seen in the early stages of the problem based learning process [48]. Throughout the entire process, discussion is

an important activity which allows learners to provide feedback and reflect upon the progress of their group and as such is vital to the development of meaningful learning scenarios [49].

Constructionism

Constructionism is closely connected with experiential learning and builds on some of the ideas first considered by Jean Piaget [28, 50]. Developed by Seymour Papert, constructionism considers learning as a (re)construction process as opposed to a process tasked with transmitting knowledge to learners [51]. As such constructionism contends that learning is most effective when learners are given the opportunity to manipulate materials and concepts [51]. Used primarily in the domains of science and mathematics, constructionism has also been used successfully in the domains of media studies and applied linguistics in the field of second language acquisition. In addition, the approach has been widely adopted by the Lego Group [52], forming the basis of the development of the Mindstorms Robotics Invention System [53].

All of these pedagogical approaches enable learners to undertake behaviours located towards the top of Bloom's hierarchy, thereby extending the educationally positive behaviour encouraged by didactic approaches by providing learning exchanges which enable learners to:

- **Apply** their knowledge to alternative scenarios.
- **Analyse** their knowledge and its application in the context of alternative scenarios.
- **Evaluate** and reflect upon their learning processes.

In addition, all approaches share similarities with the constructivist theory of learning which encourages the learner to become a central part of the learning process. By emphasising the importance of knowledge acquisition as part of a larger social process of discovery [54-56] constructivism lends itself to the development of socially aware learning scenarios, with groups of learners working together to build a common understanding of the collective knowledge gained through an activity. This process, which has been described as the co-construction of shared knowledge in Activity Theory [47, 54] and also referred to as investigation based learning [57], can have a positive impact on learner motivation and attainment for two reasons: not only does it allow learners to collectively draw conclusions based on the knowledge gained through a task, but it also allows them to break down seemingly complex activities, with team members each contributing to the overall work effort, but with no single member being held fully responsible for satisfying the requirements of the activity in full. In this way, the risks of participation are reduced, thereby encouraging weaker learners who would otherwise be overwhelmed, to make an attempt at contributing to an activity which stretches their abilities.

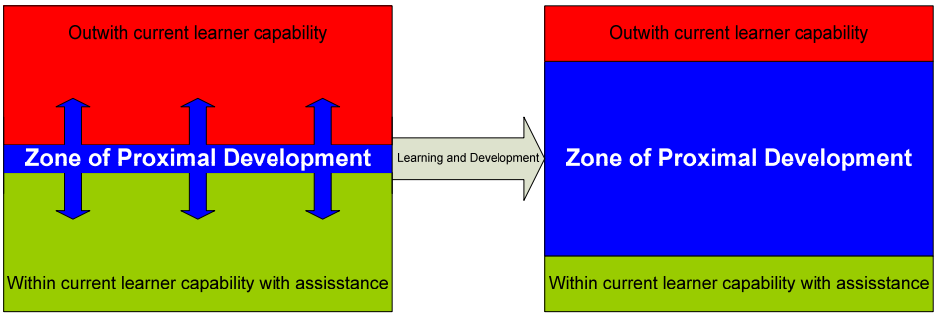

Figure 14 – Evolution of a Learner's Zone of Proximal Development

2.3.2 Constructivism and Constructivist Approaches to Education

One of the major goals of constructivism is to teach learners how to manage and direct their own learning processes. A constructivist educator will help students during the learning process by providing the tools and initial information necessary to enable the learner to undertake an activity as well as the overall goals and objectives which need to be met. However, it is very much up to the learner to decide how best to proceed: how to solve intermediate problems which may arise, how to set short term goals throughout the activity, and how to develop the necessary skills required to satisfy the overall objective. Whilst the educator will be on hand to monitor progress and provide additional materials and support as required, if a learner feels unable to break down the activity, then this is going to have a negative impact on their motivation.

However, by developing scenarios which involve groupwork activities, educators can make it possible for learners within a team to benefit from the strengths of other team members. By giving learners the ability to see how other group members approach and dissect an activity, educators can develop scenarios which help weaker learners to develop their skills and confidence by focusing on the approaches advocated by stronger learners when faced with an activity they are unsure how to complete. Not only does this allow weaker learners to develop their own personal strategies to learning, something which is essential if a learner is going to be able to take control of their own learning interactions [55], but it can also have a positive affect on learner motivations, with weaker learners gradually developing the confidence to engage in learning activities which fall on the edges of their comfort zone, or more formally as Vygotsky labels it, their zone of proximal development [54, 58].

According to Vygotsky's definition, activities which fall within a learner's zone of proximal development are activities which the learner has the requisite skills, knowledge and capability to satisfy. When working on activities within the zone of proximal development, learners make use of skills and knowledge which they are still forming, and as such activities within the zone lead to the most effective learning, with learners repeatedly practicing newly gained skills. As shown in Figure 14, activities falling outwith the zone take one of two classifications; activities above the zone are defined as being outwith the current capability of the learner, even with external assistance, whilst activities below the zone are activities defined as being within the current capabilities of the learner, but only with third party assistance. As learners develop their skills, knowledge and capabilities, their

zone of proximal development expands to consume some of the spaces which were initially designated as containing activities either outwith their current capabilities, or within their current capabilities only with third party assistance. This development is shown by the transition documented in Figure 14. Thus, by enabling groupwork, students are able to increase the size of their zone of proximal development by incorporating activities below the zone into their current capabilities. As such, the use of groupwork makes it possible for learners to engage in a wider range of learning activities, all within their zone of proximal development, thus benefiting from more effective learning interactions.

More recently there has been a notable addition to the use of constructivist concepts, with the introduction of cognitivist approaches in an attempt to deliver learning scenarios which are designed to be sympathetic to the way in which we learn [59-62]. In this way more consideration is being paid to external factors which affect learning (through the use of constructivist concepts), as well as human factors which can be exploited to further enhance the learning process (through the use of cognitivist approaches).

2.3.3 The Influence of Computer Game Methods

Computer games are traditionally structured into a series of stages, each of which has an end goal or objective which must be met. Initial stages are generally relatively easy to progress through, with the complexity increasing as a player completes each level. In general all levels of a game will follow a similar theme and structure, with later levels introducing increasingly complex objectives which allow less room for error as players apply the skills, strategies and techniques gained through earlier levels.

Initially the difficulty in a computer game will be relatively low, so as to instil confidence in a player and encourage engagement and progression. As a player progresses through the game, the difficulty level will increase in order present challenges which need to be overcome. To add to the challenges players face, games often employ tactics which penalise mistakes, with players suffering disadvantages for single mistakes before being required to repeat previous challenges after repeated mistakes. Owing to the increasing level of difficulty, once met, these challenges provide players with a sense of achievement by rewarding them with new challenges to attempt or additional parts of the game to explore.

Computer game designers also provide learners with a number of features which encourage interactivity, including problems which need to be solved and in game automated characters which can be engaged in conversation or battle. In addition, many modern computer games add to these features by providing tools which enable players to communicate with each other in real time, thereby transforming the gaming environment from simply a game level, into an social environment in which players can form teams, collaborate in reaching objectives, etc.

When considering Bloom's hierarchical structure of learning behaviours, the idea of progression introduced by computer games is particularly relevant. As discussed in section 2.2, each level of

Bloom's hierarchy is built upon the ones preceding it; as such progression to higher order learning behaviours is dependent on learners developing skills and competencies at lower levels, in much the same was as players do in a computer game.

In moving from abstract to concrete concepts of learning, further similarities can be seen, with many pedagogical approaches focusing on the development of opportunities for learners to engage and interact with materials. In addition, the use of problem solving is routinely seen in educational settings, with varying levels of complexity frequently used to form a narrative that guides learners through a learning exchange.

More recent approaches to learning have also begun to recognise the value of collaboration and teamwork, with learners increasingly provided with opportunities to engage in group-working practices. Indeed, as discussed in section 2.4, educational software increasingly provides tools to support such types of interaction amongst geographically disparate learners. However, as Chapter 4 outlines, LAVA aims to broaden this approach by developing 3D environments which provide support for real time synchronous communications to take place within a shared environment which learners can use to help develop collaborative and cooperating working practices.

2.3.4 Summary

From the perspective of this work, the adoption of a constructivist approach becomes increasingly appealing. Not only does it encourage educationally positive behaviours found towards the top of Bloom's hierarchical scheme, but it also provides the opportunity for educators to develop scenarios that focus on attributes which are desirable in a learning activity, including:

- **Learner Engagement:** Developing learning scenarios which both allow for and enable inputs from learners, i.e. allowing learners to control the pace of the learning process.

- **Personalisation:** Ability to tailor learning exchanges to account for learner specific preferences and requirements, i.e. allowing learners to maintain their own profile, avatar, etc.

- **Groupwork and Collaborative Working Practices:** Provision of technical resources and academic activities which encourage and/or require learners to collaborate as part of a larger group, i.e. an exercise which requires learners to undertake individual activities before reporting back and authoring a collaborative report which reflects the activities of several learners.

- **Realism:** Delivery of learning scenarios which accurately reflect the real world. Realism does not necessarily imply photorealistic representations of real world phenomenon, but rather

realistic behaviours, layouts etc, i.e. the accurate representation of a geographical phenomenon or archaeological excavation site.

- **Accessibility:** Accessibility is often associated with the provision of services and tools to allow learners with specific learning or physical disabilities to engage with materials. In this work accessibility is defined with the far wider remit of enabling adaptations to materials to allow learners to make use of alternative display formats, methods of interaction and modes of interactivity, etc. in order to increase the range of devices, locations and times in which learners can engage with learning materials.

These characteristics relate not only to the ways in which learning materials are presented, but also to the ways in which they are adapted to meet learner requirements and stimulate educationally positive behaviours. As such, we argue that they are important in supporting our pedagogical goals.

Whilst it is true that educators often need to spend a disproportionate amount of effort ensuring learner engagement, within the context of an educationally positive learning exchange, we deem each of the five characteristics to be of equal importance, with all being critical in maximising the educational value of a given learning exchange. As such, this list of characteristics acts as a summary of the desirable properties which should be present in any technological platform designed to assist in the development and deployment of educational learning scenarios.

These outcomes are significant when considering the development of educational scenarios as not only do they provide mechanisms for encouraging learners to engage in higher order learning behaviours, as discussed previously in this chapter, but they also encourage the development of learning environments which focus on the learner as an individual.

However challenges exist when considering the class of disciplines previously discussed in section 2.1, i.e. those in which there are significant barriers for learners to be able to apply the knowledge and comprehension which they have gained through didactic learning processes in realistic scenarios. Whilst educators in these domains have a framework to build upon, there is little in the way of technology to support their efforts. It therefore becomes increasingly difficult to apply pedagogical approaches which enable higher order learning behaviours in these fields owing to the difficulty associated with the application of abstract ideas and theories to concrete or physical environments.

This challenge acts as a motivator for our work, providing the impetus which justifies the development of alternative technologies which can enable learners to exhibit such behaviours. It also acts to show the genericity of our work, with a variety of subject domains positioned to be able to benefit from any increases in technological support that this work may offer or encourage.

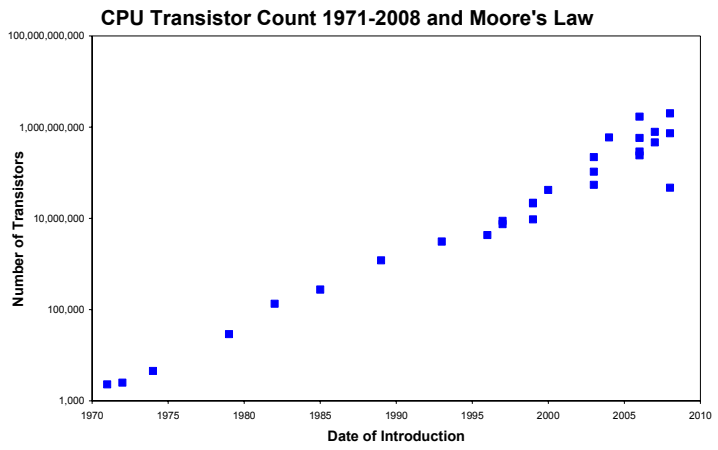

Figure 15 – The Exponential Increases in CPU Transistor Count between 1971 and 2008

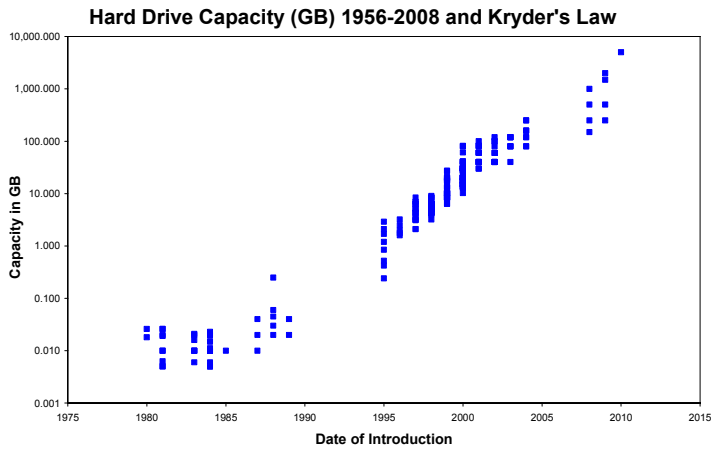

Figure 16 – The Exponential Increases in Hard Drive Capacity between 1956 and 2008

2.4 The Impact of Technology and Technological Enhancement

Technology has far reaching impact on the educational sector. Technology not only delivers learning resources to learners, but also helps shape the pedagogical approaches adopted. As such the role of technology and technological enhancement is a key consideration when developing processes which enable learners to engage in meaningful, educationally beneficial learning exchanges.

Within the computing sector there is a long term history of technological innovation. Since the introduction of the integrated circuit in 1958 [63, 64], the pace of this advancement has been significant. The effort to meet demands for ever increasing amounts of computing power has fuelled an exponential increase in the number of transistors featuring in integrated circuits over the last 50 years, with the total number doubling, on average, every 18-24 months as shown in Figure 15.

This trend, which was first observed in 1965 by Intel co-founder Gordon Moore [3, 65], has become somewhat of a self-fulfilling prophecy within the technology sector. Referred to as Moore's Law [66], the influence of Moore's observations have been far reaching. Once confined to considering the advancement in the manufacturing process of integrated circuits, the properties of Moore's Law have

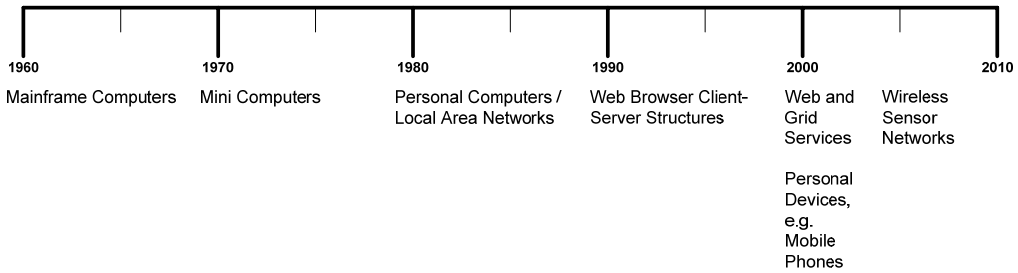

Figure 17 – Timeline of Computer Classes as described by Bell's Law

become synonymous with assessing increases in almost every measure of the capabilities of digital electronic devices including processing speed (Moore's Law), hard drive capacity (Kryder's Law [67] as shown in Figure 16), network bandwidth (Butter's Law of Photonics [68] and Nielsen's Law of Internet bandwidth [69]) and even the number and size of pixels in digital cameras [70]. Of the laws which have grown out of Moore's original findings, all show similar trends, with each of the observed attributes growing at an exponential rate over time as shown in Figure 15 and Figure 16.

Many have interpreted Moore's Law to mean that the processing power of computers doubles every two years. However, this is an overly simplistic interpretation and negates to consider other factors which affect processor performance. In reality, different processor architectures offer different levels of performance and as such performance is not necessarily a direct function of the number of transistors the processor contains: for example, the AMD Athlon processor family often outperformed their Intel Pentium 4 counterparts, despite the fact that the Pentium 4 contained more transistors [71]. Even within a single processor family the relationship between performance and transistor count is not directly linked. Indeed, there have been cases where a 45% increase in the number of transistors has resulted in a performance increase of only 15% [72]. As such, whilst Moore's Law provides a rough estimation of the development of computing power, it cannot be considered in isolation and must be considered in the wider manufacturing context.

In terms of the accuracy of Moore's projections, it is interesting to note that whilst the original projections have been broadly accurate, the law has been subject to minor updates. In 1975 Moore made a notable change where he altered his projection to a doubling of the number of transistors every two years [73]. In this way, some aspects of the law have been updated in order to account for changes in practices within the technology sector, thereby retrospectively bolstering the accuracy of the law.

As a partial corollary to Moore's Law, Bell's Law of Computer Classes [74, 75] classifies and considers the impact of the continual technological development predicted by Moore. First considered in 1972 [76], Bell's Law describes how computer classes form, evolve and eventually die out. By considering the impact that technical progression has on the range and classes of computers available, Bell's Law seeks to examine new applications for emerging technologies. In this way, whilst Moore's Law considers technical advancement from the perspective of processor design, Bell's Law considers it from the perspective of emerging platforms and the applications that they power. In this way, Bell's Law considers how technical advancement can impact the way in which we make use of computers.

Class Name	Date	Description / Properties
Mainframe Computers	1960s	Used mainly by large organisations for critical applications. Mainframes support multi-user access and are often used for bulk data processing. As such their resources are usually heavily utilised by the host organisation.
Mini computers	1970s	Smaller than mainframe systems and larger than personal computers, mini computers employ the same shared user approach of that adopted by mainframes, thereby allowing users to remotely connect in order to run their applications. Owing to their smaller size, mini computers are often found in smaller organisations which require the ability to process large amounts of data, but cannot justify the expense of a mainframe system.
Personal Computers and Local Area Networks	1980s	A personal computer is any general purpose computer which is small enough (in physical size and cost) to be used directly by individuals. Personal computers are generally used by a single user at a time, although local area networks do make it possible for some personal computer resources (hard drive space, optical drivers etc.) to be shared amongst several users, each with their own personal computer. Personal computers can take many forms, with this class covering desktop, laptop and tablet style machines.
Web Browser Client-Server Structures	1990s	Web browser client-server structures generally began appearing in the early 1990s, with users accessing services on servers through their own personal computers. The client-server architecture allows users to access data and resources stored on remote servers through the use of a unified address space. From a content provider perspective, this class makes it possible for a single resource (or small number of resources) to be shared by multiple simultaneous users.
Web/Grid Services	2000	Web/grid services are defined by the World Wide Web Consortium (W3C [77]) as: Software systems designed to support interoperable machine to machine interaction over a network [78]. In essence they are Internet application programming interfaces that can be accessed over networks. In this model computers are able to provide functionality which can be invoked by several remote users as needed. This class makes it possible for aspects of computational processes to be separated and executed on different machines. In this way, instead of copying large volumes of data between networked machines, remote execution processes can be invoked, with only the arguments initiating the computation and any resultant output being transmitted over the network.
Small Form Factor Devices such as Mobile phones	2000	Personal devices such as organisers and mobile phones are quickly evolving to provide a diverse range of services and applications for end users, including Internet access, diary scheduling, email, word processing etc. As their computing power increases, so too do the number of applications that they support, with many personal devices making use of Web services to provide end users with access to data and resources whilst outwith the traditional home or office environment.
Wireless Sensor Networks	2005	An emerging class of computing, wireless sensor networks are wireless networks which consist of spatially distributed autonomous devices which sense the surrounding environment and cooperatively report their findings. The individual nodes within a sensor network are often very small in size and as such are generally resource constrained. As a relatively new technology, wireless sensor networks are an active research area, with new areas of applications being investigated.

Table 3 - Computer Classes as Defined by Bell's Law

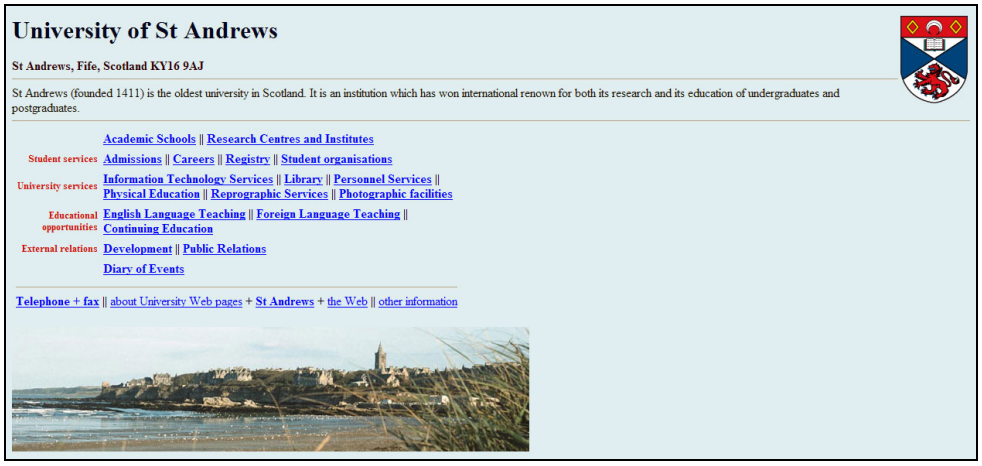

Figure 18 – University of St Andrews Website circa 1997

Stemming from Bell's Law, Figure 17 depicts a timeline showing the adoption of several distinct computing classes, with Table 3 defining each class in more detail. As highlighted by Bell's Law there has been a general move away from large scale supercomputers to widely accessible individual personal computers. As part of this shift we have seen the reliance on textual interfaces fade, with modern personal computers and mobile computing devices routinely providing user friendly and intuitive graphical user interfaces.

2.4.1 The Effect of Technological Innovation

As the power of personal computers continues to grow, there is an increasing occurrence of graphically rich 2D and 3D environments for gaming as well as general purpose use. This trend is reflected in the development of Internet applications. Initially email, which is predominantly textual in nature, was one of the most widely used applications. As the Internet has developed, the importance of the World Wide Web has grown, with the Web now accounting for much of the Internet traffic which flows between machines. The growth of the World Wide Web has brought with it the need for the Internet to support the transfer of text, as well as graphics and more recently other multimedia elements.

In addition we can see similar characteristics when considering the development of individual applications. Initially the World Wide Web was predominantly text based. Over time, text has been supplemented with graphics, which have become widespread and now form an integral part of most websites. This shift is highlighted by the differences between Figure 18 and Figure 19, with Figure 18 showing the University of St Andrews website [79] circa 1997 and Figure 19 showing the same website in 2009. As the figures show, there are distinct differences between the two websites, with Figure 19 featuring significantly more graphical elements than Figure 18. In addition to text and graphics, the websites are also becoming more reliant on the use of Adobe Flash [80] animations, Apple QuickTime movies and other high quality audio and visual multimedia components.

As the Web continues to develop, we are also seeing a change in the way the technology is used. The traditional publishing of information which saw Web Masters making content available for users to

Figure 19 – University of St Andrews Website circa 2009

download is being superseded by a model in which users are empowered to add their own content to sites, thereby enabling the Web as a means of supporting specific forms of two way communication. Social networking sites such as Bebo [81], MySpace [82], Twitter [83] and YouTube [84] are key examples of the type of interactive experience enabled by these Web 2.0 technologies, with Web Masters providing the infrastructure, and users providing much of the content to be displayed.

As part of the transition to a more user oriented environment we are also seeing increasing amounts of network traffic being generated by computer games and virtual environment technologies, with multi-user environments like Second Life, Open Simulator and Activeworlds becoming more widely used as a form of social and communication network.

2.4.2 Software in the Educational Sector

When considering the educational domain, technological innovation is clearly apparent, with the sector well versed in the deployment of traditional Web services which make use of text, graphics and multimedia elements to publish information for students to access.

Historically the educational sector has seen the deployment of a variety of technologies in an effort to enhance the teaching and learning process. Prior to the commercialisation of the sector, educational technologies were often developed in house to meet specific academic objectives. Given this, they were often highly specialised and deployed on a relatively small scale, with the academics involved taking a full and active roll in the management of such systems.

As part of the popularisation and commercialisation of the software in the sector, the development of highly tailored systems has slowly given way to the deployment of larger, more generic systems. Instead of supporting specific learning processes, these larger systems tend to focus on providing tools to support the management of the overall educational process. By providing greater support for modification and reuse in a variety of subject domains, these larger systems have become part of the range of business critical systems which are central to the host organisation's ability to meet its overriding objectives. As such, responsibility and control of these systems has moved from individual academics to centralised Information Systems staff. With this transition the knowledge and skills of educational experts has been lost, thereby reinforcing the focus on the management of the overall educational process that current educational technologies often have.

With this rationalisation of software comes a natural contraction in the types of systems in use, with many organisations opting to deploy 'industry standard' software from commercial suppliers. Today, of the types of technology routinely deployed in higher education institutions, the three most common options are virtual learning environments, managed learning environments and portals, many of which offer Web 2.0 type interactive services which allow learners to become more central to the learning process:

Virtual Learning Environments

Within the UK academic community, the uptake of virtual learning environments has been notably strong. Characterised in a report published by the Joint Information Systems Committee (JISC) in 1999 [85], virtual learning environments are described as:

> Learning management software systems that synthesise the functionality of computer-mediated communications software (email, bulletin boards, newsgroups etc) and online methods of delivering course materials (e.g. the WWW) [86]

In essence, virtual learning environments mix a number of communication tools including: notice boards, chat rooms, email lists, student homepages, calendars etc. with several educational tools

including: computer based assessments, whiteboards, resource upload and download areas etc. In addition, tools specific to the virtual learning environment are often included to enable students to search for required resources and manage their online accounts and associated learner profiles.

Initially developed as in house projects managed by academics to fulfil the specific needs of further education institutions and their associated funding bodies [87], the popularity of virtual learning environments has lead to the development of a number of commercial products as well as the commercialisation of existing academic projects: for example, the 1997 commercialisation of the WebCT system which was originally developed as an in-house application in use by the University of British Columbia [88] in 1995. This commercialisation was followed in 2006 by a merger between WebCT and Blackboard [89].

In terms of pedagogy, virtual learning environments do not explicitly favour any specific approach, but instead aim to provide supporting infrastructure which allows educators to produce educational content which is placed in/on the virtual learning environment for delivery to learners. However, owing to the ways in which content is delivered by the underlying technology, the information transfer paradigm is favoured, with the traditional didactic approach of educator as the source of knowledge and the learner as willing recipient implicitly re-enforced. Having said this, the ability for learners to converse outwith the traditional classroom environment can be seen as an enhancement of learning process, with the relative anonymity of forum postings, private chat areas etc. making some progress towards reducing the traditional learner-educator divide which can often discourage students from active participation within the classroom environment.

Managed Learning Environments

Managed learning environments were first defined by JISC in 1999 as being the integration of an institutional virtual learning environment (or possibly many virtual learning environments) with the existing information systems infrastructure operated by the host institution [90, 91] including, for example, the personnel databases, accounting systems and student data warehouse infrastructure etc.

In terms of creating a differentiation from virtual learning environments, the integration of managed learning environments is significant. Unlike virtual learning environments, which can be operated in isolation by specific departments or academics for individual courses, managed learning environments necessarily have institution wide impact owing to their integration with other business critical systems in use by the host institution. The scope of managed learning environments is significant, with their introduction often having an impact on the way in which host organisations manage data flow within existing systems.

The focus of managed learning environments is on systems integration, standards and interoperability. To this end, within the UK, the development of managed learning environments has been the focus of the JISC Centre for Educational Technology Interoperability Standards (CETIS) [92] which was

Portal Feature	Commentary
Customised for the User	The portal recognises the user and accesses a profile to determine what types of services and information is relevant for them, and possibly other preferences such as presentation format, page layout etc.
Customisable by the User	The user may customise elements within the portal interface, for example; displaying information from a list of optional services and content, applying a different look and feel to the interface, organising a preferred layout etc.
Anonymous Access	Part of the portal vision is a way of evolving existing institutional websites, so an anonymous visitor is presented with relevant, hierarchically organised information of the type often found on static websites.
Anonymous Subscription	An anonymous user can request an account and create an individual username and password. They may be able to elect to receive email notifications of specific types of event (for example changes to content) and participate in group activities. This type of access is not generally supported by standard websites.
Single Sign On (SSO)	A user can use their institutional authentication tokens to access the portal and all relevant content. Any subsequent authentication required by external resources is then managed by the portal, without user intervention.
Application Server (Implied read-write access)	The enterprise portal is seen as a means of controlling access to approved corporate software, data, policies etc. In contrast to most websites, which offer basic HTML supported interactions, portals offer genuine two way read-write access to services and data repositories.
Content Aggregation	Content is regularly copied and updated from diverse information sources. These may be existing websites, databases etc. It may be copied as low-level data and then extensively formatted for presentation in the portal.
Content Proxy	Rather than copying, re-organising, formatting and presenting data from external sources (as with content aggregation), the portal maintains a dynamic link to an external resource and displays live data from the source when requested.
Content Referral	The portal provides a standard hyperlink or URL to an external resource – the user can then access this using their preferred Web browser.
Support for Multiple Device Interfaces	The ability for the portal to adjust and adapt the layout, formatting and presentation of data based on the mode of interaction and device in use by the user.
W3C Access Compliant	The ability for the portal to maintain compliance with relevant data access standards to ensure that no users are disadvantaged when accessing data.
Sole Point of Access to Information Services	This is a somewhat paradoxical requirement. If the portal is the sole provider of access to required information and services, then why the need to provide mechanisms for content aggregation, proxying and referrals? The reality is that this feature is seldom (if ever) achieved by a portal, and as such the feature needs to be put into context, with a portal being a sole point of access to information services relevant to a specific area (for example being a student at the University of St Andrews).
Security	As the portal may provide access to private, sensitive or licensed information and services, security of access is important.

Table 4 – Portal Features and Characteristics

established to monitor and report on the standards and best practice working procedures being adopted within the educational sector.

Portals

At their most basic, portals are simply a single point of entry for a range of services and information. Within the Web there are several competing websites aiming to provide a portal service to users, with Yahoo [93], and more recently Google with the iGoogle service [94] being two of the largest and most well known general purpose portals. Other more specialised portals also exist, with Kelly Search [95]

being primarily a business to business portal and Yell.com [96] being positioned as a consumer to business portal.

Within the higher education sector, the personalisation opportunities of portal technologies have become somewhat of a focal point in both the US and UK [97]. Providing a summary and explanation of the main features offered by portal technology, Table 4, which is adapted from [98] identifies the key areas in which portal technologies can be leveraged to provide a coherent structure to Web-based learning content. In a JISC funded study carried out in 2003, the institutions involved indicated that the personalisation possibilities offered by portal technologies were of most significant interest [99]. In an effort to address this requirement, a number of commercial organisations have been quick to develop products specifically for the educational sector [41, 89].

As a community, the educational sector has also been successful in developing an open standards approach to the use and implementation of portal technologies. In the uPortal project [100] over 20 US universities collaborated on the development of an open standards based suite of software, with the resulting product being adopted by many US and UK universities as the basis for the development of in-house learning environments which can be tailored to address the specific needs of their staff and student populations [101]. Several independent in-house portals have also been developed in the UK, including COSE [102], TAGS [103], Bodington [104] and MMS [18].

As has been shown, the main types of educational software in use focus heavily on traditional didactic approaches to teaching and learning. Whilst these applications make notable enhancements to the educational process by increasing the levels of personalisation and accessibility of learning resources, their focus on the information transfer approach limits the extent to which they can be used to encourage the development of higher order learning behaviours. As the discussion of Bloom's taxonomy shows, these traditional didactic approaches successfully enable knowledge creation and the development of comprehension, but fare less well in providing frameworks to allow learners to apply and evaluate their knowledge. This becomes an issue when dealing with the class of subjects considered by this work, as without relevant technological support, the ability for students to apply and evaluate their knowledge is difficult to realise.

2.5 Applying New Technologies in the Educational Sector

The fact that the educational domain has yet to adopt the new classes of 3D applications being made possible through technological advancement is not entirely unexpected, and in no way reflects badly on the sector. Indeed, as our previous discussion shows, educators have been fast in adopting new technologies when it is deemed educationally beneficial to do so.

A significant barrier to the introduction of new technologies has always been the need for educators to maintain accessibility. Whilst Moore's Law (and the other laws that have grown out of his observations) indicates that increases in top end computing capabilities are inevitable, it is important to

acknowledge that the impact of these advances is not immediate for most users, but is instead felt over a period of time as performance increases with the refurbishment of computing classrooms or the purchase of a new home computer etc. As such, it is important that educators develop learning materials with a lowest common denominator approach, thereby ensuring that all end users (i.e. not just high end users) are able to access the resources provided.

Nielsen's Law [69] considers this issue in relation to Internet bandwidth availability and the development of Web applications and media resources. In Nielsen's findings it was determined that low end users typically lag 2-3 years behind high end users in their uptake of new technology, with Web developers being forced to tailor the bandwidth requirements of their applications and media resources to account for low end users in order to ensure mass appeal of their work.

Within the educational sector, a similar trend can be seen, with educators focusing on the adoption of technologies to support learning which have only modest resource requirements on client computers. However, we are now at a point where the advancement in computing power means that the use of multi-user virtual environments like Second Life is feasible on general purpose computer hardware of the type typically found in computing labs and home environments. In addition, if Moore's Law continues to hold true, the level of accessibility is only going to improve as the availability of computing resources increases with time. As such, this work contends that it is now worthwhile investigating the ways in which alternative 3D technologies can be used within the educational process.

As previously discussed, there are a number of existing pedagogical approaches which facilitate the development of higher order learning behaviours. However, technological support for these frameworks is incomplete, with existing educational technologies often assuming a didactic approach towards teaching and learning. Whilst this fares well at enabling learners to engage in knowledge acquisition and comprehension activities, it does not provide the necessary tools to comprehensively support higher order learning behaviours. This is problematic for the class of disciplines that this work considers, i.e. those in which barriers exist that make it difficult for learners to apply their knowledge and comprehension in realistic scenarios. Consequently, the adoption of a hybrid approach could prove beneficial, with existing Web-based educational software being used to manage the overall learning process whilst 3D environment technologies are employed to deliver scenarios which allow learners to apply, analyse and evaluate their skills and knowledge.

With specific reference to the properties identified in section 2.3.4 as being desirable in a learning environment, Table 5 highlights how the strengths of both existing and new 3D technologies can be combined to deliver a learning environment focused on enabling the higher order learning behaviours identified by Bloom as being beneficial to learning. The remainder of this section considers the unique opportunities offered by 3D technologies with respect to presentation of learning materials, development of engagement, interactivity and enhanced presence and the ways in which different learning styles can be supported.

Property	Technology	Discussion	Learning Behaviour
Learner Engagement	Portal Architecture	Existing learning environments provide the necessary tools and framework to enable learners to acquire knowledge.	Knowledge
	3D Multi-User Virtual Environment	3D environments open up the possibility of exploration, with learners exploring an environment and testing their assumptions.	Knowledge Comprehension Application Analysis
Personalisation	Portal Architecture	Personalisation is well supported by many educational software packages and allows tailored resources relevant to each learner to be displayed.	Knowledge Comprehension
	3D Multi-User Virtual Environment	Whilst the 3D environment is shared, each learner has a unique view of it. By interfacing with existing educational software, this unique view can be populated with learner specific resources.	Knowledge Comprehension
Groupwork and Collaborative Working Practices	Portal Architecture	Using Web 2.0 technologies, existing educational software can support asynchronous textual communication between 2 or more users. The use of other technologies can also allow synchronous audio and video chat capabilities to be provided.	Synthesis Evaluation
	3D Multi-User Virtual Environment	Collaboration and communication tools are built into 3D environments by default, as such synchronous audio and text chat is possible. In addition, users share the same virtual space and can work together applying their knowledge to make and evaluate changes to the environment.	Application Analysis Synthesis Evaluation
Realism	Portal Architecture	Textual, photorealistic graphical and video resources can be made available to learners through portal technologies, but often associated context is not available. Limited interactivity can also be provided.	Knowledge Comprehension
	3D Multi-User Virtual Environment	Within a virtual environment, all learning materials are provided with surrounding context. This provides opportunities for realistic, interactive learning scenarios to be presented to a learner individually or as part of a larger group. As part of a group, learners can interact with the environment to apply theories and/or skills and assess and evaluate their findings.	Knowledge Comprehension Application Analysis Synthesis Evaluation
Accessibility	Existing Portal Architecture	Web 2.0 technologies provide high levels of accessibility by offering a standardised protocol which users can use to gain access to resources. As such users are free to use whatever Web browser they wish to interact with resources.	N/A
	3D Multi-User Virtual Environment	3D environments currently require the use of specific client applications. As such they are unable to support the level of transformations to resources offered by Web 2.0 technologies.	N/A

Table 5 – The Roles of Different Technologies in the Learning Process

2.5.1 Presentation of Learning Materials

Presentation of learning materials is one of the areas in which 3D virtual environments offer a radically different approach to existing 2D learning environments. Not only do they provide a 3D perspective on content, but 3D virtual environments also provide the opportunity for students to interact with the content being presented in ways not possible on the Web; learners can view content from a variety of

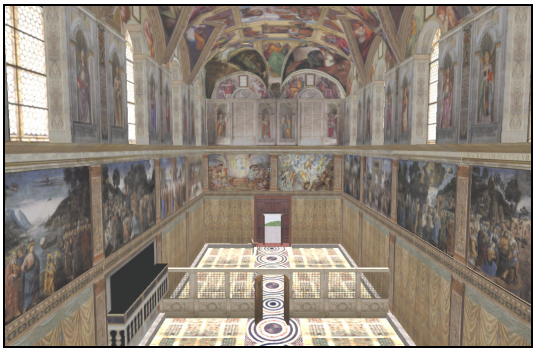

Figure 20 – Second Life Reconstruction of Sistine Chapel

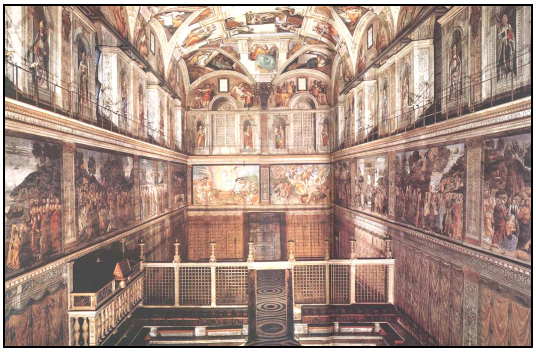

Figure 21 – Photograph of Sistine Chapel

first person perspectives and can zoom in and out on specific areas as required. In addition, many 3D virtual environments make use of a shared world. This provides opportunities for learners to interact with each other whilst engaging with learning materials, thereby opening up the possibility of engaging in collaborative and group-working practices.

The expressive powers of virtual reality technologies have been praised many times, with their flexibility and ability to support many different types of interaction often being cited as advantageous [55, 105-107]. When considering the virtual reality aspect of 3D virtual environments, there are many ways in which the presentation of learning materials can be enhanced. Virtual reality provides the opportunity for new paradigms to be explored, with information presented in a way more representative of how it would be displayed in the real world. As such, content can be displayed in context instead of being displayed as flat images on a website. In this way virtual reality technologies can be used to leverage the mechanisms that learners use to understand the natural world around them [108]. For example, within a 3D virtual environment a building can be truly represented as a 3D object (as shown in the Vassar reconstruction of the Sistine Chapel depicted in Figure 20 [109]) and not a 2D representation of a 3D object (as shown in the picture of the real world Sistine Chapel depicted in Figure 21). This means that learners can explore the architectural space from both the inside and out. By being inside, learners can actually experience the physical layout of a building and not have to only imagine what it would be like. In this way a virtual environment provides a more concrete, accessible and tactile environment for users to explore [108].

Given that learners can directly interact with the content being presented in a 3D environment, there is a reduced need for symbols or keys to confer meaning, instead educators can use reconstructions of the natural world [110]. An example of this would be the presentation of a map. Instead of having to decode the different symbols in use to represent buildings, roads, gradients etc. learners can instead directly examine the environment in order to gain an understanding of the topography and configuration of the region. In this way the intrusiveness of the user interface is reduced, with the learner free to concentrate on the data being presented [105-107, 111, 112]. As such, the use of a virtual environment allows learners to directly construct knowledge of the environment, bypassing the need to decode arbitrary symbols [110].

Within the constructivist domain, the level of authenticity of learning scenarios is also of importance: whilst each learning scenario does not have to be entirely faithful to real world examples, it is, however, important that the level of authenticity is appropriate to the task being undertaken. When considering 3D virtual environments and virtual reality technologies, a synergy with this approach can be seen. With the 3D perspective also comes the ability for educators to employ new metaphors to convey knowledge and meaning [32, 56, 107, 113, 114]. As such, instead of having to adapt and simplify content to fit in with existing representations, educators can adopt more natural approaches which, whilst inherently more complex, are more akin to the natural world, and are therefore more familiar to learners. This is a distinct advantage and significantly reduces the risk of oversimplification or reduction bias [55, 107]. In addition it encourages learners to feel familiar and at ease with their virtual surroundings and allows them to make assumptions about how the environment operates: for example, the presence of gravity or the way in which items can be moved around. These familiar concepts make it far easier for learners to work with the virtual environment in a way that is relevant to their immediate learning goals, as well as the real world [55].

Given the complexity surrounding implementations which are entirely faithful to the real world, reconstructions generally operate on a selective realism basis, with irrelevant or unneeded features removed from the reconstruction. This helps to maintain a clear and uncluttered environment which is less likely to cause confusion amongst learners. In addition it also simplifies the implementation process. However, selective realism needs to be treated carefully, as it runs the risk of introducing reductive bias which can lead to learning exercises being excessively or inappropriately simplified [47].

Finally, as the environment of virtual reality systems is dynamic and changing, educators have the ability to use multiple senses to convey meaning. As discussed by Dede [115], multisensory presentation can be used to build in redundancy, thereby reducing the chance of misunderstandings arising. This has a significant advantage in an educational context, with educators able to use multiple channels of communication to ensure that learners construct an accurate understanding of the environment being explored. An example of this would be the use of audio and graphics to show an explosion occurring. The graphical representation shows the force of the explosion, with the audio reinforcing the significant amounts of energy being released. In addition, educators can model the explosion so that it has an affect on the surrounding environment, for example knocking down trees, damaging buildings that are close by and discolouring the ground, thereby allowing the learner to explore the consequences of violent explosions, thus reinforcing the amount of energy being released.

2.5.2 Engagement, Presence and Interactivity

In order for a learning exchange to be successful it is important that learners are willing and able to engage in the process. Learners who lack the required skills or are either unmotivated or unwilling participants are less likely to benefit from the process than those who expend effort maximising their involvement.

One of the ways in which engagement can be established is by creating a sense of presence in a learner. Presence is central to virtual environments and is a critical component of virtual reality [116]. Within the virtual reality community, presence is a term which has many meanings. Irrespective of the specific approach adopted, by providing learners with understanding that enables them to decode the information presented in the interface, a sense of presence offers a sense of empowerment and as such can act as a motivator:

- **Sensory Presence:** Pure virtual reality often refers to sensory presence as a feeling of 'being there'– in essence conveying a feeling that the virtual environment, rather than the real world, is surrounding the user. In order to develop sensory presence, sensory immersion is often considered to be critically important [116]. Dependant on creating the illusion of a virtual space with a combination of sensory effects, most often based on graphics and audio, sensory immersion can be enhanced through the use of specialised haptic feedback devices [117] which allow users to engage with and receive feedback from the environment. As such, haptic feedback devices allow for richer interactions with the virtual environment.

- **Thematic Presence** provides an alternative approach to developing a feeling of presence. Unlike sensory presence, thematic presence does not create a feeling of 'being there', but instead informs a learner's senses through sound, vision etc. so that a user feels as though they are within a particular location within the virtual environment [116]. Thematic presence relates to the user's ego-centre, and positions them as the centre of all interactions within the virtual environment [118].

Measuring presence is a difficult undertaking owing to the subjective nature of many tests. Of the most commonly used methods, introspective questioning is generally considered to give the most robust measure [119-123]. From an educational perspective, it is often cited that sensory immersion is desirable owing to the increase in student engagement that it brings [32, 55, 59, 115, 124]. Indeed in many studies, the degree of sensory presence was positively correlated with learning and enjoyment [106, 112, 115, 125], however, other ways of fostering engagement exist, with interactivity being of importance. Given this, the need for full sensory immersion and sensory presence is somewhat diluted, with increased levels of engagement possible through non-immersive virtual environments which focus on creating thematic presence [5, 126-128].

In addition to introducing an element of presence, the use of 3D virtual environments can also support new paradigms for human computer interaction. If learning is to be an active process, it is essential that the learner can interact with the information being presented. In addition to enhancements to the presentation of learning materials (as discussed in section 2.5.1), virtual environments also provide opportunities for more natural methods of user interaction, through the use of alternative interface devices including: gloves, wireless controllers which are able to detect motion and direction, etc. Thus the difficulty and clumsiness often associated with the use of traditional input devices and modes of

communication can be reduced. [129] provides an example of such an approach, with astronauts learning to rendezvous with a spinning space capsule. Instead of having the capsule spinning around the astronaut, the learner's perceptive orientation is reversed, with the capsule grounded and the astronaut flying above it, thereby more accurately reflecting the real world scenario. In this way trying to rendezvous with the capsule in real life becomes easier for the astronaut to envision and therefore undertake owing to the more accurate representation depicted in the learning environment.

To summarise, whilst enhanced presence has the potential to enhance learning, it is important to recognise that it will not necessarily achieve any improvements in isolation. Design principles play an important role in determining whether virtual environments enhance learning, as such the role of the educator remains significant. However the success of any instructional technology depends on its ability to satisfy the particular needs of the learner, and so learner involvement is also an important part of the process.

2.5.3 Learner Differences, Learning Styles and Cooperative Working Arrangements

It is generally accepted that some differences can be measured in ways that usefully divide students into categories which are useful for informing the instructional design process [130], these categories include:

- **Prior Knowledge:** Measuring a student's prior knowledge is a relatively common occurrence, with attainment tests, rankings and groupings frequently undertaken in formal education [2].

- **Motivation:** A student's desire to learn about a particular topic or concept may already exist before they enrol on a course of academic study, or may be developed by instructors and educational resources in the course of academic study. However so developed, it is important that educators provide opportunities for motivated students to engage in learning activities which further a student's understanding and help develop their knowledge of a given subject.

- **Learning Ability:** Measuring a student's propensity to learn is a relatively common undertaking, with standardised achievement and IQ tests being used to predict performance in typical educational settings [130]. However, the validity of such tests is not universally acknowledged, with their bias towards verbal and mathematical ability being questioned [131].

- **Demographics:** Population defining features such as age, gender, race, educational attainment and profession are often cited as factors that influence learning [132-134], with some demographic features relating to levels of prior knowledge, motivation, communication preferences and other cultural and social influences which may shape the learning experience of a particular student.

Within an educational setting it is important that these types of learner differences are considered. However, a practical approach needs to be adopted: it is infeasible for an educational resource to fully adapt to the needs of all learners all of the time. Given this it is important that learners feel able to satisfy their own needs by utilising the resources available to them.

Learning style refers to the way a student acquires new knowledge: for example, some students may adopt a book based approach, researching theories about a specific phenomena before progressing to see it in action, whilst others may focus more heavily on the specific examples of the phenomena in action before working out ways in which the theories can be generalised and applied in a wider context. Within the educational community there is little work involved in the measurement of learning styles and the extent to which they are employed in the wider population [130]. However, several well known taxonomies have been proposed by Carver [135], Larkin-Hein [136], Danielson [137] and Chen [138] which go some way to identifying and categorising these style differences.

In order to account for differences in learning styles, it is important for a learning environment to support multiple modes of interaction, with learners able to engage with the interface most suited to their learning approach. This implies that it is therefore beneficial for a learning environment to provide multiple interfaces which appeal to different methods of learning: for example, textual, graphical etc.

2.5.4 Summary

This section has discussed the impact that the introduction of 3D technologies may have on the way in which technology is used to support the teaching and learning process. Affecting the way in which learning materials are presented and the way in which learners can interact with them, the introduction of 3D technologies makes provision for the introduction of support for the higher order learning behaviours of application, analysis and evaluation, all of which are poorly supported in existing technological frameworks.

In addition, 3D technologies make it possible to establish alternative means through which to motivate learners, with a sense of presence and collaboration located at the heart of 3D multi-user virtual environment technologies. By extending existing technological frameworks, existing methods of personalisation can be incorporated into 3D technologies, thereby allowing learning resources to be designed to more accurately meet the needs of different types of learners. Furthermore, given that 3D technologies provide the opportunity for alternative methods of presentation of learning materials, the possibility of providing multiple interfaces into the same learning materials becomes possible. In this way, learners can pick and choose the way in which they interact with learning materials based on their personal preferences or individual learning styles.

2.6 Chapter Summary

This chapter has presented a detailed discussion of the learning process and the theories of Bloom and others which are used to inform the approaches adopted by educators. The importance of encouraging higher order learning behaviours is noted, with a number areas in which technology can be used to assist in the learning process highlighted.

A class of disciplines is identified in which significant barriers exist which effectively prevent learners from engaging in application, analysis and evaluation behaviours. Furthermore, limitations in the support provided to these disciplines by existing educational software are identified. Without the ability to use technologies to mediate higher order learning behaviours, the extent to which effective teaching and learning can occur is naturally limited owing to the limited real world access available to learners.

To determine ways in which this issue can be addressed, a close examination of existing pedagogical approaches is undertaken. As part of this analysis, the chapter examines the relationship between the process of teaching and learning and relates it to the way in which people learn. As an outcome of this analysis, the ability to apply knowledge is identified as key component to enabling higher order learning behaviours.

A series of five desirable properties which we believe learning technologies should support have been identified, with the extent to which existing technologies provide support considered:

- **Learner Engagement.**
- **Personalisation.**
- **Groupwork and Collaborative Working Practices.**
- **Realism.**
- **Accessibility.**

As part of the technical analysis, the focus of existing educational technologies is identified, as are shortcomings in this approach which make it difficult for the technologies to be extended to provide support for higher order learning behaviours. In order to address these deficiencies and provide support for educators to position learners at the centre of a learning exchange in which they can apply their skills and knowledge, the use of 3D technologies is proposed.

The feasibility of the adoption of 3D technologies is considered, with specific reference being made to Moore's Law and the way in which computing resources improve exponentially over time. Through

this evaluation it is determined that it is presently feasible for general purpose computers to be used to power 3D technologies, with any short term accessibility issues being resolved over time as further enhancements in computing capabilities filter down to end users. In considering how existing educational technologies can be enhanced through the addition of 3D virtual environment technologies, an archaeological excavation is used as a case study which demonstrates enhancements to the learning process that 3D technologies are able to provide.

Chapter 3 – Design Process and Development Methodology

3.1 Introduction

There are generally two approaches to the deployment of technology in educational settings. One would be to make use of an existing set of generic tools or specifications that can be adapted to meet a variety of educational needs. An example of this approach would be the use of IMS-LD [139] to manage content within learning materials, or the use of SCORM [140] to organise sequencing of, and progression between multiple resources. Another approach would be to identify concrete challenges facing educators and explore the extent to which technology can be leveraged to meet specific challenges. Under this approach, a solution is developed to address a very specific challenge or problem. The applicability of the solution to alternative domains is then considered by examining the genericity of the underlying problem and the level of adaptability offered by the solution delivered.

It is the latter approach which has influenced the development of LAVA, with technology being adopted to enable educators to overcome real and specific problems faced in the domain of archaeology. As discussed in Chapter 1 and Chapter 4, by using technology to develop an accessible and scalable simulation environment, not only is it possible to mitigate the problems caused by the scarcity of student places on archaeological excavations, but also to expand learning opportunities by leveraging emerging technologies to develop scenarios which allow students to experience and manage aspects of an excavation that they would not normally be privy to. An example of such expansion is the use of simulation technologies to enable students to engage with excavation management functions in a virtual setting.

Through a focus on pedagogical objectives and existing methodologies, LAVA is sympathetic to existing educational practice, whilst providing educators with the opportunity to expand and enhance the student experience offered. In this vein the technology is driven by pedagogy, with LAVA bringing together a range of loosely coupled components in order to deliver an environment which allows students to engage in experiential learning scenarios based on sound archaeological data, practices and principles.

3.2 The User Environment

Using a mixture of 2D and 3D technologies, LAVA provides students with a varied set of interfaces which change based on the task being undertaken. As discussed in more detail in Chapter 4, the majority of the excavation planning, management and organisation tasks are undertaken using the 2D interface which provides students with cartographic, photographic, diagrammatic and textual data as shown in Figure 22 and Figure 23. To supplement the 2D interfaces, 3D perspectives are provided to allow students to engage with a virtual reconstruction of the acropolis and excavation site as shown in Figure 24. The decision to adopt multiple perspectives was made based on the educational objectives of the underlying archaeology course; with students being expected to develop an understanding of the

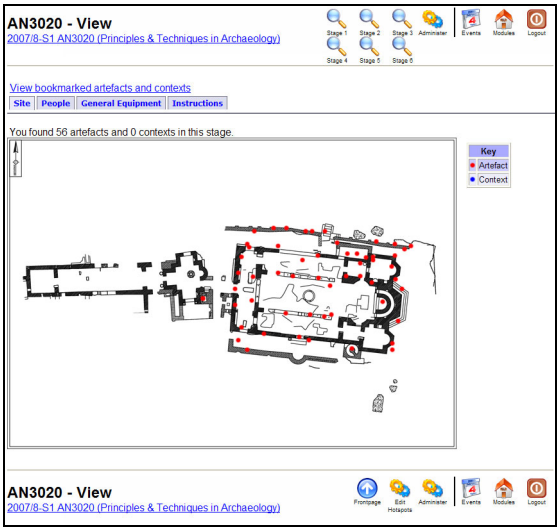

Figure 22 – 2D Map Interface Depicting the Excavation Site

Figure 23 – Photograph of Area of Excavation Site

Figure 24 – Second Life Reconstruction of the Sparta Acropolis

types of skills required to manage an excavation site, as well as those required to actively engage in the physical excavation process.

Throughout the development process, several technologies were considered as a basis for the LAVA simulations, including both local and Web-based applications, with the overall objective of allowing the technology choices to be determined by the pedagogical concerns of the underlying archaeology course remaining a high priority throughout the development process. For further details please see Appendix B.

3.3 The Development Process

The final implementation of LAVA was arrived at through an explorative approach, during which a number of prototypes of the 3D excavation site were built using Quake 2 [141], 3D Studio Max [142], the jPCT and Java 3D APIs [143, 144], Second Life and Open Simulator. Trials of the 2D interface were also undertaken, with the use of the Moodle [145], LAMS [146], WebCT Campus Edition and

MMS platforms all being considered. Following the initial investigative work, prototypes of the LAVA management interface were developed for the Moodle and MMS platforms, before MMS was chosen as the underlying platform for the 2D interface components of LAVA.

In addition to assessing the suitability of alternative technologies for the user facing components of LAVA, the prototyping process also raised a number of important implementation issues which needed to be addressed, including: the issue of scale within the 3D environment, the management of synchronisation between 2D and 3D components and the process of dealing with concurrency and multi-user access to the system by group members.

3.3.1 Scale Within the 3D Environment

During the prototyping phase, the issue of scale proved to be an interesting issue to resolve. Given the detailed excavation plans contained in the excavation reports of Sweetman and Katsara [16], it was possible to develop a reconstruction of the excavation site in which the relative scale of each measurement was accurate. As a basis for recreating a realistic life size version of the model, known measurements within the scale model were then compared with the estimated or known heights of in world avatars in order to determine a scaling factor, which was then used to enlarge the model in the virtual environment.

Determining the scaling factor in the Quake 2 reconstruction proved more difficult than expected due to the unknown height and physically disproportionate size of avatars within the game. Unlike Second Life and Open Simulator, Quake 2 did not allow for the physical characteristics of players to be easily changed, so it was important that the reconstruction was resized to account for the excessive height and width of avatars within Quake 2. To validate the overall size of the reconstructed environment, a number of small scale perception tests were undertaken. Involving the most complete reconstructions of the basilica in Quake 2 and Second Life, subjects were asked to navigate the environment and assess the perceived size of architectural features such as doors, windows etc. To gauge responses a number of over/under-sized elements were included within the environment. In addition, a number of visual cues were presented to users.

Within Second Life, the issue of scale was more easily addressed. Unlike Quake 2, the Second Life environment is built entirely by users. As such, the issue of scale has been dealt with many times over, with books [147, 148] and online resources [149] providing an introduction to the issue of scale within the virtual environment. In addition, as the physical attributes of avatars within Second Life can be changed quickly and easily, ensuring access to enclosed areas of the reconstruction was less of a concern, with avatars able to modify their physical presence if required in order to gain access to confined spaces.

3.3.2 Concurrency, Coordination and Synchronisation

During the prototyping phase, issues of concurrency, coordination and synchronisation between the 2D and 3D environments were experienced on a number of occasions. The cause of many of the issues

were routed in the technology choice in use, with each technology requiring different treatment to ensure that excavation data was presented in a consistent fashion.

3D Modelling and Rendering Tools

As the 3D modelling and rendering tools presented only a static representation of the excavation at a given point time, the issues relating to concurrency, coordination and synchronisation between the 2D and 3D components were greatly reduced. As changes could not be made to the statically rendered visualisations, updates to the excavation state did not need to be managed. All that was required was for the system to present visualisations at appropriate times during their excavation work: for example, after completing their work clearing the overgrowth from the site, a 3D rendering of the cleared site would be shown. To enable this functionality, several static models of the excavation were built, showing generic sections of the site after progressive stages of excavation work. These were then presented upon the completion of each stage of the excavation work as described in section 4.7.2.

First Person Perspective Games

Within the first person perspective environment, concurrency, coordination and synchronisation needed to be carefully considered. Unlike a static representation of the excavation site, first person perspective games allowed users to explore and interact with the excavation site. As such it was important that accurate excavation state was displayed. In addition, as support was in place for multiple users to interact with the excavation simultaneously, it was important that groups were presented with the same reconstruction of their excavation work so that they could review and interact with it as a team.

Many of the multi-user features of first person perspective games proved beneficial during the prototyping process: separate games were managed to allow each team to explore instantiations of their own excavation work which were isolated from other teams, the underlying game server was used to maintain the virtual state of the excavation on an ongoing basis and built in communication mechanisms were used to allow group members to communicate and coordinate their activities within the virtual environment. As discussed in section 4.8, in order to support this functionality, an excavation logic component was developed in order to coordinate state between the 2D and 3D environments. One of the drawbacks of this separation approach was the fact that cross-group communication was impossible to achieve. Given this, the ability for groups to review each other's work outwith formal collaboration periods was severely restricted when using the first person perspective game model.

Multi-User Virtual Environments

Whilst much of the infrastructure required by first person perspective games was applicable to the multi-user virtual environment implementation, with the underlying multi-user virtual environment supporting the creation and management of visualisations, group communication and maintenance of excavation state, there was the added challenge of enabling multiple groups to simultaneously access their excavation. Unlike first person perspective games which can have multiple games maintaining

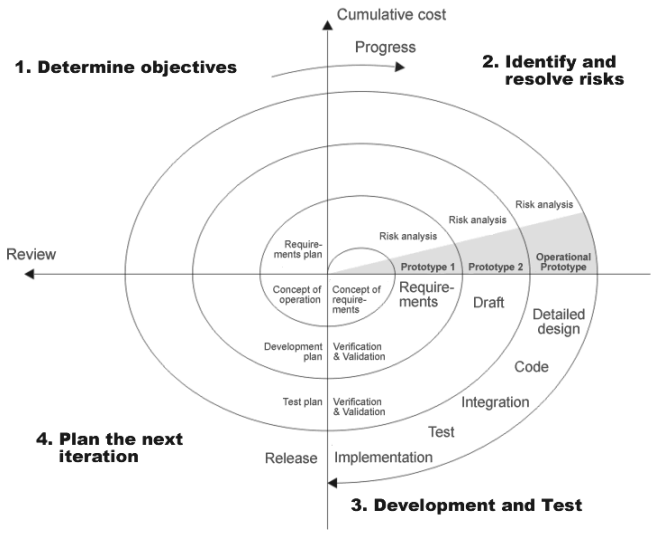

Figure 25 – Boehm's Spiral Model of Software Development

independent environments simultaneously, multi-user virtual environments traditionally maintain a single, shared state. As such groups must either be physically or temporally separated. Within Second Life both physical and temporal separations were trialled, with physical separation quickly becoming the better choice as the numbers of groups increased. Within Open Simulator, a trial was undertaken in which multiple environments were generated to emulate the type of separation provided by first person perspective games. Whilst this separation resolved the resource contention issues associated with multiple groups accessing their excavation simultaneously, it was not entirely in keeping with the overall objective of the multi-user virtual environment model and also reintroduced the restriction which prevented cross-group communication and reviewing outwith planned collaboration periods.

3.3.3 Managing the Software Lifecycle

The development of the 2D management interface was managed using the spiral model as shown in Figure 25. As initially envisioned by Barry Boehm [150], when dealing with the 2D development work, each of the iterative cycles in the development process were timed to last around 6 months, thereby allowing two prototypes of the LAVA MMS components to be deployed for evaluation purposes each academic year. Not only did this provide opportunities for multiple evaluation sessions, but it also made it possible to assess the impact of these changes by having the same evaluation group interact with the system at the beginning and end of each academic year.

When considering the 3D development, the same spiral model was used to manage the software lifecycle. However, the timescale of each of the iterative cycles was significantly reduced, with revisions to the archaeological environment being made every 3-6 weeks. In addition, at specified points in the development cycle, domain experts were invited to tour the basilica and surrounding environment in order to provide feedback on the authenticity and accuracy of the reconstruction. These expert evaluation sessions not only provided detailed development notes, but also made it possible for domain experts to assess the feasibility of alternative construction methods: for example, the use of

pitched versus domed roofing on the towers of the basilica building. In this way, the development cycle helped to inform the current archaeological understanding surrounding the construction methods employed in Byzantine architecture.

3.4 Chapter Summary

This chapter has presented an overview of the design process and development methodology adopted by this work. The approach discussed in this chapter demonstrates sound software engineering practices and highlights the way in which evaluation and prototyping of technologies has affected the development of the system. Furthermore by considering human computer interaction issues, this chapter has highlighted and described the methodology adopted to address a number of implementation issues which were discovered during the early phases of development.

By examining two alternative approaches to the development of educational software, this chapter emphasises the benefits associated with adopting a pedagogically driven approach to the development of educational software. By focusing on specific and real educational needs, the resulting software is naturally fairly specific in its application. However, by examining the genericity of the underlying problem being addressed, it is possible to identify a wider range of scenarios and alternative educational domains in which the software can be deployed.

After considering the technological basis for the 2D components of LAVA, the chapter continues by considering five types of 3D technologies: 3D modelling and rendering tools, 3D engines and libraries, first person perspective games, massively multiplayer online games and multi-user virtual environments. By considering the types of 3D environment provided by each type of technology, the chapter in turn considers the way in which each technology could be used within LAVA.

As discussed in section 3.3, by documenting the prototyping process undertaken during the early stages of development this chapter highlights the way in which educational objectives drove the choice of technology adopted, thereby maintaining a strong focus on pedagogical goals. Throughout section 3.3 a number of interesting implementation issues are discussed, with particular attention being paid to those issues relating to Human Computer Interaction (HCI), in order to show how the development process focused on user experiences and perceptions.

Finally the chapter concludes by considering the ways in which the software lifecycle has been managed to fit in with pre-existing evaluation and deployment commitments. In particular, the spiral model of software development was chosen in order to allow multiple updates to LAVA throughout the academic year, thereby allowing the development and evaluation processes to feedback user perceptions in an effort to improve the overall quality of the software delivered by this work.

Chapter 4 – Case Study

4.1 Introduction

In this chapter an implementation of a system designed to support exploratory fieldwork is presented. Based on an archaeological excavation project undertaken in the Sparta region of Greece, LAVA was developed to enhance the teaching and learning process associated with archaeological excavation work. The implementation of the case study was informed by the discussion of educational theory in Chapter 2, using the methodology discussed in Chapter 3.

This chapter begins by defining the problem space and introducing the reader to some of the challenges often associated with teaching archaeology in a higher education setting. During the discussion, which is based on a reading of related literature and dialogue with domain experts responsible for developing archaeological teaching materials, a number of key requirements for the case study to address are identified. After concluding the discussion, the key requirements previously identified are consolidated and presented as a series of aims and objectives which need to be met by the LAVA simulation software. The archaeological excavation site which forms the basis of the case study is then introduced to the reader. By outlining the archaeological work previously undertaken on the site and identifying existing questions which remain unanswered, this section of the chapter highlights the academic significance of the case study.

Once the challenges, motivation and archaeological background which shape this work have been discussed, a detailed description of the implementation work which has been undertaken is provided. Considering the architecture of the software system, this section of the chapter identifies the structure of, and functionality provided by, the excavation simulator, as well as describing how it is integrated with pre-existing institutional infrastructure. A decomposition of the system into its constituent parts allows each component in the system to be examined, with its design outlined, its role identified and the functionality that it offers described. A series of use-case scenarios are used to identify the different interfaces that are provided for students and tutors to use. The HCI issues that these interfaces raise are examined and their applications reviewed. By identifying the resource requirements and impact that these processes have on the host operating system and local area network, a usage profile which outlines the minimum system requirements needed to support the deployment of the excavation simulator in a multi-user classroom environment is presented.

After presenting the excavation simulator, the chapter continues by identifying a number of key design decisions that were made during the implementation process. By considering the importance of each design decision, and justifying the outcome that was chosen, this section of the chapter provides a rationale for the design approach adopted, as well as the choice of technologies used for each of the components within the system. Finally the chapter concludes by presenting a summary of the key points raised and the main themes discussed.

4.2 The LAVA Case Study

The LAVA case study aims to provide students with a realistic substitute for real-world excavation experience. As such LAVA essentially allows students to collaborate in planning, undertaking and exploring the findings of a series of archaeological fieldwork activities. The overall objective is to enable students to construct an improved understanding of the subject area by engaging in higher order learning behaviours as described in Chapter 2. LAVA achieves this objective by focussing on five main tenets: learner engagement, personalisation, groupwork and collaborative working, realism and accessibility.

4.2.1 Learner Engagement

It is important for the system to be engaging so that it helps motivate students to explore the subject matter, developing their technical skills and deepening their understanding of practical archaeological processes. In achieving this, methodologies employed in the development of computer games are borrowed. Angband [151, 152] was found to be a useful model. It is a text based game that allows characters to develop their skills, acquire artefacts, explore the environment, and progress through various challenges before achieving the core goal of defeating Morgorth and saving Middle Earth. Within Angband, characters have varying skill levels. Players have to explore and interact with the environment. Progress through a succession of levels is dependent on the player's actions. When considering LAVA, the goal of defeating Morgorth is replaced with uncovering and analysing material culture and ancient architectural features of the excavation site. Technically this approach does not fit well with Web-based architectures as the progress made and state of the environment both need to be maintained on an ongoing basis. Hence a Web 2.0 based service architecture is adopted which allows state to be maintained over multiple sessions, with different presentation interfaces being used to provide learners with 2D and 3D access to the underlying excavation state.

4.2.2 Personalisation

Personalisation is important as it emphasises the role of the learner as the central point of the learning process. Within the education sector the benefits of personalisation have been widely understood, as discussed in section 2.4.2, with the benefits of Portal type technologies frequently employed by educational institutions in their efforts to develop systems to manage the overall learning process [97].

By extending the reach of existing personalisation techniques into the realm of 3D environments, LAVA makes it possible to introduce personalisation into MUVEs. Within LAVA this approach has been used to enable the synchronisation of the 2D and 3D excavation sites presented to learners, with the progress and number of finds uncovered in the 2D environment being mirrored in the 3D recreations of the excavation site.

4.2.3 Groupwork and Collaborative Working

The motivation behind enabling support for collaborative learning is two fold. On the one hand, real archaeological excavations involve a high level of collaboration. On the other hand, groupwork is an

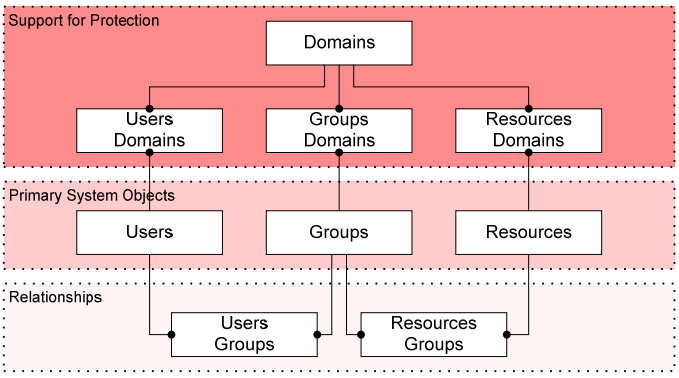

Figure 26 – The MMS Users, Groups and Resources Model

important transferable skill which is often underdeveloped within traditional educational contexts. In LAVA, learners are organised into groups that have to agree upon key decisions that are made. Each group has a different perception of the environment with each member of a group sharing a common view. Therefore, if a user performs an action which changes the state of the environment, the change is filtered through to all other members of the same group.

The implication of this requirement is that support for groupwork should be at the heart of a service based architecture. This is met by an architecture built around the abstractions of users, groups and resources (as shown in the database organisation depicted in Figure 26). Users are allocated to a group. Each resource that is allocated to that group is automatically made accessible to all the users within the group. Groupwork is supported through the provision of synchronous and asynchronous communication tools. It is noteworthy that the use of 3D environments based on first person shooter game and MUVE technologies naturally lend themselves to co-operative endeavours.

4.2.4 Realism

It is important that learning activities, as far as possible, are situated within realistic scenarios as this helps motivate those engaged in the learning process and helps ensure that both the practical and more abstract learning outcomes are realised. There are several approaches employed to develop realism.

Firstly LAVA is based upon a real archaeological site [8, 153] with a well researched background that has been extensively excavated by several academics [16, 154]. A wide range of archaeological resources from this site have been digitised and are made available to the learner. These resources are organised geographically through maps so that learners can select geographic locations in which to find relevant artefacts. In addition the digital resources are organised temporally so that learners engage in sequenced activities, the successful conclusion of which yields archaeological finds that are appropriate to the activity being undertaken. These sequences are discussed in more detail in section 4.7.2.

The second way in which realism is achieved is by employing a range of different technologies at different stages of the simulation: text is used to provide contextual information, 2D maps are used to define location, photographs are used to provide high fidelity images, and 3D environments based on

game and MUVE technologies are used to provide a sense of spatial awareness and to facilitate exploration.

To achieve this, the technical challenges of adapting 3D technologies to facilitate appropriate interactions had to be met, with the results integrated into a service-based learning environment. The architecture used to achieve this integration is discussed further in section 4.9.2.

4.2.5 Accessibility

Accessibility is important so that LAVA is able to be accessed within lecture theatres, IT labs and classrooms and from a student's home computer. This allows learners to exercise control over their engagement in the learning process so that they can proceed at a pace which is appropriate for them. Using a service-based architecture helps to meet this aim, as does the use of gaming and 3D technologies that may be deployed across the Internet without the need for specialised computer hardware or networks or extensive prior configuration of client machines.

4.3 Challenges Associated with Teaching Archaeology

As can be seen with the resurgent popularity of books [11], films [155-158] and television programmes [159] dedicated to archaeological discovery, people are genuinely intrigued by the past, how our ancestors lived and the process of detective work that goes in to uncovering the hidden secrets locked away in archaeological sites. Behind the mass-market appeal that archaeology possesses lays an enormous array of academic and commercial interests. The efforts that are required to organise, undertake and analyse the results of an archaeological excavation are significant, with a huge industry being solely focussed on the development of archaeological techniques and processes.

As a subject of academic and scientific endeavour, archaeology draws upon a wide variety of disciplines, with elements of anthropology, history, physics, chemistry, geography, geology and statistics being directly involved in the excavation process and analysis of archaeological site data. In order to excel, an archaeologist needs to be familiar with the practical aspects of excavation work as well as the analytical and organisational approaches needed to draw conclusions and assess and validate findings. This broad scope of coverage is a significant challenge to those tasked with designing courses to teach students archaeology, with educators often adopting a predominantly theory-based approach to teaching which focuses on developing transferrable skills and imparting an understanding of the scientific rationale and processes entrenched within archaeology. Whilst this focus is able to provide a broad academic background to students, it does not provide many opportunities to develop specific and specialised practical skills. Thus, newly graduating students often have a skill set which fails to meet the expectations and needs of industry practitioners [160]. In this way, a purely theory-based approach can be seen to exasperate the culture clash between industry and academia [161, 162]. In 2004 this issue was recognised by the Higher Education Academy subject centre for History, Classics and Archaeology [163], with the plenary session of the TAG 2004 conference being used to encourage academics to more actively and explicitly engage in discussing the

ways in which innovation in teaching can help better prepare archaeology students for industrial practice [164].

Archaeology is appealing on both sociological and historical levels; the core process of exploration that leads to the uncovering of the past can be highly engaging as shown by the level of interest in archaeology in the public perception. Given this, it would seem that archaeology is a subject that is well suited to the application of exploratory learning techniques. Indeed, much of archaeology concerns itself with the exploration of the origins and development of human cultures as can be seen by the way in which the attribution of the basilica used in the LAVA case study is directly related to the ability to identify cultural artefacts and effects within the basilica grounds [16, 165, 166]. However, this assumed suitability does not automatically translate into well-formed educational activities. When developing exploratory learning materials for the teaching of archaeology, faculty are often faced with a number of barriers that make it difficult for learning scenarios to be developed which encompass both the theoretical and practical elements associated with archaeological excavation work.

Conceptualising archaeological processes and developing realistic learning scenarios that encompass all aspects of a site's excavation is difficult to do owing to the wide variety of disciplines that archaeology draws on. This makes it difficult for entire excavation scenarios to be enacted within a classroom environment and so canned scenarios are often developed instead, with each scenario being based on different aspects of excavation work. This approach provides students with an understanding of the required concepts, but not necessarily the relationships between them. In addition to these learning-based challenges, there are a number of physical obstacles which make the teaching of archaeology difficult:

- The locations of excavation sites and students are not generally well matched. Whilst the UK has in excess of 115,000 sites of archaeological interest [167] many of them are located in remote areas of the country and not subject to, or suitable for, active exploration work. In addition, the UK's sites of archaeological interest are naturally most relevant to those interested in UK history and past cultures, thus students wishing to focus on alternative cultures and civilisations are likely to be forced to travel outwith the UK in order to find sites of direct relevance to their field of study.

- Students wishing to work on an archaeological excavation are likely to find the costs associated with such participation to be high in both financial and temporal terms. In many cases students will be required to pay for their food, lodgings and equipment when participating in an excavation project. This will need to be accounted for by the student and can quickly become prohibitively expensive unless supplementary funding from external bodies and research agencies can be found.

- Finally the destructive nature of the archaeological excavation process adds to the difficulty of enabling students to engage in excavation work. Assuming that a site can be found, and financial support obtained, the number of students that an excavation site can support is naturally limited by its size. Unlike other learning processes which can be repeated over several iterations, excavation work on a single site can only be carried out once as it destroys the underlying structure of the site. This makes it impossible for multiple students to carry out the same activity several times and as such it is difficult to scale student participation in excavation projects to accommodate large class sizes.

  In addition, the destructive nature of the excavation process also has an impact on the types of role that students are likely to be granted on an excavation site. As mistakes are likely to be irrecoverable, students are generally only permitted to participate at a low level in the project team hierarchy. This effectively limits their input in the excavation process; they are generally unable to engage with the planning and organisational practices associated with archaeological excavation work and as such are usually only afforded limited exposure to experience the ways in which an excavation project is planned, executed and analysed.

From an educational perspective it is desirable for the excavation process to be opened to a wider audience, with students empowered to assume a variety of roles so that they can experiment with and reflect on the advantages and disadvantages of a number of different working practices. Thus enabling them to readily understand the results that different archaeological processes achieve and the impact they have on the environment of the excavation site. To this end an excavation simulator has been developed that provides opportunities for students to engage with an excavation scenario based on real world excavation data. This exposure allows students to more readily gain an understanding of the ways in which excavation work is planned and undertaken, whilst also allowing them to assume a managerial role in the excavation process – a level of access not normally granted to students participating in real world excavation projects.

4.4 Case Study Aims and Objectives

The development of the Sparta Basilica case study aims to provide materials to help meet the challenges associated with the teaching of archaeology, whilst also furthering research in the field of Byzantine architecture. These two high level aims have given rise to a series of objectives that can be attributed to either the teaching and learning, or research elements of this work.

4.4.1 Teaching and Learning Objectives

Pedagogical concerns suggest that students often learn well in an environment where they are able to explore a subject area in a way that allows them to make discoveries and integrate their findings with their own past experiences [2, 50, 168, 169]. From a teaching and learning perspective, this work is informed by a constructivist [169, 170] approach to learning [171]. It provides a comprehensive series of learning materials which focus on the needs of individual learners. By providing learners with the

resources and tools required to enable them to engage with other learners in meaningful cooperative working activities, LAVA allows learners to organise and manage their progression through the case study scenarios presented. Specifically LAVA focuses on the following key areas:

- **Learner Engagement:** It is important for learners to find the system engaging as this helps motivate their exploration of the subjects presented [172], developing their technical skills and deepening their understanding of practical archaeological processes as they progress.

  In developing engagement strategies LAVA draws from methodologies employed in the development of computer games. The dungeon style of game, examples of which include Angband [151], Moria [173] and ToME [174], was found to be a useful model to mimic in terms of building long-term engagement. With users able to develop their character's skills, acquire artefacts, explore environments and progress through a wide variety of challenges designed to stretch a player's abilities, the dungeon style of game has many similarities with the educational process; piece by piece knowledge is developed, with the eventual goal of using that knowledge to achieve a core objective which, in the case of Angband means defeating Morgorth and saving Middle Earth! The manifestations of this approach in LAVA are clear: characters have varying skill levels and learners have to explore and interact with the environment, with progression through a succession of levels dependent on their actions. In LAVA the goal of defeating Morgorth is replaced with the more relevant task of uncovering and analysing material culture and significant architectural features in a bid to determine the most likely attribution of the basilica based on the data collected by each group.

  To help develop an initial level of engagement with the learner, this long-term strategy is complimented with the use of detailed and highly realistic 3D environments which are based on real world archaeological excavation data. By creating a visually appealing and highly tactile environment for learners to explore, LAVA again draws from the games industry, with the immediate and highly visual appeal of first person shooter games, examples of which include the highly successful Quake [4], Half Life [175] and Grand Theft Auto [176] series, being used to capture the learner's attention.

  When considering the deployment of these types of technologies, a Web-based system fits in well with the dungeon style gaming environment. The first person perspective environment is, however, more problematic given the limitations of Web-based delivery. As such LAVA makes use of alternative technologies which are more readily able to support cooperative interactions in 3D environments, with MUVEs [13] and first person shooter game [177] clients being used to deliver 3D content.

- **Groupwork and Collaborative Working Practices:** The motivation driving the need for the system to support collaborative learning is twofold. Firstly, real world archaeological excavations generally feature high levels of collaboration, with teams comprising a number of different specialists or experts, each responsible for different aspects of the excavation. In an environment such as an excavation site, in which mistakes are often unrecoverable due to the destructive nature of the excavation process, the ability for team members to effectively communicate is of vital importance. A direct correlation exists between the need for effective collaboration and the success of an excavation; poor communication can significantly reduce the effectiveness of the excavation team, leading to mistakes and oversights that have the potential to adversely affect the quality of material culture found in the excavated site. Whilst the inability to reverse mistakes could be overcome in a virtual environment, there is educational value attached to developing scenarios that closely resemble their real world counterparts in emphasising the importance of collaboration within the virtual learning scenario. Not only does it improve the realism of a given scenario, but it also helps students to develop the types of communication skills that they require in order to effectively collaborate with others in a variety of different excavation scenarios.

  Secondly, the ability to collaborate as part of a group is an important one in terms of development of transferable skills and engagement in reflective learning activities [178]. Whilst it encourages students to review their performance with respect to each other, it is something that is often underdeveloped in traditional educational contexts where students are encouraged to work outwith a group structure. In LAVA learners are specifically organised into groups that are required to agree upon key decisions that are made. Each team has an independent instantiation of the excavation scenario that is visible to, and can be updated by all members. Thus, the outcome of a group's efforts is correlated to their ability to collaborate effectively and coordinate their activities within their team.

  Given the key role that collaboration plays in both the real world excavation process and the development of reflective learning, it is considered to be an essential part of the learning process in LAVA. Thus it is supported throughout the excavation simulator. To facilitate support for group-working practices, the system is built around an architecture that supports the abstractions of users, groups and resources: as previously shown in Figure 26, with groupwork supported through the provision of synchronous and asynchronous communication tools. It is noteworthy that the use of 3D environments based on game and MUVE technologies naturally lends itself to the type of co-operative endeavours LAVA aims to encourage in the learning scenarios presented to students.

- **Realism:** As the aim of the system is to provide an educationally beneficial experience, it is important that the learning interactions presented are, as far as possible, situated within realistic scenarios. Not only does this ensure educational value, but can also be motivating

from the learner's perspective. To maintain and develop realism within the case study scenarios, a range of different technologies are deployed: text is used to provide contextual information, 2D maps are used to define location, photographs are used to provide high fidelity images, and 3D virtual environments are used to provide a sense of spatial awareness and exploration. In addition, LAVA adopts two complimentary approaches which help to develop realistic learning scenarios:

1. All learning scenarios within the system are based on a real excavation project of a site of archaeological interest [15, 16]. Not only does this allow LAVA to mimic the archaeological processes undertaken on the real world excavation project, but it also makes it possible to present a wide range of digitalised material culture that was obtained during the excavation work. By organising the material culture geographically it is possible to further add to the realism of the learning scenarios, with learners finding artefacts in contextually accurate locations within each virtual excavation scenario.

2. LAVA learning scenarios are developed so that learners engage in a sequenced set of activities which closely resemble the working arrangement on the real world excavation, with the successful conclusion of each activity yielding a varying amount of material culture depending on the appropriateness of the way in which the learners organised and managed the activities. These sequences are discussed in more detail in section 4.7.2.

- **Accessibility:** For a system to be used it needs to be fit for purpose. In the context of LAVA this means both educationally sound and also easy for the end user to interact with. Clearly this implies some form of logical HCI [179] processes that are both clearly defined and easy for students to become familiar with.

  In addition, there is also an element of appropriate accessibility that needs to be addressed. The learning scenarios are designed to enable students to work both synchronously within the lab environment, and also asynchronously outside of the classroom. It is therefore important that the system is accessible to students whenever they wish to access it, from wherever they are. This anytime-anywhere access requirement allows learners to exercise control over the learning process, deciding when and where they want to engage with the system so that they can proceed through the scenarios at a pace which is both appropriate for them and the rest of their group. Using Web accessible interfaces and a variety of 3D environments that may be deployed and accessed across the Internet helps to achieve this aim, without the need for specialised network configurations.

4.4.2 Research Objectives

To provide the resources required for the learning scenarios, this work has focused on the development of a series of 3D models based on the Sparta basilica. Using an iterative process, the models were initially built from 2D architectural plans developed during archaeological excavations of the site. Historical documents were then used to further refine the models, with knowledge of similar Byzantine buildings being used to complete sections of the building for which no architectural or historical records remain. Throughout the process, expert opinion was solicited through face-to-face interviews, email correspondence and review sessions. More details of the development processes adopted are provided in Chapter 3.

To maximise reuse potential, a variety of tools were used, including 3D modelling environments such as Autodesk 3D Studio Max and the Quake 2 first person shooter game environment, as well as the Second Life and Open Simulator MUVEs. In addition to allowing wider access to the models, the choice to use a variety of authoring environments was made in order to allow the relative merits and demerits of each authoring environment to be more readily understood with respect to the following areas:

- **Spatial Awareness** is an important issue when dealing with tactile environments such as an archaeological excavation site. Being able to determine the location of, and therefore context associated with, material culture is of vital importance in an excavation project as it provides additional insight to those reviewing and cataloguing finds. Spatial awareness is often cited as being well accommodated in 3D environments offering a first person perspective, with both first person shooter games and MUVEs providing highly detailed visualisations. What is not clear, however, is whether other 3D models provide similarly intuitive interfaces for users. Also of interest is how the ability to review other team members' actions within the environment in real time affects ones own awareness of the environment.

- **Architectural Design:** During the development of the models in the MUVEs and first person shooter games it was possible to provide experts with unrestricted access to the buildings. This allowed all areas to be analysed and reviewed in real time from a first person perspective. As changes were made, their impact could be quickly assessed, and further modifications made. Of interest to this work is the impact that this had on the overriding architectural design of the models and the ability to reconstruct sections of the building for which little or no architectural clues exist.

  Whilst 2D plans were able to show certain levels of detail, they provided information on only a limited number of aspects of a building. This makes it difficult to build a picture of the entire structure. Throughout the iterative development of the 3D models, the impact of being able to visualise all aspects of a change in the structure of a building was interesting with respect to how domain experts responded, with changes being revised and subjected to further

Figure 27 – Byzantine Basilica with Domed Roofing

Figure 28 – Byzantine Basilica with Pitched Roofing

modifications once they were visualised. In this way, changes were assessed against known architectural features of the building.

4.5 The Excavation of the Sparta Basilica

The excavation of the Sparta acropolis basilica was chosen as a case study for several reasons. Not only is it an interesting site from an archaeological perspective, with the attribution and architecture of the basilica subject to much academic discussion, but it is also a site which has been the subject of a number of significant, well documented excavation projects funded by several research bodies [16, 154, 180, 181]. As such the site offers plentiful quantities of excavation data, much of which is readily adaptable for educational use.

4.5.1 Historical Significance of the Excavation Site

During its lifetime the basilica was an important religious and social icon. Even in its decline the church, which some argue to date back as early as the 5th or 6th Centuries [16, 181], maintains an air of excitement. Due to a strongly contested history that often associates the basilica with the monastery erected by Osios Nikon during the 10th Century [181], the site is subject to intense archaeological interest. In addition to this, the basilica's unique architectural peculiarities have gained the attention of a number of academics [7, 16, 165, 182, 183]. Of particular interest to archaeologists is the style and structure of the church's roof, which some academics claim to have been domed in a similar style to the church shown in Figure 27, whilst others argue in favour of more simplistic pitched design with, or without the inclusion of design elements such as barrel vaults, etc. as shown on the buildings at the top left and bottom right of Figure 28 [16]. Historical documentation of the basilica remains inconclusive, with evidence existing which could support either architectural arrangement. This has lead to sustained interest in the excavation of the site, with the British School at Athens (BSA) [184] providing funding to support several attempts to discover the true architectural structure and attribution of the basilica.

4.5.2 Excavation Timeline

Given its contested attribution and architectural peculiarities, the basilica has been the subject of a significant number of excavations throughout the 20th Century, with each fuelling the academic debate surrounding the site yet further. As one of the major supporters of excavations at the site, the BSA has

had an extended period of involvement with the basilica, with Robert Carr Bosanquet (1906) [180], Richard Dawkins (1907-10) [154, 185-187], William Cuttle (1925-6) and Rebecca Sweetman and Evi Katsara (2000-2) [16] all leading excavations funded by the school. In addition, a number of other organisations have also been involved with the site, investigating different areas of the acropolis in a bid to further understanding of the history of the region and the Byzantine Empire.

Despite this interest in the acropolis, Cuttle's was the first team to focus entirely on the excavation of the basilica itself [165]. Although stored in their entirety in the archives of the British School at Athens, Cuttle's excavation logs and notebooks were never published directly. Indeed, it was not until Sweetman and Katsara published their findings of the 2000-2 excavation of the site that Cuttle's excavation notes were released for publication, albeit in summarised form as part of Sweetman and Katsara's excavation report [16]. Prior to Cuttle's excavation, it is believed that Adamantios Adamantiou ran a small number of trenches through the basilica site under the auspices of the Archaeological Society [165]. However, as Adamantiou's initial excavation notes were never publicly reported, the extent of his early work on the site remains unclear. Following his return to the site in 1934, a full excavation project was undertaken and a brief report of the findings published; it was in this publication that Adamantiou first made the association between the basilica church and the Monastery of Osios Nikon [188], a view which was echoed by Georgios Soteriou's analysis based on his 1939 excavation of the site [188].

Since the publication of Adamantiou's excavation reports, there has been great speculation that the association with Nikon is in fact incorrect [189]. This has lead to a great deal of effort examining the sparse findings of Adamantiou and re-excavating the site in search of more compelling evidence to either confirm or discredit the association with Nikon's Monastery. However, as the most recent excavation of the site confirms, dating the basilica on a study of architecture alone is not an easy task owing to the variation and echoing of architectural styles present in the building [16]. Sweetman and Katsara suggest that whilst there is evidence that a church stood on the site as early as the 6th Century, with walls strong enough to support a domed roof, additional buildings including the Baptistery in the West Complex were added at a later date [16]. Until the chronology and history of the basilica can be established, the attribution to Osios Nikon will remain a strongly contested issue, and as such this ensures that the basilica church will remain an important, and widely discussed archaeological site.

4.5.3 Analysis of Excavation Findings

As the work carried out in the early excavations of the basilica was generally not accurately recorded, it is difficult to identify exactly what practices have been used to excavate the basilica. Sweetman and Katsara's reports of the 2000-2 campaign [15, 16] are by far the most comprehensive review of the site, including an analysis of their findings, as well as those of Adamantiou, Soteriou and Cuttle.

During Sweetman and Katsara's 2000-2 excavations of the site, a comprehensive review of the area surrounding the basilica was undertaken with the immediate area cleaned and topsoil removed. During

the clearing process, debris from fallen masonry was revealed, as was evidence identifying contexts dug during previous excavations of the site. In addition, the surviving walls and architectural features of the basilica were exposed, recorded in various drawings and diagrams and published in the excavation report. Throughout the site, detailed photography was undertaken, with every wall and loose architectural fragment being included in varying levels of detail.

Copies of Adamantiou, Soteriou and Cuttle's excavation notebooks were used by Sweetman and Katsara's team during their time on the site, with Cuttle's data primarily relating to the main building, whilst Adamantiou and Soteriou's efforts focussed on the outlying buildings to the west of the main basilica. The outputs of Sweetman and Katsara's excavation were significant, providing an accurate floor plan of the main basilica and outlying buildings as well as detailed drawings and photographs of the remaining walls and loose architectural fragments. The previous works of Adamantiou, Soteriou and Cuttle were also re-examined and their conclusions evaluated against the evidence obtained during the re-excavation of the site. In the discussion that followed the completion of Sweetman and Katsara's excavation of the basilica, the following issues were flagged as being significant.

Phasing and Building Relationships

The northern area of the excavation site shows some interesting phasing, with evidence that some of the walls were later additions to the main structure of the church. As confirmed by Sweetman and Katsara, the north annex (Location 1 in Figure 29) is clearly an addition to the original basilica structure, with the tower region (Location 2 in Figure 29) to the south also likely to have been added later. In addition, evidence found on the site suggests that the wall to the south of the basilica (Location 3 in Figure 29) was constructed in two phases, with the phases linked to the construction of the tower (Location 2 in Figure 29).

Whilst Cuttle mentions the possibility of an earlier church on the site of the basilica, Sweetman and Katsara found no architectural evidence to confirm this claim. They do, however, find evidence that the south tower may have been built on an earlier feature, though they make it clear that there is no evidence to suggest that this feature was connected to the church.

The West Complex (Location 4 in Figure 29) was at some point connected to the basilica. However, owing to differences in masonry, contemporary construction of the church and West Complex seems unlikely, with the complex added to the basilica site at a later date. Built in three distinct phases, it housed a number of rooms dealing with a variety of church functions as well as providing room for a hostelry or a bishop's quarters, or possibly both.

Use of Space

As early Christian liturgy is not well defined [182], it is difficult to assign functions to all areas of the basilica. Additionally given that there is evidence suggesting that the basilica buildings have evolved, it becomes more difficult to determine the purpose of some areas, as their usage may have changed

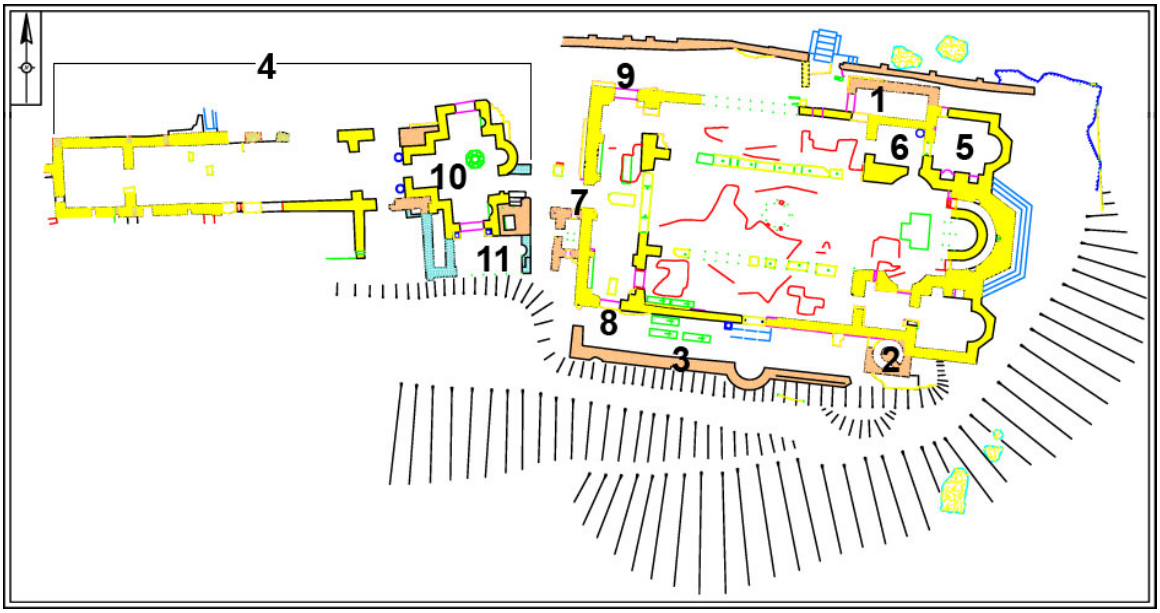

Figure 29 – A Plan of the Excavated Sparta Basilica

over time. However, based on material culture and architectural details uncovered during Sweetman and Katsara's excavation of the site, they have been able to identify the purpose of some key areas of the basilica.

- In the north apse (Location 5 in Figure 29) there is evidence that the room was used by the clergy for ritual cleansing and the preparation of the communion elements with a well head found within the room, as well as pebbles to aid drainage.

- The north room (Location 6 in Figure 29), with its arrangement bearing resemblance to Early Christian pastophoria appears to have been used as a location for the congregation to give their offerings for the church. In addition to the layout of the room, there is evidence of a grey marble column fragment which could have served as a base for an offering table.

- The north annex (Location 1 in Figure 29) is an addition to the original architecture of the basilica, and may have been completely separate from the main structure. The existence of the doorway into the north aisle of the basilica is in doubt and as such the north annex could have been used for the deposition of offerings, thus assuming the role previously assigned to the north room

- There is clear evidence for three entrances into the basilica: one to the west, one to the south and one to the north (Locations 7, 8 and 9 in Figure 29). This layout is slightly different to that normally associated with Early Christian basilicas, with entrances located in the west or southern sides of the building only. Whilst it is not possible to determine why this unusual arrangement was put in place, Sweetman and Katsara suggest in their excavation report that it

may be due to the topography of the area and/or the location of transport routes around the acropolis.

- The first phase of the West Complex (Location 10 in Figure 29) was likely used as a baptistery. This conclusion is supported by the fact that a possible font was found in the cruciform room (Location 10 in Figure 29), as well as the arrangement of the doors and the apse which follow a traditional style found in many Greek baptisteries.

- The south annex in the second phase of the West Complex (Location 11 in Figure 29) was used as a martyrium, with evidence of a tomb in the region supporting this assumption.

Contexts

Cuttle's excavation of the basilica found evidence of several types of flooring, with white marble flagging and cement floors preserved in some areas of the basilica. Although no preserved marble was found during Sweetman and Katsara's excavation work, evidence supporting Cuttle's findings was discovered. Sweetman and Katsara also found evidence of earlier flooring, possible mosaic in type, with the remains of mosaics found in several of the trenches dug by Cuttle.

In addition, given the presence of fragments of broken tile found at an angle, and dents in the surface of the floor bedding, it seems possible that there may have been quite a violent destruction of the basilica, with something heavy falling from above, smashing into and destroying the floor level with considerable force. Given the disruption visible in the remains of the floor-bedding, Sweetman and Katsara suggest that the flooring of the church may have already been removed or destroyed prior to this destruction [16].

4.5.4 Scope for Future Excavation and Research on the Site

In concluding their excavation report, Sweetman and Katsara recognise that a number of questions relating to the architecture of the basilica remain. In their report they indicate that further architectural studies are required in order to fully reconstruct the church and identify how it may have been roofed. They also question whether the buildings to the west of the basilica were connected to other buildings located east of the theatre on the acropolis to form part of a possibly extensive Byzantine settlement. Whilst there is evidence from excavations of the theatre that there are remains of a Late Antique settlement, without any geophysical data the presence of a Byzantine settlement cannot be confirmed. In addition to these specific questions, Sweetman and Katsara also emphasise that their work does not answer a number of questions regarding chronology, development, and contextual relationships within the site and that, without further excavation work, it will be difficult to fully understand the basilica and its development within the context of the acropolis and Byzantine Empire at large.

As no significant work has been carried out on the site since Sweetman and Katsara's excavation work, the questions that they identify as unanswered in their report remain so today. Their report provides the most current and comprehensive account of what excavation activities have been undertaken on the site so far, and what further research is required in order to more completely place the basilica in a wider Byzantine context. Given this, their work acts as the basis of the LAVA virtual excavation case study, with students expected to identify and utilise similar priorities and techniques in their virtual excavations of the site.

Sweetman and Katsara's work has been a source of important conclusions about Byzantine society and architecture. Whilst there are significant open questions which remain, there is evidence available to support several possible theories. All of these factors help to promote student engagement in the virtual excavation as they become aware of the significance of the archaeological questions they are attempting to answer. Given the openness of some of the archaeological questions, the availability and involvement of domain experts has been critical in enabling an authentic and realistic simulation to be created, which is discussed in the next section.

4.6 Design of the Excavation Simulator

The following section describes the software which lies at the heart of this dissertation. It describes the system that has been developed to support the delivery of the virtual excavation of the Sparta basilica. This is a significant piece of work in that it meets the educational goal of supporting realistic, collaborative, exploratory learning within the concrete and complex scenario of the excavation of the Sparta basilica. Whilst the primary objective of the work has been to allow students to apply and reflect on the theories and principles of archaeology within a concrete setting, it has also been found that the visualisations offered by the system can help researchers to better understand the spatial dynamics and architecture of the reconstructed buildings on the basilica site.

Whilst the use of 3D environments in educational settings has recently become en-vogue through MUVEs like Second Life and Open Simulator, much of this work predates these trends. The design, development and implementation of the software has required significant work: the development of game logic, the construction of an historically accurate 3D reconstruction of the basilica, the development of support tools, some redesign and redefinition of interfaces within the MMS learning environment, the creation of a system which allows the collective management of a virtual excavation and the bringing together of these components within a consistent framework.

In particular the use of 3D technologies has offered both important benefits and significant challenges. Notable effort has gone into exploring the appropriateness of technologies from 3D design packages to virtual reality systems, 3D games and more recently MUVEs. This is a field which is continually changing. Even now the relative merits of using first person perspectives games and MUVE technologies are changing as open source MUVEs are maturing to the point where they will soon be suitable for deployment within production environments.

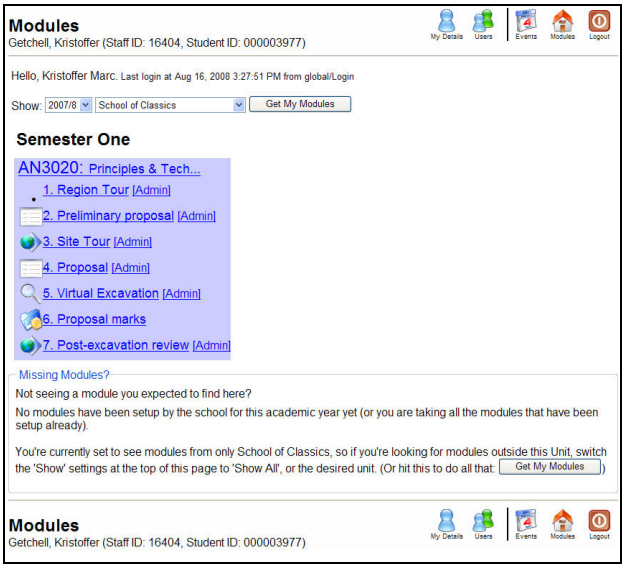

Figure 30 – The MMS Personalised Portal Page

The result of this system development effort has been to demonstrate how the challenge of supporting exploratory learning within archaeology and other similar disciplines can be met. The remainder of this chapter will be used to describe the system from a user perspective, before considering its structure, key design decisions and implementation features.

4.7 User Perspective

4.7.1 Accessing the System and Resource Organisation

Access to the set of resources that students use to progress through the virtual excavation is provided through MMS, as shown in Figure 30. This allows students to access the simulations using their institutional user name and passwords, with MMS authenticating users by reference to an institutional LDAP authentication system. This extensible approach to identification and authorisation makes it possible for students from other institutions to authenticate against their home institution's authentication mechanisms, with management interfaces being provided to facilitate this configuration. This makes deployment to other institutions fairly easy, without the need for major changes to existing infrastructure.

The use of MMS provides a framework which facilitates the support of self paced learning and groupwork. As the system knows the identity of students when logging in, they can be directed to their own personal portal, through which they are able to access the resources associated with their course enrolments. Using MMS makes it is possible for progress and feedback to be maintained centrally for each individual student, with both students and relevant staff able to access this data as required through their own personalised portals.

In LAVA learners are organised into teams, with the system supporting group-working practices by allocating resources on a per group basis. A module comprises of several student teams, with the

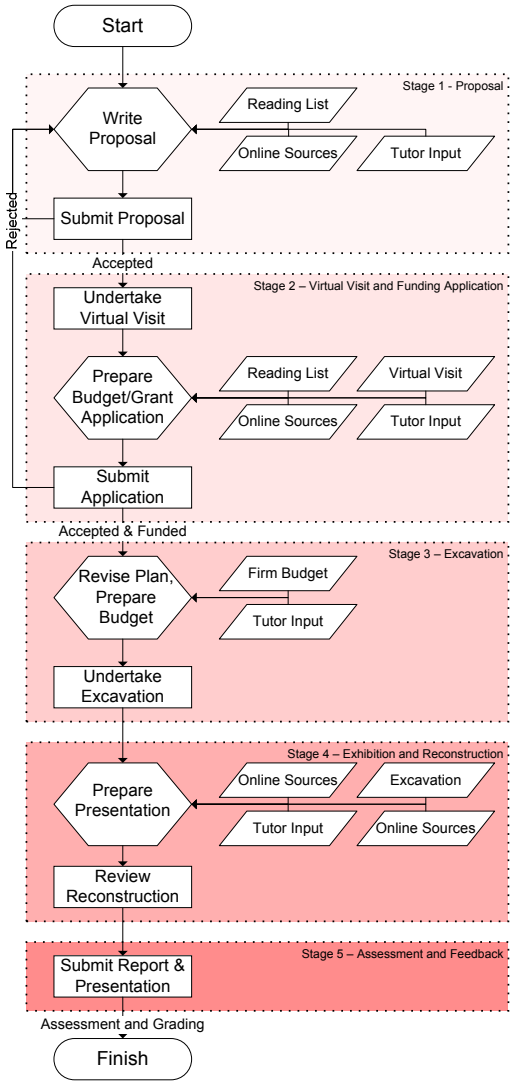

Figure 31 – The Excavation Process as Modelled in LAVA

members of each team sharing a common view of the excavation state. Thus, students within a team operate using a single excavation budget, produce shared documents and communicate through chat and other shared resources provided through their personalised MMS portal page.

4.7.2 Progression Through an Excavation

In order to present meaningful experiential scenarios to students, LAVA operates a sequencing model, with scenarios broken down into a series of contiguous stages. Progression between stages is controlled by the underlying simulation logic and is based on teams meeting a series of criteria. When considering the case study learning scenario, an archaeological excavation of the Sparta acropolis basilica, five stages have been developed as shown in Figure 31.

Stage 1: Write Proposal

During the first stage, the team undertakes some preliminary investigation work in order to identify and record the sites of significance featured on the acropolis. The proposal is then submitted as coursework using standard tools provided by the MMS learning environment. The proposal is assessed by the

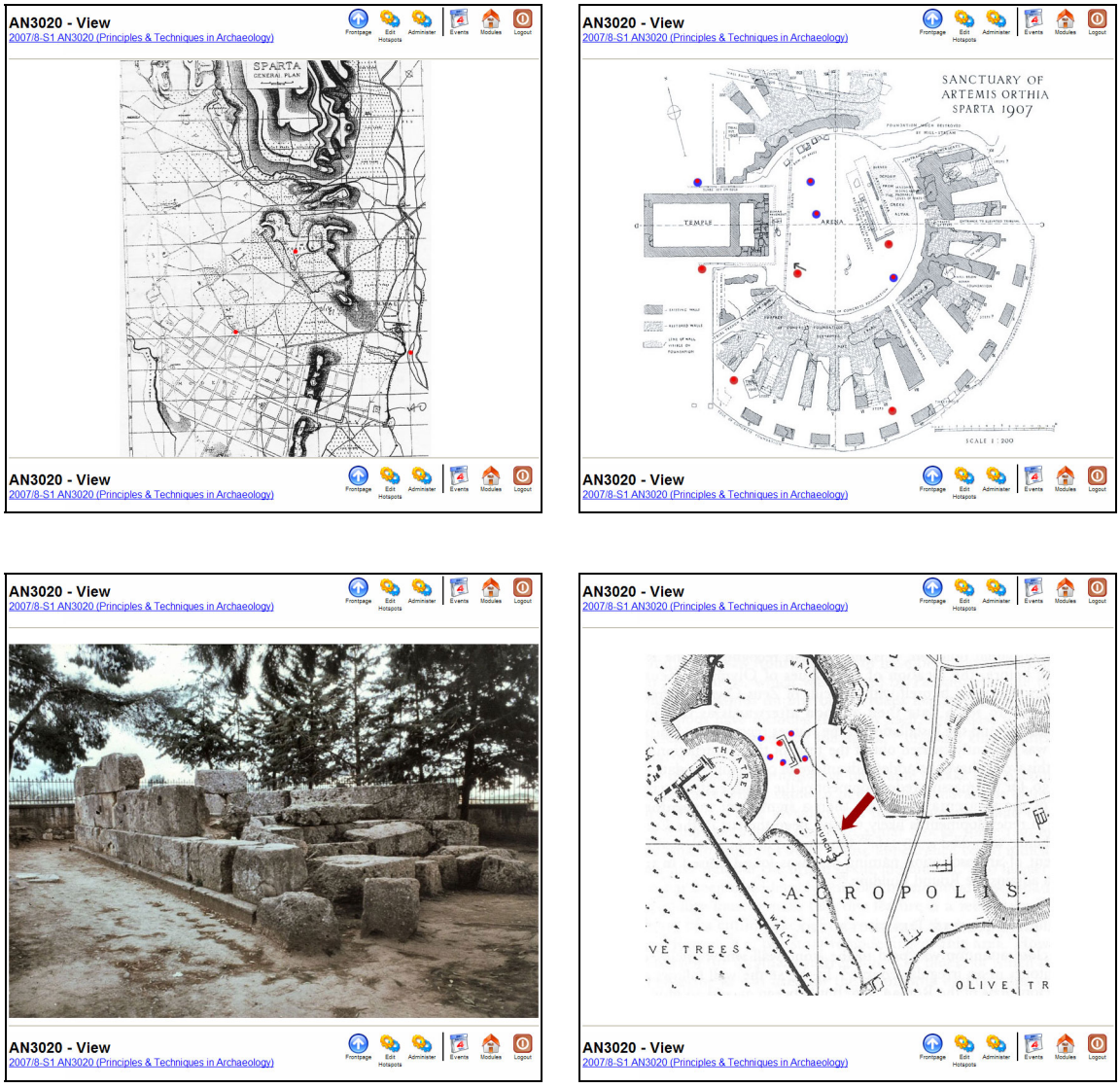

Figure 32 – Various examples of LAVA *Virtual Visit* Clickable Region Maps

module coordinator, with feedback and authorisation to continue given to the group once their report shows a suitably strong research plan. Once agreement in principle has been granted, the team automatically progress to the next stage.

Stage 2: Virtual Visit and Funding Application

The team undertakes a preliminary archaeological survey of the ancient acropolis of Sparta to identify and record the range of sites of significance. Students are expected to use a variety of sources both within and outwith LAVA to determine the location of the basilica. The primary resource which supports this activity is a set of Web pages containing clickable maps of the region, with hotspots that take the student through to more detailed maps or, at the lowest level, photographs of sites and artefacts of interest. As shown in Figure 32, this resource allows students to obtain an overview of the geography and topology of the region.

A second resource, shown in Figure 33, contains interactive Apple QuickTime Panoramas of several areas of the acropolis. This allows students to get a better feel for the physical surroundings, the lay of

Figure 33 – LAVA Virtual Visit Apple QuickTime Photo Based Panoramas

Figure 34 – LAVA Region in Second Life Showing a Reconstruction of the Basilica

the land and the look and feel of the basilica site and surrounding areas. These resources are supplemented by a 3D model of the area located within Second Life. Shown in Figure 34, this model allows groups of students to collaboratively explore the region in real time, with the first person perspective offered by the MUVE technology helping students develop their spatial awareness of the acropolis. Taken together these three resources allow a rounded and accurate picture of the excavation site and surroundings to be developed, which in turn will allow student teams to make informed decisions about the required scale of the excavation, the types of tools and personnel specialisations to deploy. These are all important inputs to the budget proposal.

Once the location of the basilica has been deduced, the team collaboratively draft a proposal that seeks an agreement from a virtual research council to fund an excavation of the site. This is electronically delivered to the module coordinator using MMS, with feedback, authorisation and a confirmed budget being awarded based on the strength of the submitted plan. Once a firm budget has been agreed, the teams are able to tailor their excavation plans and obtain the equipment and experts required for the

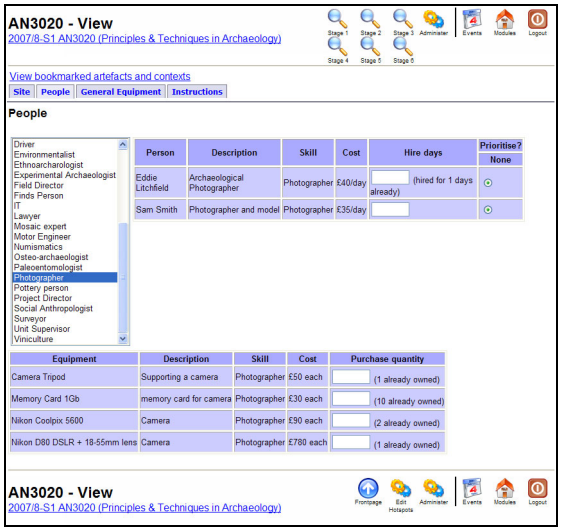

Figure 35 – Student Personnel and Equipment Selection Page

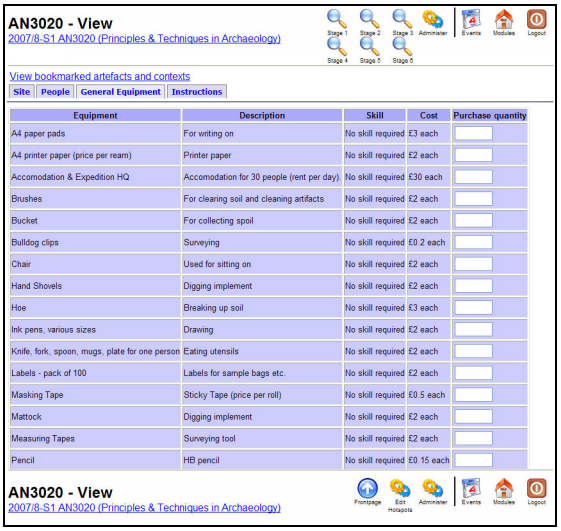

Figure 36 – Student General Equipment Selection Page

Figure 37 – Tutor Personnel Administration Page

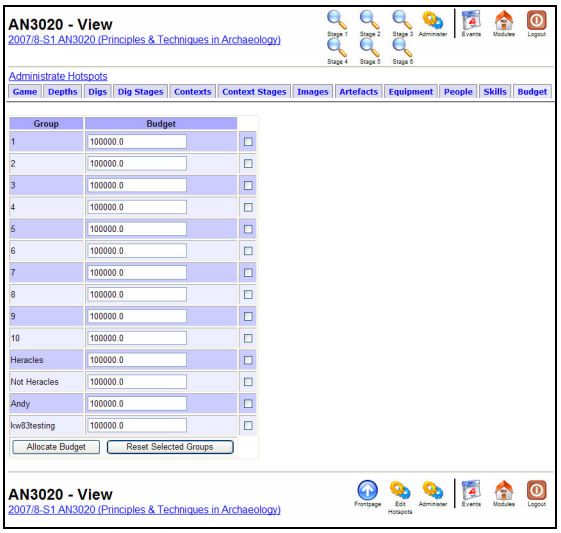

Figure 38 – Tutor Budget Administration Page

project, with the team collaboratively handling this planning process using the Web-based management interface delivered through MMS.

Stage 3: Excavation

At the start of stage 3, each group decides how to allocate their budget. They need to decide what equipment to buy or rent and what personnel to hire. As the excavation progresses, the teams will have additional chances to hire new personnel and acquire more equipment. These opportunities can be used to obtain equipment and personnel for short periods of time: for example, if a new specialist is required for a specific part of the excavation process.

As Figure 35 and Figure 36 show, when selecting personnel and equipment, each group is presented with a list of relevant items from which to select. The equipment lists include items that are directly required for the excavation to take place: items such as spades, brushes and cameras, for example. In

addition, items that are of no real value to the excavation are also included, as well as items that are indirectly required such as cooking pans and tents. Teams need to carefully consider what is required and select appropriately from the inventory. If a team neglects to make arrangements for food and shelter, the effectiveness of their workforce will be inhibited.

In terms of personnel, teams need to select appropriately from lists including trained management, specialist, digging, student and support staff. There are over twenty categories of specialist to choose from, including: anthropologists, cartographers, dendrochronolgists and osteoarchaeologists. Support staff includes: drivers, cooks, lawyers and IT personnel. A form based interface is provided (as shown in Figure 35) , which contains the names of the staff that are available for hire, their cost, a description of their specialism, lists of equipment that they are skilled in using and notes about their experience and competency. When specialist staff are hired an option to obtain related specialist equipment is provided. More general equipment such as spades, tents, pens and paper are obtained separately, again using a form based interface, as shown in Figure 36.

Deciding on how the budget is spent will have an important impact on the success of each team's excavation work, with the deployment of relevant resources at each stage of the process having a direct impact on the speed of progress, and critically on the quantity and quality of finds that are made.

In addition to the interface used by student teams, a management interface is also provided. Shown in Figure 37 and Figure 38, the management interface allows module coordinators to configure the staff and equipment that are available to each team (Figure 37) as well as the budget and time allocated for them to complete their excavation work (Figure 38).

With staff hired and equipment in place, groups are able to begin the excavation process. The excavation is divided up into a number of global levels. A level is defined as an activity that is central to the excavation process, which must be completed by the team before progression to the next level is possible. In the Sparta basilica case study, there are 6 levels that each team must complete in order to finish their excavation work:

- **Clear Over growth remove top soil:** Before excavating the site it is necessary to remove any plant overgrowth and top soil which may have encroached onto the site. During the first level of the excavation work, teams are required to carefully remove any such debris in order to uncover the remains of the structure of the basilica.

- **Identifying the layout of the basilica walls:** Once the site has been cleaned and the remains of the basilica uncovered, teams need to identify the architectural layout of the basilica, outlining the various rooms housed within its structure. By segmenting the site in this way, teams are able to uncover the full extent of the buildings on the site and maintain accurate records of the locations of any finds they make during the excavation process.

- **Expose features in the floor, locate 7th and 9th century artefacts and identify fallen masonry:** After identifying the structure of the basilica building, teams must begin to carefully excavate areas of the site in order to uncover artefacts and fragments of architectural details which have been hidden over time. During this process, teams will find material culture from both the 7th and 9th centuries. They will need to carefully consider the context within which items are found if they are to understand how the basilica fell into disrepair.

- **Expose the West building, features inside basilica and 6th century artefacts:** As the team's work inside the basilica progresses, additional structures around the main building will be uncovered. As new structures are discovered, teams must undertake investigative work in these regions. Within the main basilica building, artefacts from earlier periods may be uncovered as the excavation trenches deepen. Teams need to carefully manage and organise their work in this section, recording the processes they follow accurately if they want to maximise the value of their end of excavation reports and presentations.

- **Expose floor and Mosaic from walls and floor, clean exposed walls:** Once teams have excavated down to the floor level of the buildings, they need to begin a cleaning process in order to uncover hidden architectural details within the walls and floor of the site structures. Some of the details they uncover will have been designed into the architecture, others will have been caused by damage as the basilica fell into disrepair.

- **Locate and expose graves:** As a religious building there are likely to be a number of graves located on the basilica site. Whilst completing their investigation of the basilica and surrounding buildings, teams may discover burial sites containing skeletons and artefacts of archaeological interest that provide an insight into Byzantine culture.

As their excavation work progresses, teams will build up a more comprehensive understanding of the basilica site as reflected in the developing plans shown to them in the excavation management interface (Figure 39 to Figure 44).

Within each level, teams may get the opportunity to explore a number of different contexts. A context is simply a path of investigation which the team can optionally choose to excavate. Not every context is relevant to the excavation of the basilica, so teams need to carefully consider the relevance of the context to the overall excavation when deciding which to investigate and what resources to allocate to that investigation. A context may exist on a number of levels, so even if a team initially choose to leave a context unexcavated, they may be able to reverse this decision as the excavation processes.

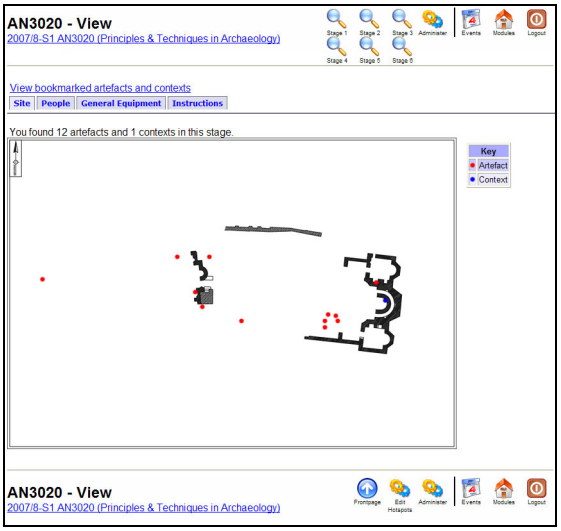

Figure 39 – Student View of Excavation Stage 1 Map

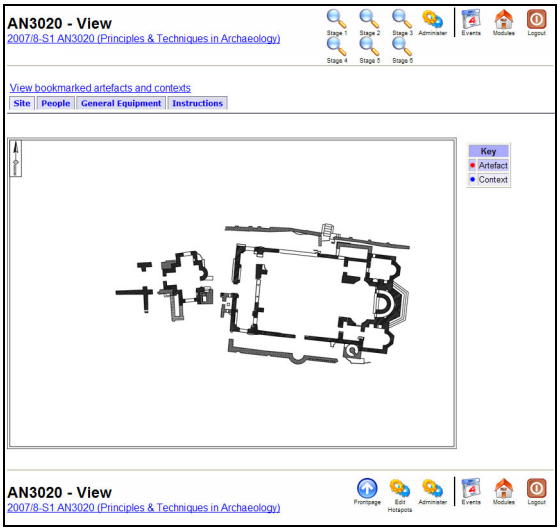

Figure 40 – Student View of Excavation Stage 2 Map

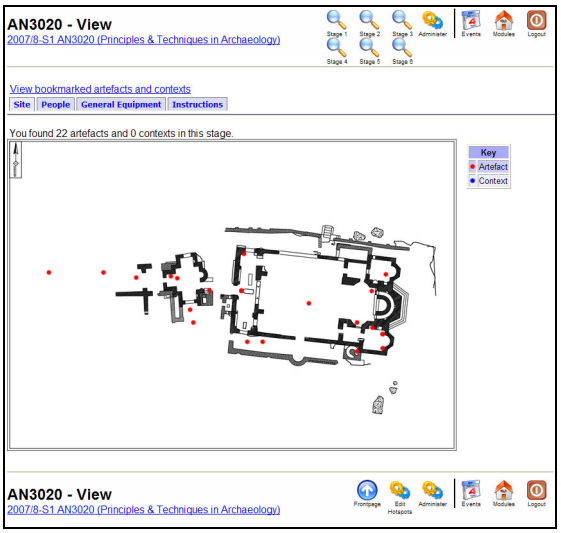

Figure 41 – Student View of Excavation Stage 3 Map

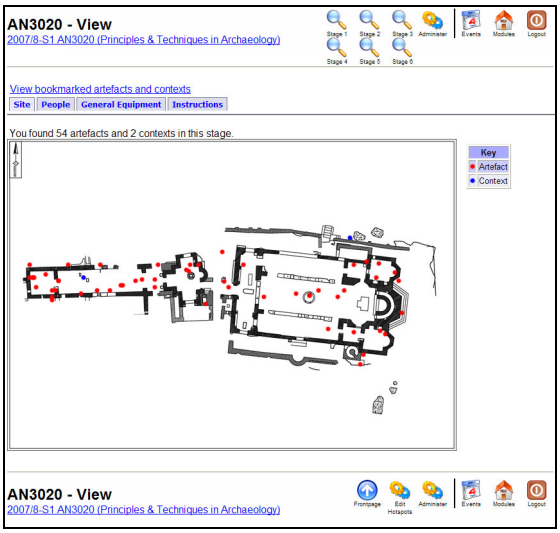

Figure 42 – Student View of Excavation Stage 4 Map

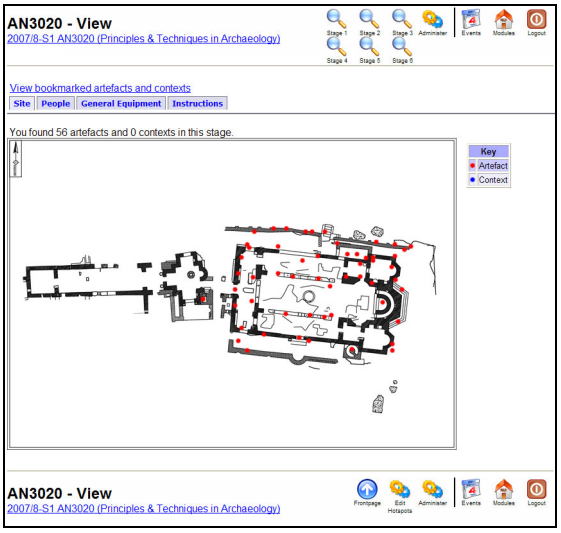

Figure 43 – Student View of Excavation Stage 5 Map

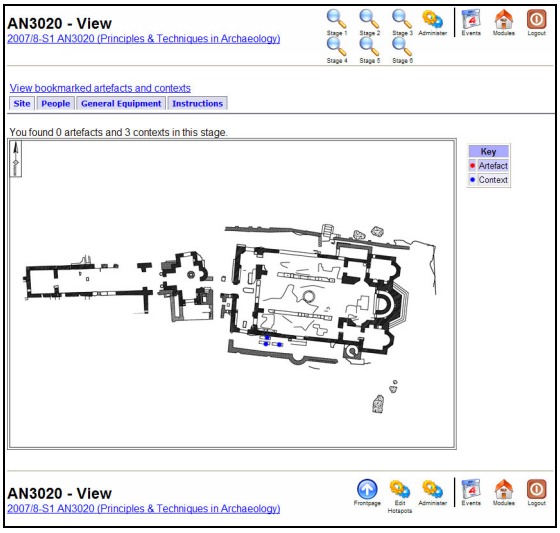

Figure 44 – Student View of Excavation Stage 6 Map

However, once the main excavation trenches reach below the depth of the context, that context will cease to exist and thus teams will be unable to explore it independently.

At the start of each level the team decides on how much time and, by inference, resource to allocate to the completion of the activity. Adjustments may be made to staffing levels and equipment stock as the excavation unfolds, with teams given feedback on their progress, and the costs incurred as they proceed. As shown in Figure 39 to Figure 44, a 2D map is used to outline a team's progress. By outlining the architecture that has been revealed and the locations of the contexts and material culture found, teams can quickly get an appreciation of the effectiveness of their efforts.

Throughout the excavation process, teams are likely to uncover a rich variety of material culture which they must examine. Marked on the level map using clickable red hotspots as shown in Figure 45, some of the finds will be of significance and some not. By clicking on the hotspots, teams can obtain specific data for each item of material culture discovered as shown in Figure 47. Depending on the resources allocated to each activity, teams will be given one of three levels of information about each discovery of material culture, with full information about an artefact only being revealed if the team has allocated the correct archaeological expert to the activity:

1. **No information**, just a photograph of the artefact.

2. **Basic information** accompanied by a photograph of the artefact.

3. **Full information** accompanied by a photograph of the artefact.

During their excavation, teams are free to consult external sources of information when identifying finds and can, as they wish, allocate specialists to examine previously discovered items in order to attempt to reveal the full information held on a specific item.

As with finds, each context uncovered is also marked on the level map, with blue hotspots differentiating them (again see Figure 45). Clicking on a context hotspot will take the team to a new page which contains a short textual description and a graphical illustration of the context as shown in Figure 46. A decision then needs to be made as to whether to excavate the context or not. If the decision is made to excavate the context then staff and time will need to be independently allocated to that task. This can be done using the personnel screen as shown in Figure 48, with an option available to determine the areas of the site to which a person should be deployed (as shown by the highlighting in the figure). If finds are discovered within the context, they will be displayed as a red hotspot on the graphical representation of the context. They may then be processed in the same was as finds located within the main level.

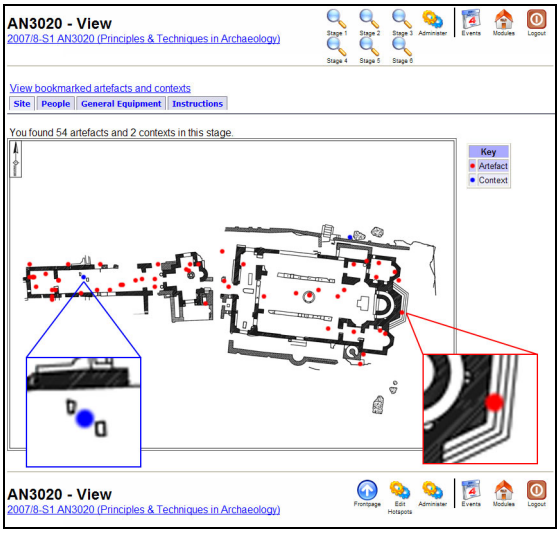

Figure 45 – Hotspots to Enable Student Exploration; Red for Artefacts, Blue for Contexts

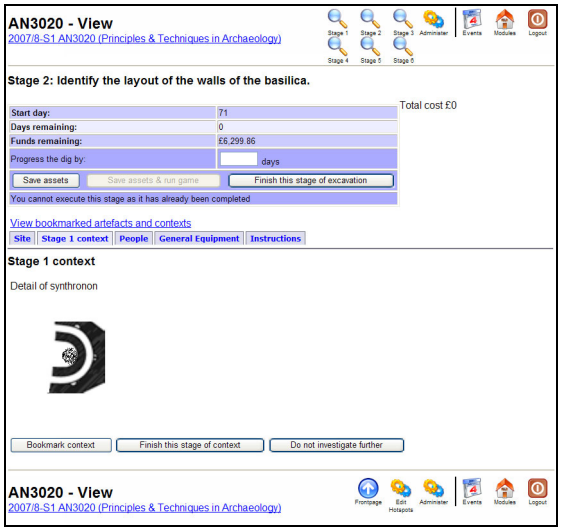

Figure 46 – Context Information Page giving the option to Investigate or Close the Context

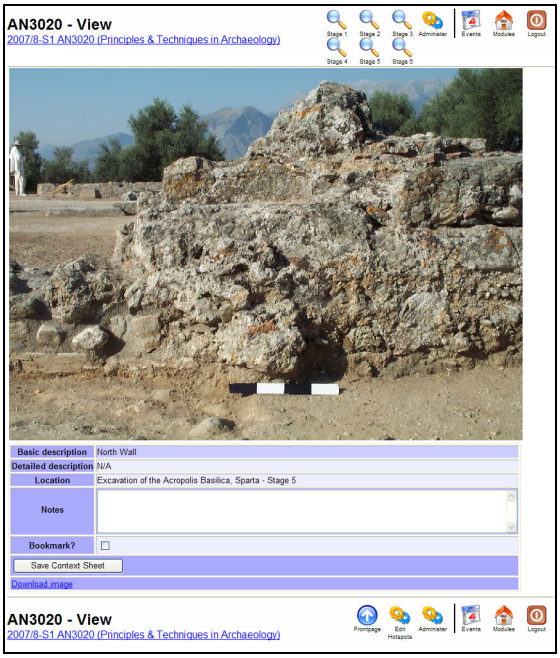

Figure 47 – Artefact Information and Context Sheet to allow Groups to Maintain Site Records

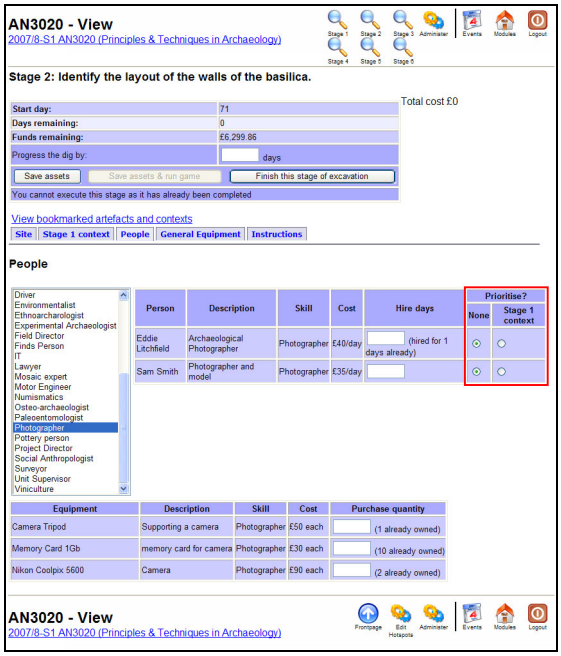

Figure 48 – Personnel Assignment Page, allowing Staff to be Assigned to Specific Contexts

As the excavation work progresses, teams will need to maintain accurate context sheets and site logs, just as they would do on a real excavation project. If they wish to retain any of the information they reveal about a find, teams must bookmark the find information and complete a context sheet. This process is facilitated by the interface shown in Figure 47. Should teams neglect to maintain accurate context sheets they will quickly realise that, when they come to analyse and prepare their finds for presentation in a virtual exhibition, they have lost all contextual information associated with each of their discoveries. This will make it difficult to provide detailed excavation data in their excavation reports and presentations, thus forcing them to rely on external sources of information in order to determine the significance of their findings, just as they would do in a real excavation scenario. Whilst

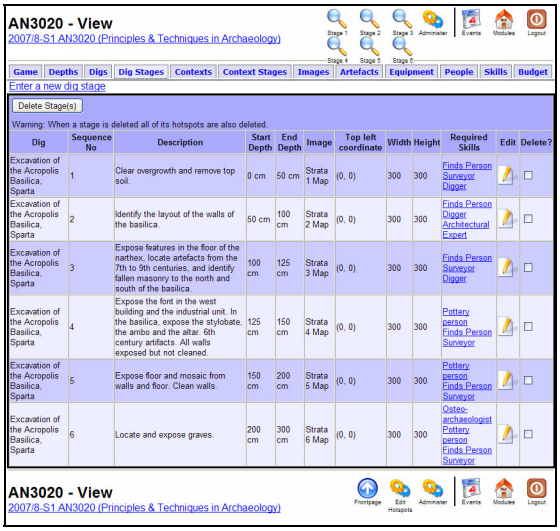

Figure 49 – LAVA Stage Administration Interface

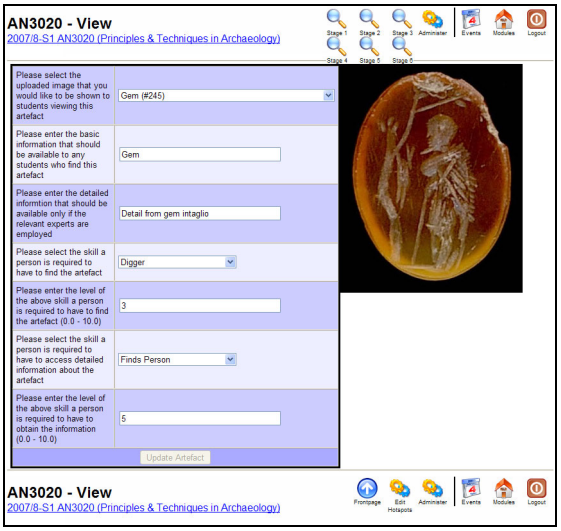

Figure 50 – LAVA Stage Administration Details Page

this process can prove to be reasonably successful, it is likely to take longer, require more effort and be less accurate than maintaining the original contextual information gained during the excavation.

As with real excavation work, once a team has completed an activity, it is not possible for them to go back and do it again in a different way. This emphasises the need for teams to carefully consider the activities they undertake and the resources that they allocate during the excavation process. Through experimentation teams will be able to identify the relationship between the amount and type of resources allocated to a task and the number of finds uncovered. In simple terms, applying more resources that address the requirements of the activity in hand will lead to more discoveries. However, resources are expensive and teams will need to carefully consider their budget and allocate resources in an efficient way if they wish to complete their excavation work. To add realism to the relationship between resources and the number of finds discovered, there is an element of non-determinism introduced by the logic that determines the number of finds a team has uncovered. This makes it impossible for students to pre-empt the outcome of the excavation process by ensuring that the finds returned to each team are different, even if the same resources are allocated to each stage of the excavation process. In this way, the LAVA simulation engine is influenced by gaming methods, with chance being used to ensure that outcomes cannot be pre-determined by students.

To enable management of existing scenarios and development of new ones, a comprehensive management interface is provided as shown in Figure 49 and Figure 50. This interface enables non computing specialists to manage every aspect of a simulated excavation, with Figure 49 showing the stage administration interface and Figure 50 showing the artefact management screen.

To summarise, after their excavation plans are assessed as being suitable for progression, teams are able to begin their excavation work in stage 3. Teams are free to approach the excavation as they wish; there are, however, mechanisms which enable the module coordinator to monitor progress and provide both pre-emptive and on-demand assistance to each team. During the excavation, teams are free to

Figure 51 – External View of the Reconstructed Basilica

Figure 52 – Internal View of the Reconstructed Basilica

attempt a wide range of archaeological procedures using the excavation staff and equipment of their choosing. As they progress, teams are informed of the number of discoveries made. If teams deem any finds to be of archaeological significance, they can choose to record them in a context sheet. However, not all of their finds will be significant, and so the team will need to carefully consider the importance of the materials presented to them. By considering the materials discovered in relation to the working practices adopted, teams are able to collaboratively review their onsite effectiveness, making changes to their approach as the excavation develops. This allows each member of the team to build a mediated understanding of the relative success of the decisions they make.

Stage 4: Exhibition and Reconstruction

In this stage teams are able to synchronously explore a full size 3D reconstruction of the basilica in the Second Life MUVE. As shown in Figure 51 they are able to view the external walls and architecture to compare the structure of the original buildings with the impressions that they gained through the excavation process. This will enable them to critically evaluate the opinions that they have formed based upon the archaeology that they have uncovered. In addition they will be able to utilise the first person perspective offered by Second Life to move around the internal spaces offered by the basilica as shown in Figure 52. This helps in establishing a sense of space and scale, bringing to the fore the grandeur of the church which is hard to envisage from the remnants of the walls which remain today. In addition teams are able to observe the furnishings and decorations which adorn the reconstruction

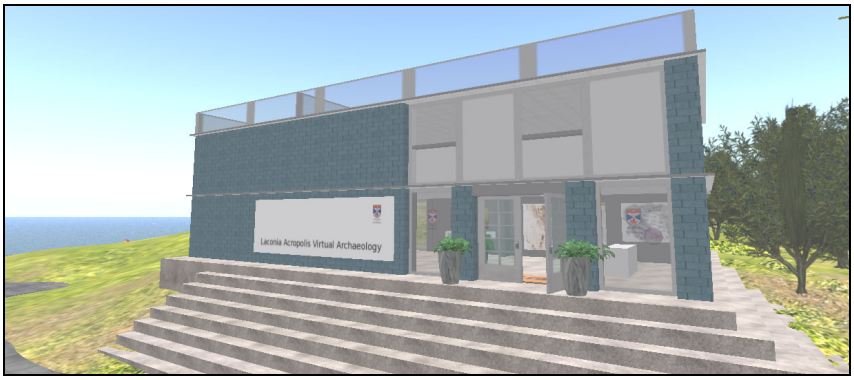

Figure 53 – The LAVA Visitor Centre within Second Life

Figure 54 – Exhibition Space inside the LAVA Visitor Centre

and help bring alive the link between the archaeological process and the cultural achievements of 6th century Byzantines.

In terms of completing the excavation process, in stage 4 teams produce a presentation of their findings and an associated excavation report. Within the MUVE, students are given access to a space in the basilica visitor centre shown in Figure 53 that they can use to curate a museum exhibition which their peers and course tutor will visit (Figure 54). Additionally resources are provided within the MUVE to allow the teams to deliver a presentation based on their excavation work.

After completing the presentation of their excavation findings, teams are able to review the reconstruction of the basilica which is located within the MUVE with their module coordinator. This allows the teams to critique the reconstruction of the basilica based on the findings of their own excavation work. This review provides an ideal opportunity for students to reflect on the approaches they adopted and the conclusions they formed in light of new data obtained by exploring the basilica.

Stage 5: Assessment and Feedback

Stage 5 completes the excavation process, with students submitting their reports and analysing their personal and team performance. This stage is very much a reflective exercise, designed to encourage learners to evaluate their own performance, thereby analysing their own learning. It is also an opportunity for any important observations to be made by the module coordinator, and therefore offers the opportunity for misunderstandings and incorrect interpretations to be addressed.

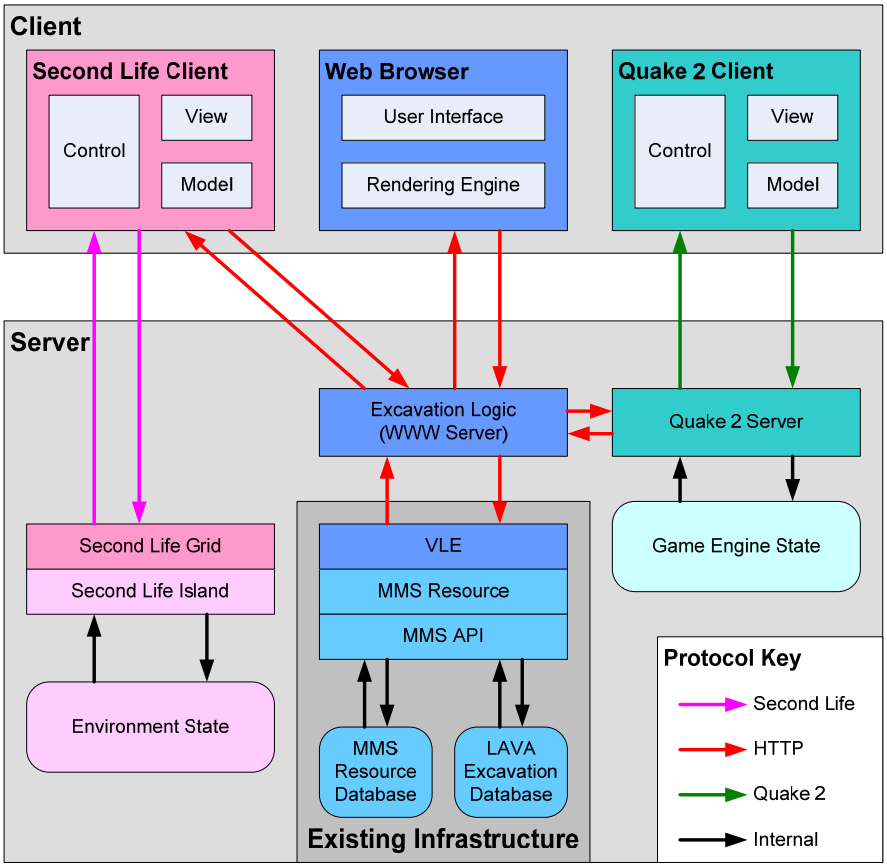

Figure 55 – LAVA Integration with Existing Institutional Infrastructure

4.7.3 Summary

In this section the user perspective of a LAVA excavation has been discussed. It has been established that exploratory learning is supported in a way that adds significant value to the educational process. In addition it has been shown that the provision of a 3D reconstruction adds value by encouraging students to engage in reflective learning by comparing their original mental image of the basilica with the reconstruction presented. The next question to address is how, technically, this can be achieved. We start by outlining the architecture of the system in the next section.

4.8 System Structure

LAVA uses a number of technologies to meet the educational goal of supporting exploratory learning within the context of archaeological excavations. The architecture presented here allows LAVA to integrate these technologies so that each is cognisant of the relevant actions undertaken by learners in other parts of the system. In particular, LAVA borrows from the model view controller architecture, which allows LAVA to maintain a single set of consistent excavation state, but to have multiple views on that state using 2D and 3D interfaces. Thus, the learner will interact with 2D maps of the excavation site, applying resources and undertaking management functions, with the results of these activities made available to Second Life for the creation of the virtual exhibition. This architecture is flexible and has allowed an investigation into the value of using other technologies, such as first person shooter games, for example; Quake 2 and Unreal Tournament, to be undertaken.

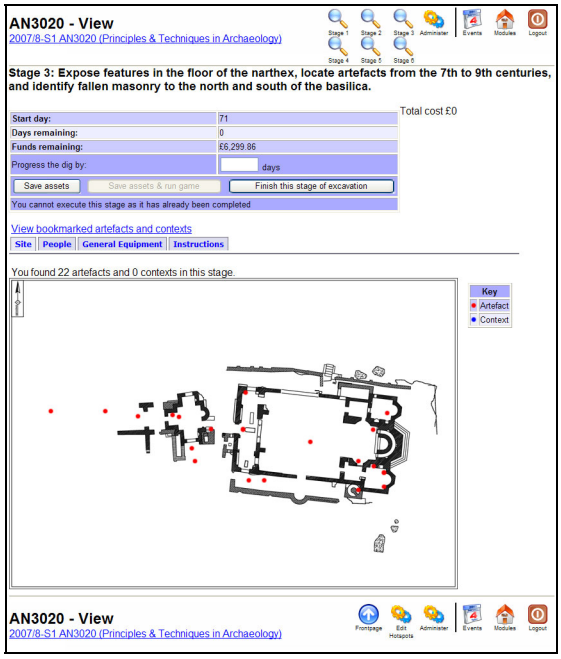

Figure 56 – The Excavation Overview Page in MMS

Figure 57 – The Personalised Module Portal Page in MMS

Figure 55 provides an overview of how LAVA integrates with existing institutional infrastructure, utilising resources and services provided by the institution: the institutional learning environment, and external organisations: the Second Life grid provided by Linden Labs. By integrating with a variety of services, LAVA is able to provide a varied interface to students. Not only does this provide students with the opportunity to choose their preferred method of interaction with the system, but it also allows for services from other organisations to be integrated by the framework: for example, authentication through the institutional learning environment allows individual students to be authenticated so that excavations can be tailored specifically for each team, whilst interfacing directly with the Linden Labs Second Life grid makes it possible for students to collaboratively explore the excavation site in a 3D graphical environment.

From a student's perspective, the framework provides 2D and 3D interfaces, with teams able to manage their excavation using a variety of systems:

- A 2D Web interface, as shown in Figure 56, is used to manage the excavation process. Providing an overview of the excavation which contains a variety of textual, graphical and audio resources, the interface allows students to collectively monitor their progress through a personalised portal in the learning environment as shown in Figure 57.

- The 3D interface to the excavation is provided through the Second Life grid. As an external service, students connect to the Second Life grid which in turn communicates with LAVA to obtain excavation data. The 3D environment is used by students to undertake a more exploratory role, examining the excavation site from a variety of 3D perspectives similar to those in Figure 58 and Figure 59.

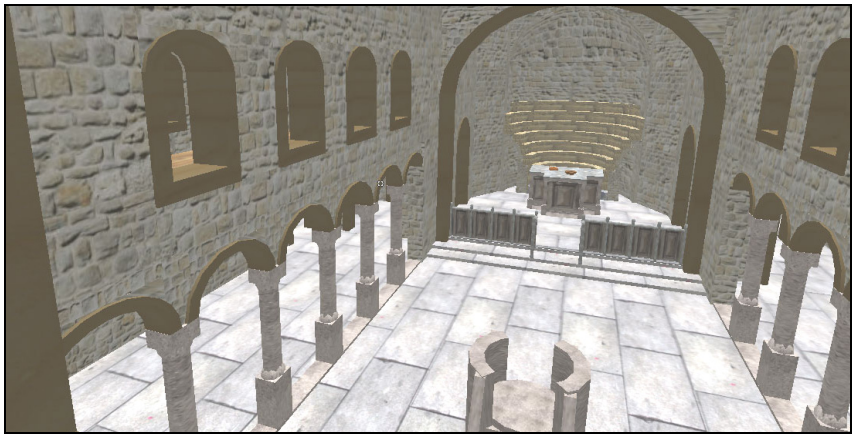

Figure 58 – First Person Perspective View from Basilica Roof

Figure 59 – First Person Perspective View of Artefacts in the Second Life Visitor Centre

Although each mode of interaction is managed by a separate system, a shared model of the excavation is maintained by a centralised component, the excavation logic, which ensures consistency throughout the system (as shown in Figure 55). Within the excavation logic, each instantiation of an excavation is maintained using a series of database tables which are designed in accordance with the schema in keeping with the architectural model outlined in Figure 60. By maintaining a centralised excavation state, coordinating changes to it and providing timely propagation of state changes, the excavation logic ensures that a consistent view of the excavation is presented across a variety of different systems which may span multiple administrative boundaries and present data using a variety of distinct user interfaces.

4.8.1 LAVA Excavation Logic

The excavation logic at the centre of LAVA is responsible for linking the components of the system together. It is also the place where learners' progression through the system is mediated. As such, the excavation logic is critical for monitoring progress, providing access to consecutive levels and bringing together the elements of chance and circumstance which allow the decision making process to both reflect the actions of teams and the randomness that would be present in a real excavation. These

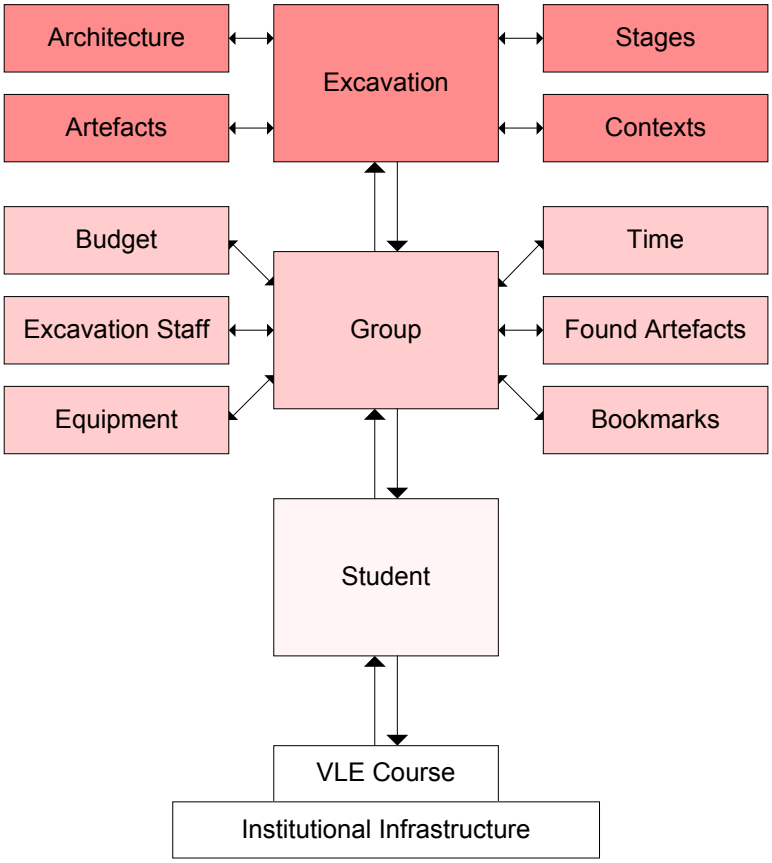

Figure 60 – The Internal Excavation Model maintained by the LAVA Excavation Logic

functions support the utilisation of gaming methodologies in a way which provides realism, non-repeatability and engagement.

In addition, the excavation logic is also responsible for maintaining access to simulation state data and ensuring consistency of presentation across multiple client interfaces. To achieve this, simulation data is maintained in a centralised location, with access to it controlled by the excavation logic. The excavation logic combines the simulation state data with student data read from the learning environment to produce a model of the excavation. Figure 60 shows the excavation model maintained by the case study simulation of the excavation of the Sparta basilica.

As an excavation progresses, the model maintained by the excavation logic changes. These changes are replicated to all client interfaces, with updates made to learning environment data whenever a student completes an activity which leads them to progress to a new stage within the excavation. In this way, all excavation based data is maintained outwith the learning environment, whilst all assessment based data resides within it.

4.8.2 Integration with Existing Institutional Infrastructure

LAVA enhances the functionality offered by existing learning environments by extending their functionality in order to allow them to support simulations that enable experiential learning and development of higher order learning behaviours. As such, LAVA makes the use of learning

environments more appealing in the class of disciplines, which we defined in section 2.1, that face challenges in enabling the application of abstract theories and concepts to concrete scenarios.

By integrating with existing learning environments, and the services and infrastructure that surround them, LAVA makes it possible for experiential learning simulations to be introduced into learning modules without changes to institutional reporting tools or data structures – simulation specific data is maintained by LAVA, with the learning environment continuing to maintain learning data that needs to be fed back into institutional data sources. In this way existing institutional data flow remains unchanged.

As LAVA offers location independent access, a variety of synchronous and asynchronous communication mechanisms are provided in order to enable student teams to coordinate their activities within the learning environment, thereby enabling students to access and engage with LAVA activities in much the same way as they do with other learning environment tools.

LAVA caters for a different type of learning experience to those traditionally supported by learning environments. In order to integrate with existing learning infrastructure, LAVA, where possible, makes use of services provided by the host learning environment, including: authentication, user and group management, access control and data storage. Any additional functionality that is required to enable student groups to engage in collaborative experiential learning simulations is provided by external services, with LAVA managing simulation data and ensuring consistency across multiple systems. In order to achieve this, the following assumptions are made:

- The host learning environment is able to provide an interface that LAVA can use to access learning environment services and data.

- LAVA is able to pass on simulation state data to external services as required.

With respect to the learning environment used by LAVA, an assumption is made that the following abstractions are supported:

- **Users:** A user may assume a number of roles within the system. Through each role they are granted levels of access to perform tasks within the system. The roles will typically be associated with their educational situation: for example, student, tutor and administrator.

- **Groups:** Groups contain a number of users with each user sharing some common attributes: for example, students of a course or tutorial group, or an ad-hoc working group. This structure is well disposed to provide support for collaborative learning.

- **Resources:** Resources exist within the learning environment to allow users to undertake a variety of different activities. They provide functionality to support the learning process. Resources are allocated to groups, thus group membership implies the sharing of resources such as chat facilities, shared workspaces and, in the case of LAVA, the excavation simulator.

Through this support it becomes possible to make use of the learning environment for user authentication, resource allocation and the provision of a variety of document sharing and collaborative workspace resources. LAVA integrates with the learning environment through a defined and documented application programming interface. This means that LAVA is loosely coupled with the particular learning environment in use. This facilitates integration with alternative learning environments as required.

4.8.3 Integration with Multi-User Virtual Environments

MUVEs support a combination of functionality that is of interest in a number of educational domains, including the ability for educators and learners to create or significantly modify the environment offered by the MUVE, a 3D space within which environments can be modelled, a first person perspective which enables learners to explore the environment, and the ability for multiple learners to be synchronously accessing and interacting with the same resource. Taken together this functionality sets this class of application apart from other 3D environments and makes it possible to provide support appropriate for exploratory learning about environments that may be inhospitable and/or difficult to explore in the real world.

By providing a defined set of services which can be used by MUVEs, LAVA makes it possible for excavation data to be copied between systems. Interfaces and scripting languages are often provided by MUVEs which allow code to be written to import and export data and to automate the construction of 3D environments. With this architecture, these facilities are taken advantage of in order to connect MUVEs with LAVA, thus making it possible for the results of an excavation to be imported into the MUVE in order to present students with a 3D representation of their excavation activities.

Given the shared nature of the MUVE, this functionality can be harnessed to enable student groups to present their findings and critique those of their peers. From an educational perspective this reflection and peer assessment is beneficial in developing positive learning interactions within the MUVE.

4.8.4 Conclusion

The architecture presented above discusses the main components, their functionality, interactions, and the interfaces which make the user experience described in section 4.7 possible. This architecture supports the pedagogical goals set out in the introduction to this section within the context of the virtual excavation of the Sparta basilica. In particular there is support for exploratory learning and groupwork.

Engagement is facilitated through the application of gaming methodologies, realistic 3D environments and believability.

Whilst the architecture presented above has been discussed within the context of the LAVA case study, it has been shown how the functionality provided to students is supported by a generic framework. As such the architecture is widely applicable to alternative settings. Specifically it can be used to support any archaeological excavation scenario. In addition the combination of maintaining state for individual users, support for groupwork, support for anytime-anywhere access through Web and MUVE interfaces and the modularisation of system logic could be applied to educational activities which involve the exploration of remote or inaccessible environments. Examples would include the creation of historical scenarios, geological fieldwork, development of architectural projects and space travel.

4.9 Design Decisions

This section makes explicit the key design decisions that have been taken in the development of the LAVA excavation simulator. As well as identifying each decision, the justification and consequences of the decisions are explored. In addition some alternatives are discussed. At the highest level, each design decision is guided by the desire to meet the educational goals of encouraging engagement and collaboration through realistic and accessible learning scenarios, which in turn are aligned with the pedagogical approach adopted by this work.

The scope of this work is quite large; consequently, it has not been possible to discuss every design decision made. Traditionally requirements are divided into those relating to system functionality (functional requirements) and those related to other aspects of the system (non functional requirements). However, in the discussion of the design decisions three high level categories are used:

- Those that relate directly to how the user interacts with the system and how LAVA's educational goals are achieved. These design decisions are largely technology independent and still pose the question of how they will be achieved. In a sense these decisions flow from, and are a justification of, the section of this chapter which relates to the user experience.

- Design decisions that relate to the structure and architecture of the system.

- Decisions about which technologies to use within the context of the architecture.

For decisions relating to the architecture of the system, additional criteria were considered: for example, wanting to deliver a well engineered system with homogeneous and loosely coupled components. In addition, consideration was given to the need to develop a system that can deliver acceptable levels of user level quality of service to students engaging in a lab session or at home.

For the decisions relating to the use of technologies, factors such as the desire to have an open, non-proprietary system and to use technologies which naturally satisfy the functional requirements of the system were important considerations. An emphasis was also placed on the use of freely available, standardised components in order to facilitate reuse in alternative applications.

From the point of view of the overall system, the motivation for, and the use of 3D technologies can be considered the most important design decision. The nature of this domain, with significant changes in technology and its availability over the course of this work has meant that a number of iterations of the design have been developed with significant exploratory implementation work being undertaken.

This section will continue by discussing the decisions made that affect the educational goals of this work before continuing to consider those affecting its structure and the technologies deployed within it.

4.9.1 Educational Design Decisions

Table 6 defines ten design decisions linking educational goals to the user interactions with the system. The decisions are organised hierarchically, with many of the later decisions being made possible through the earlier ones: for example, the use of digitalised resources makes it possible for resources to be organised spatially within LAVA. For each decision a definition, the goals addressed and apposite comments are provided. This is followed by a discussion of issues surrounding the more innovative decisions such as the use of non-determinism and first person perspective interfaces.

Why using a Computer Games Approach is Educationally Beneficial

A computer games methodology is used in the design as it provides high levels of audience engagement. Realism is achieved by deploying a range of technologies from 3D virtual worlds to high definition photographs and maps. As discussed by Malone [20, 190], computer games can be decomposed into a series of contiguous goals which challenge and stimulate the user. For a goal to be effective it must be possible for the user to identify with the knowledge domain in question and to judge their performance with respect to reaching the final objective [190]. Within each goal, the outcome of game play should be uncertain. This can be achieved in a variety of ways:

- Through the development of different levels of difficulty that act to challenge the user.

- By hiding and selectively revealing information within the game environment, thereby controlling the way in which the user is able to access information that assists them in fulfilling the game objectives.

- By introducing randomness into the game play so that each time a specific scene is reached by the player, the outcome cannot be pre-empted.

Design Decision	Educational Goals Addressed	Comments
Base the work as far as possible upon a real and important excavation.	Maintains realism and encourages engagement from learners.	It was possible to meet this requirement because of the cooperation of Dr Rebecca Sweetman who conducted and therefore has privileged access to materials relating to the excavation of the Sparta basilica.
To digitise resources to make them available to students through computer systems.	Lays the basis for the organisation of materials in ways that will improve realism and allows multiple students to simultaneously access resources, thereby improving accessibility.	The digitalisation of resources is a labour intensive activity. We were fortunate in that many of the resources required by this project had been previously digitalised.
To use the Web and networking technology to achieve anytime-anywhere access.	Pedagogically this is an important design decision as it allows learners to use LAVA in a lab environment and other locations. This gives the student control over the learning process and through that provides support for self paced, student centred learning.	Increasingly students expect easy access to learning materials through the Internet. Meeting these expectations makes the system more accessible and encourages engagement.
To organise student access to digital resources spatially.	Situating resources within 2D maps and 3D reconstructions helps students develop awareness of the context of objects and their interrelationships, both in terms of location and culture.	Organising data in this way is a significant improvement over simply making large numbers of photographs available for students to access sequentially.
To organise student access to digital resources temporally.	Supports realism in that activities have to be undertaken before material culture is discovered. This process encourages engagement as materials are only uncovered as students progress through the system.	Mediating access to resources in this fashion reinforces the need for progression through the system.
To make the system interactive.	Interaction is actively encouraged as students do not simply view aspects of the excavation in isolation. Instead their decisions and actions have a direct impact upon the excavation and the path of their progression.	Developing a sense of engagement in each learning scenario encourages student participation.
To structure progression through the excavation into a number of discrete stages.	This borrows from gaming methodologies and encourages engagement with the system by providing clearly identifiable goals.	The use of several linked scenarios creates natural break points within the system. This allows users the opportunity to reflect on their progress at the end of each period of interaction.
To provide access to digital resources based upon a combination of user actions and chance.	Informed by gaming methodologies, this approach increases realism and playability by reducing the predictability of the system. Hence it is possible for students to undertake the same excavation twice and get different results.	Maintaining an element of chance reduces the predictability of the system, thus even students familiar with a particular scenario cannot pre-empt the finds that their team will make.
For students to access the excavation scenario as part of a cooperative group.	This supports collaborative learning which encourages students to learn through interacting with each other as well as the simulation. This collaborative element also supports realism.	Team working is an important generic skill appropriate to a variety of activities.
Use of a mixture of textual, 2D graphical and 3D first person perspective interfaces.	Providing synchronous and asynchronous access to a realistic and engaging simulation using a variety of media resources enables students to focus on the resources they are most comfortable using.	Allowing students to use the resources they choose enables them to control the pace and style of their interactions with the system.

Table 6 – Summary of Educational Design Decisions

Why it is Important to get the Right Level of Complexity and Chance

Whilst the game play has a degree of randomness, it is important to ensure that the attainability of game objectives is matched to the player's ability and skill level. Successfully achieving a goal can increase a player's self-esteem and therefore have an effect on their motivation to continue, with failure in small quantities acting to enhance this drive. However, if players perceive game goals to be impossible to achieve, they will become disillusioned by repeated failures and hence become increasingly de-motivated by the game [191]. Obtaining the optimal level of informational complexity [50, 192] is of real importance when considering in-game engagement; a player needs to be able to understand the gaming environment if they are to engage with it. By closely aligning excavation goals and educational objectives, LAVA borrows from gaming approaches, with learners advancing their educational progress by developing skills that satisfy the excavation challenges presented.

Why a 3D First Person Perspective

In much the same way that the World Wide Web opened up access to information through intuitive point and click graphical user interfaces, 3D interactive environments (i.e. first person shooter games and MUVEs) offer new and innovative opportunities for the development of realistic and engaging educational scenarios based in previously inaccessible environments. By providing users with multiple interfaces to explore a problem space, instead of a single static representation of one aspect of it, LAVA allows learners to use their investigative skills to explore from a variety of vantage points. Mixing both 2D and 3D perspectives LAVA both provides direction and allows users to explore at their leisure.

3D environments provide users with an almost infinite number of perspectives through which to examine a scenario and provide ideal opportunities for simulated events to be re-enacted for teaching purposes. America's Army: Special Forces Overmatch [193] is a good example of a teaching application that makes use of 3D technology, with virtual battlefields presented to possible recruits in order to test their reactions to different simulated scenarios. In addition, a large machinima [194] community has developed around many popular game engines, with re-enactments filmed and published on specialist websites [195] as well as popular media sharing websites including YouTube [84] and Vimeo [196]. In addition, social networking sites which facilitate group communication are also becoming more popular with Facebook [197] and MySpace [82] hosting pages relating to several machinima special interest groups.

It is often assumed that this type of approach to exploratory learning is a relatively new phenomenon. However the use of 3D environments and simulations has a strong pedigree in the field of aviation, with flight simulators well placed to leverage the strength of simulated 3D environments. Indeed, many commercial flight qualifications require pilots to engage with some form of simulator based training to test their responses to emergency situations under instructor evaluation [198, 199]. In addition, the teaching of anatomy also has a strong track record for making use of simulations delivered in 3D environments to enhance teaching. In much the same vein as the work discussed in this

dissertation, Brenton's work at Imperial College [200] attempts to widen participation by increasing opportunities for students to practice procedures usually requiring access to scarce resources; instead of working on cadavers, students are given access to simulations built using Web3D technologies – not only does this allow more students to participate in a given activity, but it also allows the activity to be practiced multiple times, without side effects, until the process is mastered.

In addition to these application areas, 3D technologies can also be used in less obvious scenarios in order to clarify complex visualisations; by modelling the relationships, dependencies and interactions between components in object oriented computer programs, 3D visualisation techniques can add clarity by allowing users to focus on specific areas of a complex system in isolation, thereby increasing accessibility and encouraging self-paced learner engagement [201].

One of the key advantages frequently overlooked by alternative teaching and learning environments is their ability to remove the barriers often associated with traditional educational settings. Within the classroom environment, the roles of teacher and student are entrenched and difficult to change [202]; within a virtual 3D environment real-world relationships are less well defined, with educators assuming the role of facilitator as opposed to that of an authoritative teacher figure. This change in perception encourages an approach to learning which places more focus on achieving goals and solving problems than it does on the roles each person assumes. As Knowles and Moore and Kearsley argue, an open environment is far more suited to self directed learning [203, 204] and as such can more readily support a self-directed approach to learning [205].

4.9.2 System Structure and Design

Table 7 presents five design decisions which relate the functionality required by the system and how it is achieved. Initially focussing on first principles, which are developed by later decisions, the table identifies the building block decisions that are made before outlining their impact on the direction of this work: for example, the decoupling the user interface and excavation logic makes segmentation of the game play into synchronous and asynchronous, 2D and 3D modes of interaction possible. Table 8 expands on this by considering how different modes of interaction can be used to provide educational benefits within a LAVA simulation. In both tables, for each decision the motivation is presented along with a commentary assessing its impact on the system. This is followed by a discussion of the issues surrounding the modelling of the excavation in 2D and 3D interfaces at different phases of the process.

Separation of Type of Interaction and the Levels of Abstraction Presented

As an important aspect of this work, the separation of synchronous and asynchronous and 2D and 3D interactions is an important design decision that has a direct impact on the interactions offered to students. Primarily tied to the level of abstraction adopted for each learning exchange, the separation is undertaken in order to allow students to develop skills in the virtual environment which can be applied to a real world excavation, for example:

Design Decision	Motivation	Comments
Development of a service based architecture.	Adopting a service based architecture adds flexibility and makes it possible for components of the system to be used in a variety of applications. This enhances the generality of the solution and allows updates to be applied easily. In addition this approach allows configuration and control to be exercised from the server side, thereby easing deployment to a large number of clients.	An alternative approach would be to develop a standalone application. This would make deployment of the software and updates more difficult to manage. It would also reduce the accessibility of the system. However it would make it possible for the software to be used without Internet connectivity, something a Web-based approach does not allow for.
Decoupling of user interface from excavation logic.	Maintaining separation between the logic that controls the excavation simulation and the interface through which it is controlled makes it possible for alternative interfaces to be developed without requiring changes to the underlying excavation logic.	This is facilitated by the adoption of a service based architecture. The ability to provide several interfaces to the excavation process aids accessibility and encourages use in different environments: for example, on a PDA, mobile phone or set top box.
Use of users, groups and resources abstraction to facilitate organisation and mediate access to system functionality.	Organising access to resources and maintaining separation of groups is important in providing an infrastructure which supports collaborative groupwork. It allows resources to be allocated to groups. The members of which may share allocated resources and, where appropriate, may have a common view of data associated with each resource.	The system provides a clear organisational structure which supports the use of access controls and provision of user rights.
Resources designed as independent MMS components built to conform to a common interface which enables functionality and data to be bound together.	Developing the components of the system in this way allows for underlying learning environment functionality to be utilised: for example, sequencing, user authorisation and protection mechanisms. In addition the flexibility offered by this approach makes it possible for resources to be used in alternative applications.	An alternative approach would be to develop a single monolithic resource which fulfils the requirements of this work. This resource would have limited application in alternative domains and would be difficult to maintain.
Use of a relational database to model state related to the excavation.	By eliminating repetition of data, this approach provides a flexible and efficient way to retrieve and update excavation state data. Classifying tables into a hierarchical structure, with first class tables of student, group and excavation and other tables relating directly to one of the above adds flexibility and aids maintenance. A well defined API to the data is used which reduces the complexity required in other parts of the system and allows changes to the data structure to be made without threatening the integrity of the system.	As multiple types of data are being used, with the relationships between them significant to the dynamics of the system, it becomes important to have a well developed approach to describing, storing and retrieving data.

Table 7 – Summary of System Structure and Design Decisions

Design Decision	Motivation	Comments
Separation of synchronous and asynchronous game play into separate phases of the excavation.	The use of synchronous and asynchronous interactions in a 2D or 3D environment is tied to the level of abstraction adopted. Throughout the excavation simulation, different levels of abstraction are used to present different aspects of the excavation to students, with the choice aiming to maximise the educational benefit of each interaction. For example, in the 2D environment LAVA abstracts away from the physical activities associated with digging trenches and dusting for finds, as the skills required to manipulate the keyboard and mouse to achieve these activities in a virtual environment are very different to the skills required to achieve these activities in the real world. This allows LAVA to draw student focus to aspects of the excavation process that are applicable in both the simulated 2D and real world environments: report writing, strategy, identification of requirements, application of resources etc. Similarly, in the 3D environment LAVA focuses on activities which maximise the use of skills applicable to the real world: for example, identifying objects visually, considering architectural features etc.	Separating synchronous and asynchronous interactions also leads to a cleaner design. If the 3D synchronous and 2D asynchronous views were simultaneously active, problems in maintaining the consistency of state would arise. Separating the domains where the different modes of interaction are active allows the consistency of system state to be easily maintained without the need to freeze state in either environment. This would effectively render the 2D asynchronous environment inoperable for possibly long periods of time.
Separation of 2D and 3D game play into separate phases of the excavation.		

Table 8 – Summary of System Structure and Design Decisions relating to Modes of Interaction

- The skills required to identify and apply resources to the excavation of an area of the archaeological site are likely to be similar in both types of environment. However, as access to a virtual excavation is mediated through the use of a computer, the type of skills required to actually carry out the excavation work are likely to be very different; the process of digging a trench with a mouse in the virtual environment is significantly different to the process of digging a trench with a shovel in the real world. In this way LAVA uses a 2D asynchronous interface to allow students to focus on the processes associated with the planning of excavation work in order to enable the development of skills that are applicable to real world excavation projects.

- When considering the process of reviewing architectural elements and presenting findings, the skills required are similar in both virtual and real world environments, with the concepts of space and context being important factors to consider. Thus LAVA makes use of a synchronous 3D interface to allow students to understand the context and spatial relationships between architectural elements whilst engaging with each other and the environment, just as they would in a real world scenario.

The approach adopted draws from a number of well established gaming methods. To illustrate this point, consider an example which is drawn from popular football games. The 2D asynchronous interface presented to students via MMS shares many characteristics with the popular and highly successful Championship Manager [206] football management game – focusing primarily on the development of skills which can be practiced in a virtual environment and applied in a real one without significant changes. Whilst other titles focus on providing a synchronous 3D interface which delivers a match like environment that encourages users to learn how to control each player [207], Championship Manager provides a more abstract asynchronous 2D interface, as shown in Figure 61, which focuses on the skills and strategies required to build a successful football squad. In this way, the learning outcomes of using Championship Manager could be applied to real world football management, in much the same way as the learning outcomes associated with the LAVA 2D interface could be applied to real world excavation scenarios. In contrast, FIFA 2008 [207] provides limited transferrable skills with respect to playing a match: with users learning game specific interactions which have limited applicability in real world matches; being able to manipulate a joystick to score a goal in FIFA 2008 clearly has no direct application on being able to score a goal in a real football match. Thus the opportunities for the application of the skills taught by FIFA 2008 are limited to a specific, narrow domain.

However, the 3D synchronous interface offered by FIFA 2008, as shown in Figure 62, does provide tangible benefits with respect to developing cooperation strategies between multiple players within a single match. In addition, the realistic environment presented also increases a users' familiarity with the procedures undertaken during a football match: for example, substitutions, timing and scorekeeping. It is for these reasons that the later phases of the virtual excavation make use of a

Figure 61 – 2D Management Interface used by Championship Manager 2007

Figure 62 – 3D First Person Perspective Interface used by FIFA 2008

synchronous 3D environment; when student teams are ready to analyse reconstructions of the excavation site and present their findings, the cooperation encouraged in the 3D synchronous environment is directly applicable to real world scenarios, and as such is educationally beneficial. Additionally, the ability for students to assume a familiar first person perspective when reviewing architectural elements or presenting their excavation findings is also clearly applicable to real world scenarios and is thus made possible in the synchronous 3D environment.

Modelling Interactions

In addition to the educational motivation driving the separation of the modes of interaction offered in the simulations, an added benefit of maintaining separation exists from the point of view of system design. Within the 3D viewport time is modelled in an inelastic fashion; it is not possible for individual group members to jump forward in time as this would cause problems with other group members who were not intending to progress time forward so quickly. In order to maintain consistency between group members, time is modelled in a uniform synchronous fashion throughout the 3D environment. This poses a problem when it comes to undertaking slow and repetitive work using the

2D asynchronous interface. If both the 3D synchronous and 2D asynchronous views were simultaneously active, consistency issues would quickly arise, with users of the 2D asynchronous interface making changes to the environment currently being explored by users of the 3D synchronous interface. How these changes would be propagated into the 3D environment remains unclear as any activities in the 3D environment have been undertaken assuming a fixed starting state to the environment. Interleaving changes made in the 3D synchronous and 2D asynchronous environments may be feasible, however given the lack of coordination between the two the result would likely be difficult to accurately predict.

One solution to this problem would be to block access to the 2D environment when users were active in the 3D environment and vice versa. This approach would, however, have a negative impact on the anytime-anywhere accessibility of the simulations, creating a direct link between the previously independent interfaces which breaks the service orientated approach adopted by this work. Instead, a logical separation of the interfaces has been adopted, with each interface tasked with delivering certain phases of the excavation to students. Not only does this ensure consistency of state and reliability of presentation, but it also ensures that each interface remains independently maintained thereby reducing the complexity of the system whilst maintaining the desired service orientated architecture.

4.9.3 Technological Decisions

In moving towards the concrete instantiation of the system, five key design decisions were made with respect to the technologies adopted in the system. Whilst made independently, each decision considered issues of integration and cooperation between system components. For each decision, the functionality offered is presented, along with comments outlining the rationale adopted and/or alternatives considered. Table 9 presents these decisions and is followed by a discussion of the issues surrounding the choice of 3D technology adopted and the impact that this has on the operation of the system itself.

Comparison of 3D APIs, First Person Shooter Games and MUVEs

As a number of 3D technologies exist, it is important that the differences between each are understood. Several 3D technologies were examined in the course of this work. From an archaeological excavation perspective, for students to explore and understand an excavation site it is important that they are able to access realistic materials in an environment that encourages self-motivated discovery. When developing the excavation simulator, three different types of 3D environment were considered: first person shooter games, MUVEs and 3D APIs. Each category of 3D technology was evaluated against four of the criteria as discussed in section 4.4.1:

- **Learner Engagement.**

- **Groupwork and Collaborative Working Practices.**

Design Decision	Functionality Offered	Comments
Use of Second Life for 3D visualisations.	Second Life provides a stable, accessible environment which supports extensive modification and scripting. The changeable perspective enables users to adopt a first person perspective when required to focus on specific objects, with a wider field of vision being possible when navigating the excavation site. The comprehensive scripting engine offered by Second Life provides support for modification of the environment as well as communication with external services, hence enabling the link between the 3D synchronous interface provided by Second Life and the excavation logic behind the LAVA simulations. The shared environment space provides support for collaboration amongst student groups, with access control mechanisms making it possible for individual student groups to be separated into different, private regions.	Alternatives to Second Life include Active Worlds and Open Simulator, with Open Simulator being compatible with the Second Life client. Unlike Second Life both Active Worlds and Open Simulator have only limited scripting capabilities, thus making interaction with external services more difficult. Whilst Open Simulator will eventually provide a Second Life compatible scripting engine which can be extended with alternative scripting modules, the current scripting support is only partially implemented
The use of MUVEs over first person shooter games.	Both first person shooter games and MUVEs support the desired 3D perspectives of an environment. However, unlike game based choices, MUVEs do not have a pre-defined concept of levels, progression or game play. This makes it possible for the MUVE environment to be fully customised to the requirements of LAVA. Built on a larger scale, MUVEs also provide support for the development of large environments for students to explore. Whilst this support is provided in many game engines, access to the engines is often strictly controlled through licensing agreements. MUVEs do not suffer from this administrative burden as client access is generally freely available.	In terms of developing in first person shooter games, investigative work was carried out using Quake 2 and Unreal Tournament as well as the Unreal Runtime engine. The control offered by first person shooter games in terms of creating environments was good; however, the underlying concepts of levels, progression and killing did not fit well with the concepts of levels and progression within the excavation scenario. In addition it was found that support for modification of the underlying environment was not comprehensive, making it difficult for excavation processes to be accurately modelled.
Use of MMS.	Group based access to excavation data was an important factor in deciding to use MMS to build the 2D user interface. As a learning environment MMS provides support for authentication, authorisation and grouping of users. In addition it also supports the management of course modules, sequencing of resources and progressive revealing of learning materials. Not only are these aspects of MMS directly relevant to the requirements of LAVA excavation simulations, but they also assist in the management and maintenance of LAVA excavation simulations.	Alternative learning environments were explored; however, the lack of extensibility was an issue. MMS provides a clearly defined interface which facilitates the swift development of third party resources without requiring changes to the underlying structure of existing ones.
Use of Apple QuickTime Photo Based Panoramas.	The interactivity provided by Apple QuickTime Photo Based Panoramas is desirable. The ability for students to zoom in on regions and adjust camera angles also adds value by making it possible for students to obtain an understanding of a remote region from a variety of alternative perspectives.	The Apple QuickTime format was adopted owing to the availability of panoramas of the excavation site in this format. Whilst the format has been used in the excavation simulation of the Sparta basilica, alternative formats are equally well supported by the resources developed in this work.

Table 9 – Summary of Technological Decisions

- **Realism.**

- **Accessibility.**

When considering each of the three classes of 3D environment, it quickly became apparent that all provide support for each of the criterion, with MUVEs and first person shooter games providing far more developmental support in terms of pre-defined environments. Given the out of the box applicability of MUVEs and first person shooter games, the development of a customised 3D environment based on a 3D API was abandoned.

Unlike first person shooter games, MUVEs do not have any predefined objectives or goals. However, given the customisation supported by many first person shooter games, this does not automatically preclude their use. Indeed, first person shooter games have been used in a variety of applications, with the research and training communities quick to adopt them as the basis for specialised simulation platforms.

The virtualisation of the Urban Search and Rescue arena of the National Institute of Standards and Technology (NIST) Reference Test Facility for Autonomous Mobile Robots (Unreal Engine 2.0) [208] is a significant use of the first person shooter genre of computer games for serious use, as is the visualisation of the University of Cambridge's William Gates Building (Quake Engine) [209] and the development of a virtual architecture course using game engine technology at the University of Auckland, New Zealand (StringCVE based on the Torque Game engine [210]) [211, 212].

In addition, several tools have been developed which make it possible for external data to be fed through network sockets in to game engines [213], which are then able to represent the data using game robots (bots) which are simulated players running simple reactive programs, thus mirroring the ability for external stimulus to direct activity with MUVE environments. Given the success of the use of game engines in non-gaming fields and the development of tools to feed data from the real world into virtual reality simulations, it seems as though the functionality provided by game engines rightly justifies their use in more realistic simulation environments. However, one significant drawback featured in first person shooter games relates to their focus on user interactions. Within first person shooter games the environment in which the action occurs is predominantly part of the background material, with the main focus on user to user (or sometimes more accurately user to enemy!) interactions.

In contrast, MUVEs provide rich support for users to interact equally with other users, the environment and any objects within it. Unlike first person shooter games, the environment within MUVEs is entirely user generated and customisable. Thus it can be developed to support exactly the type of interactions required. This ability adds significant weight to using MUVEs within LAVA owing to the emphasis on environmental modelling and interaction that occurs within an excavation project.

In terms of accessing MUVEs and first person shooter games, both technologies make use of a variety of network protocols often generating both TCP [214, 215] and UDP [216] network traffic. First person shooter games are generally designed to require limited network traffic in order to ensure fast response times over a variety of network types and are generally reasonably resilient to changes in network traffic patterns [217]. MUVEs however are less efficient, partly due to the large numbers of communication mechanisms offered (voice, text, video, etc.), with many opening a large number of network connections [218-221]. This means that MUVEs have the propensity to consume significant amounts of bandwidth if not carefully managed. Indeed, many MUVEs have minimum bandwidth requirements which precludes their use over analogue and ISDN dial up connections [222]. When considering a university network or home broadband connection, the bandwidth requirements of both first person shooter games and MUVEs can normally be met without difficulty, with university networks in the UK generally being adequately provisioned to support simultaneous access by hundreds of users. However, given the remote hosting model adopted by most MUVEs, having an entire university online simultaneously would likely be problematic, hence the increasing interest in open source MUVE technologies which allow locally hosted MUVE environments within universities and commercial organisations.

Irrespective of the networking resources required by MUVEs, their applicability to LAVA excavation scenarios is compelling. Whilst solutions using both first person shooter games (using the Quake 2 game engine) and MUVEs (using the Second Life grid) have been explored, only the MUVE based approach has been adopted given the significant benefits it offers in terms of environmental modification and user interaction.

4.10 Implementation

In this section some of the interesting implementation issues surrounding this work are considered. Whilst there are many implementation issues which arose, for the sake of brevity three key aspects which are central to this work are considered: the simulation logic, the modelling of an excavation at the data layer and the integration of Second Life.

4.10.1 Simulation Logic

The simulation logic allows the success of the excavation to be scaled in relation to the suitability of resources applied to it. This approach also introduces a level of randomness to ensure that no two excavations are identical. This randomisation is used to reduce the predictability of each stage of an excavation, therefore encouraging engagement by reducing a learner's ability to pre-empt the exact outcome of their decisions.

In the current implementation, the simulation logic iterates through each day that the students have allocated to a particular task and performs the following calculation (see Figure 63 for a flowchart outlining this process):

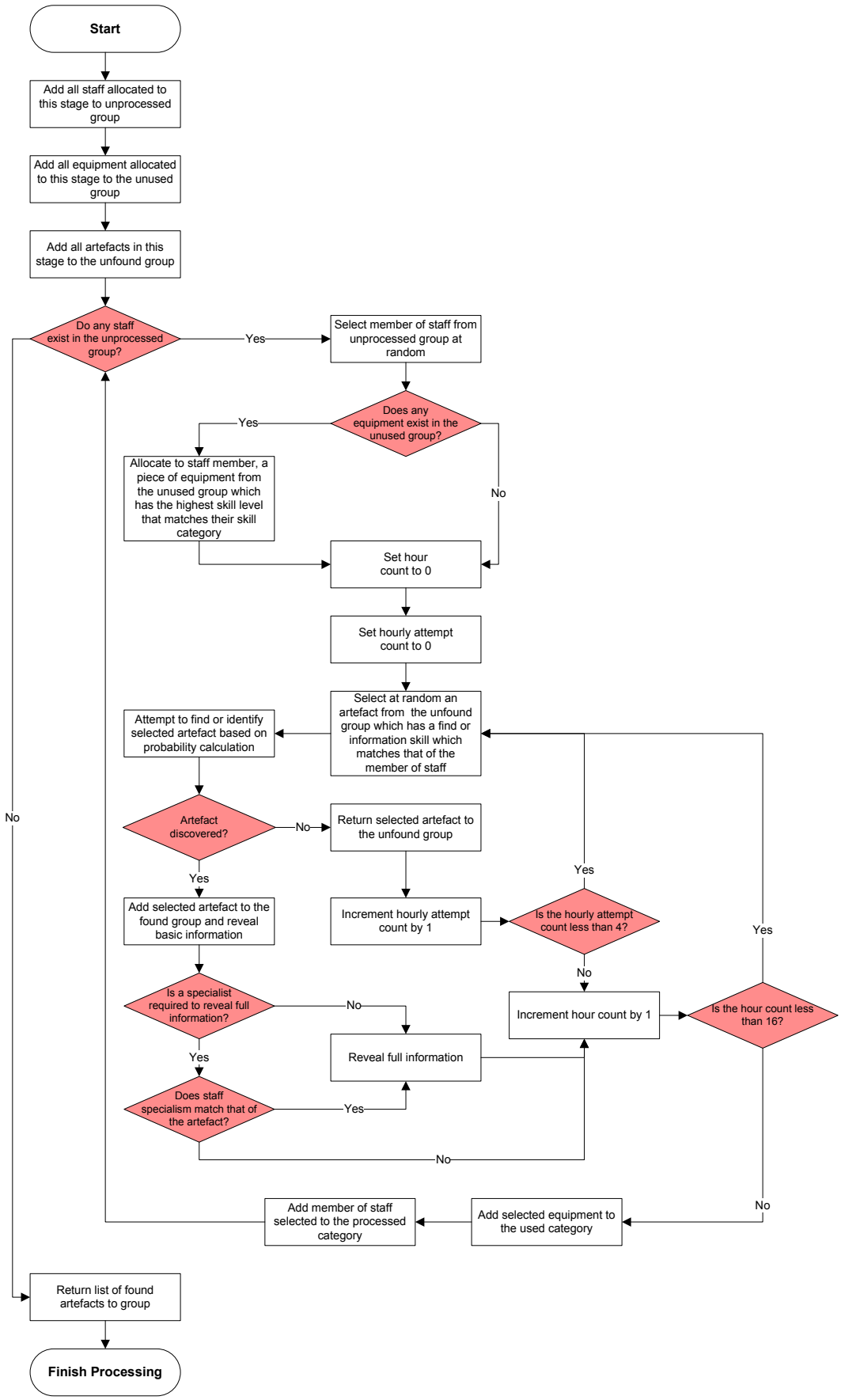

Figure 63 – Flowchart of LAVA Artefact Discovery Process

1. For each allocated person, select a piece of equipment with the highest skill level, matching their skill that is not already in use.

2. Iterate through the hours of each day.

3. During each hour, test up to 4 artefacts from the level that have not yet been found or identified, and whose find or information skill matches the person's skill.

The probability of someone finding or identifying an artefact is calculated by comparing the skill level of the person and any equipment they are using, with the difficulty level of the artefact. Each person and piece of equipment calculates their find probability using the following expression:

```
p = 0.4 + ((person/equipment skill - artefact difficulty) * 0.1)
```

In the case of a person having a piece of equipment, the two probabilities are combined using:

```
p = 1 - ((1 - person probability) * (1 - equipment probability))
```

This probability is then compared to a random number in the range 0 to 1. The artefact is found and identified if the probability is greater than this random number. The logic has been developed to afford a significant advantage to teams that provide an adequate equipment inventory to each task. When considering the following variables the effect is clearly pronounced:

```
Person Skill of 0.5 (out of a maximum of 1.0)
Equipment Skill of 0.5 (out of a maximum of 1.0)
Artefact Difficulty of 0.7 (out of a maximum of 1.0)
```

Without equipment, the probability of discovering an artefact is:

```
p = 0.4 + ((person/equipment skill - artefact difficulty) * 0.1)
p = 0.4 + ((0.5 – 0.7) * 0.1)
p = 0.4 + ((-0.2) * 0.1)
p = 0.4 + -0.02
p = 0.38 or 38%
```

When equipment is factored in, the probability returned is:

```
p = 1 - ((1 - person probability) * (1 - equipment probability))
p = 1 – ((1 – 0.38) * (1 – 0.38))
p = 1 – ((0.62) * (0.62))
p = 1 – 0.3844
p = 0.6156 or 61.56%
```

Thus, the addition of appropriate equipment has a significant effect on the probability of personnel discovering artefacts during the excavation process.

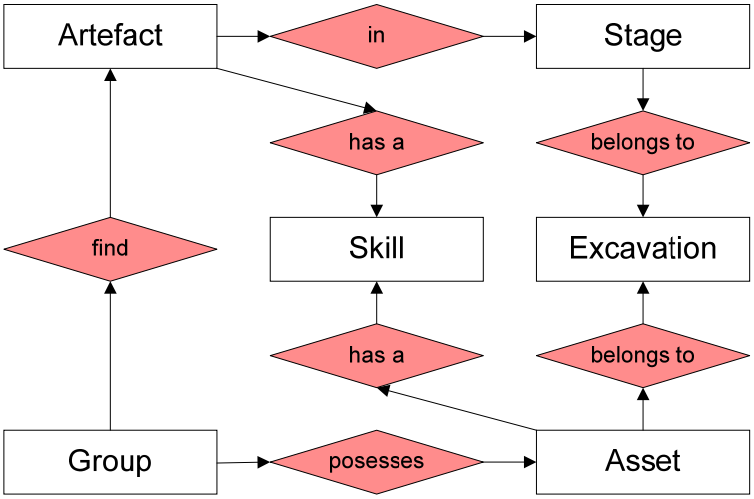

Figure 64 – LAVA Database Entity-Relationship Diagram

4.10.2 Data Layer

Contained in the excavation logic component, the data layer maintains a consistent simulation state for the duration of the excavation process. This enables multiple learners to simultaneously progress through a changing environment with learners who are part of the same group receiving the same view of the simulation at all times.

The simulation state consists of 6 key data types: artefact, asset, simulation, group, skill and stage. The relationship between these data types are shown in Figure 64.

- **Simulation** represents a single simulation instance, containing key data such as the length of the simulation and a reference to the logic to be used in calculating the success of each stage. Assets, groups, skills and stages are associated directly with a simulation instance, in a many to one mapping. The only objects not directly associated with a specific simulation are artefacts – these are related to stages in a many to one mapping, meaning, like all other objects, they only exist in a single simulation.

- **Artefacts** are items that students can find in an excavation. They have basic and detailed descriptions, a find skill, an information skill, and a difficulty level for each of those skills. The find skill is the skill required to locate the artefact; by default this is digging, but the mechanism provides scope for artefacts that are too fragile or difficult to be excavated by anyone without a specific skill. Finding an artefact automatically reveals its photograph and some basic details. The information skill is the skill required to get the detailed description of an artefact. If the artefact is found by someone with a matching (or higher) skill level then the detailed description is additionally provided.

- **Assets** are people or items that help with the excavation. Three core classes of asset are used: accommodation, equipment and people. Accommodation is not directly used to help with the

excavation, but is required in order for the excavation to proceed (this not only includes tents, but also items such as pots and pans, food, etc.). Equipment objects help directly with the excavation and require a person with the relevant skill to use them (for example, shovels, trowels, dental equipment). People are the workers excavating the site. Equipment and people both have a single skill and associated skill level, although there are plans for people to have multiple skills in later revisions.

- **Groups** are the objects to which students are associated, and are used to keep track of the number of days spent on the excavation so far, original and remaining budget, assets bought and hired, and artefacts found.

- **Skills** are a name string, and are used to store the authoritative list of skills that equipment and people involved in the excavation can have.

- **Stages** store the maps to be shown to students as they progress through the excavation, as well as an explanation of what tasks the next part of the excavation involves (for example, clearing topsoil). These also have a list of skills that are required in order for the task to be completed, for example a survey skill is required for a group to progress past the first stage.

4.10.3 Second Life Development

There are certain limitations on the realism that is possible in 3D environments in general and in Second Life in particular. The resolution and graphical realism achievable is not of the quality obtainable in many 2D settings. This is offset by the gains in user perspective and spatial awareness. Within these constraints, in constructing the basilica it was important for it to be a realistic representation, in structure, appearance and scale. It was also important that it be accessible so that students could view it from multiple internal and external locations.

The design of the basilica in Second Life brings together information from a number of sources in an attempt to develop an historically accurate reconstruction.

1. **Archaeological surveys** – for example floor plans which define the location of walls and the boundaries of the basilica.

2. The iterative application of **domain expert knowledge**.

3. **Photographs** of other buildings from the same time period.

Below three examples of how the design evolved are discussed. Of particular interest are: issues of scale, developing reconstructions based on partial information, and the overall modelling process.

Scale within 3D Environments

Scale was a significant challenge to address. Whilst the site plans provided the relative scale of areas of the basilica, they did not provide a mapping to real world measurements. This was obtained by reviewing photographs of the site which contained measuring markers. From this baseline it was then possible to develop an accurate scale model of the basilica.

The question then arose as to whether it was desirable to build the basilica to a fixed scale, or whether it would be better to build the basilica to a scale which would mimic the feel of the building in relation to the size of 6th Century Byzantine people. In terms of developing an accurate representation of the basilica in Second Life, both approaches required an identical approach, with an iterative process being used to provide a mapping between the real and virtual world measurements.

In developing the mapping, the height of the doorways was used as a reference point. By comparing the height of a doorway with the height of an average size person it was possible to obtain a scaling factor which could be used to map real world measurements into suitable Second Life sizes.

Prior to developing the model in Second Life, a similar exercise was undertaken using a number of Quake 2 game maps. During this process, a complete floor plan of the basilica was developed in order to evaluate whether the approach generated a reasonable real world to virtual world scaling factor. As described in Chapter 3 the process was informed by existing work in the area and solicited input from domain experts and students. This investigation suggested that the relative scale was perceived as more important than absolute scale.

Reconstruction Issues

When developing the model of the basilica, certain structural issues were challenging to address. In particular the design of the roof was difficult to ascertain owing to the fact that very little archaeological data was uncovered during the excavation of the site. This is not unexpected, given the way in which the roof would have been exposed to the elements to a far greater extent than the walls and ground works of the church. In addition, the reported explosive destruction of the basilica [16] may have hastened the destruction of the roof, leaving little remaining evidence from which to deduce its original structure.

Given the lack of archaeological evidence available on the site, piecing together an accurate reconstruction required some detective work. Evidence was brought together from a variety of sources to enable the construction of mock-ups which were then critically evaluated by domain experts.

When considering the example of the location and appearance of domes on the basilica roof, the layout of the walls in a square formation could suggest a location of a dome. Locating the basilica within its historical context meant that photographs of surviving buildings of similar providence could be used.

In addition, knowledge about the function and culture of the Byzantine Empire could help in these deductions.

The model went through a number of phases in its development, from paper and pencil drawings to 3D models in 3D Studio Max and, finally, Second Life. During each phase, refinements were made. It was particularly noticeable that the 3D first person perspective offered by Second Life allowed a number of adjustments to be identified and made whilst the model was being reviewed by domain experts, the location of the domes being one example. Other examples include the size and shape of statues, the location of windows, the location and shape of the altar and the interior decoration of the building.

The Modelling Process

From the desire for a historically accurate reconstruction, a number of choices about how to use the technology offered by Second Life flowed. For example, there are two ways to build in Second Life: using multiple basic primitive shapes which are grouped together into complex objects, or applying texturing to create sculpted primitives that look like complex objects.

Both approaches give a similar visual appearance when viewed from a distance; however, the sculpted primitives approach does not provide the functionality associated with the complex object it represents: for example, a window or hole in the wall – with a sculpted primitive, the window cannot be opened, or the hole in the wall traversed. This is because, in reality, the window and hole are nothing more than paintings on a solid canvass, with Second Life playing visual tricks to give the appearance of the object being represented. In addition, when viewed close up sculpted primitives tend to appear flat. This reduces their realism as the full visual effect provided by a sculpted primitive object is only visible from a relatively narrow viewing angle.

In contrast, combining multiple basic primitive shapes into a single complex object is able to give both the correct appearance and the functionality associated with the object being represented. When considering the previous examples, the window could be built to support being opened and closed and the hole in the wall could be introduced to allow objects to pass through it. This is because visual tricks are not used to give a flat shape the appearance of a more complex object. In addition, as complex objects comprise several primitive shapes, they can be viewed from any angle and will continue to provide realistic visual representations no matter how closely they are viewed.

A policy of using multiple simple primitive shapes was adopted. Not only does this approach provide an accurate close up representation of the church, but it also makes it possible for students to explore them from a variety of different angles. In addition, the use of simple primitive shapes also makes it possible for the basilica to be constructed in much the same way as it would have been when originally built. The down side, however, is that the approach requires the use of far more primitive shapes than alternative techniques, which in turn means that construction process is more labour intensive and leads to a more complicated building overall.

The Visitor Centre – Linking Second Life with the Excavation Process

The visitor centre provides space for students to construct exhibitions based on their excavation work within the virtual simulator. Providing this facility posed a number of technical challenges which needed to be addressed:

- Authentication and authorisation (Individual and group based).
- Importing digital data relating to the material culture discovered during the excavation process into Second Life.
- Provision of metadata describing these digital resources to enable them to be presented in an accurate context.

When students come to create their exhibition they invoke a script which identifies them and authorises them to access their excavation findings. All the state, objects and information about the excavation that can be used by students is preloaded into Second Life. However, in order to gain access to these resources, students need to make progress in the excavation simulator. When a student visits the visitor centre, their identity and authorisation are checked and a script is invoked which takes a copy of all the objects that they have discovered and places them into a finds box to which the students have access. Students can then add the items to their inventory as required. As the excavation objects already exist within Second Life, this process only has to retrieve excavation metadata from outwith the Second Life environment. This metadata is then used by the scripts to copy the required excavation objects for the students to access from their finds box. In order to achieve this it was necessary to:

- Make use of Second Life's internal scripting language Linden Scripting Language.
- Define and implement an MMS interface to support the exportation of data from resources.
- Make use of the Second Life interfaces which allow importation and exportation of data.

Importing and Exporting Data into and out of Second Life

To enable communication between Second Life and external services HTTP [223, 224] requests are used. Supported by Linden Scripting Language, HTTP requests are designed to transfer small amounts of data. This limitation means that intelligent scripts needed to be developed to transfer data which is larger than that normally permitted by the size limits.

In terms of exporting data from Second Life, this process is reasonably straightforward, with scripts composing multiple requests which encapsulate the data to be transmitted. Each request is constructed

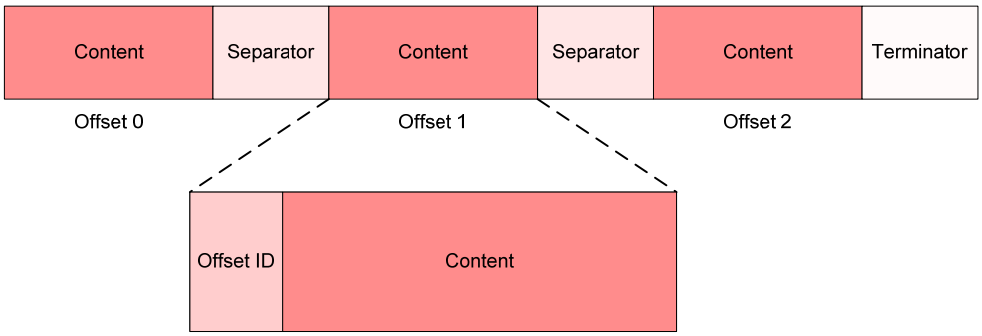

Figure 65 – Content Stream used for Communication between MMS and Second Life

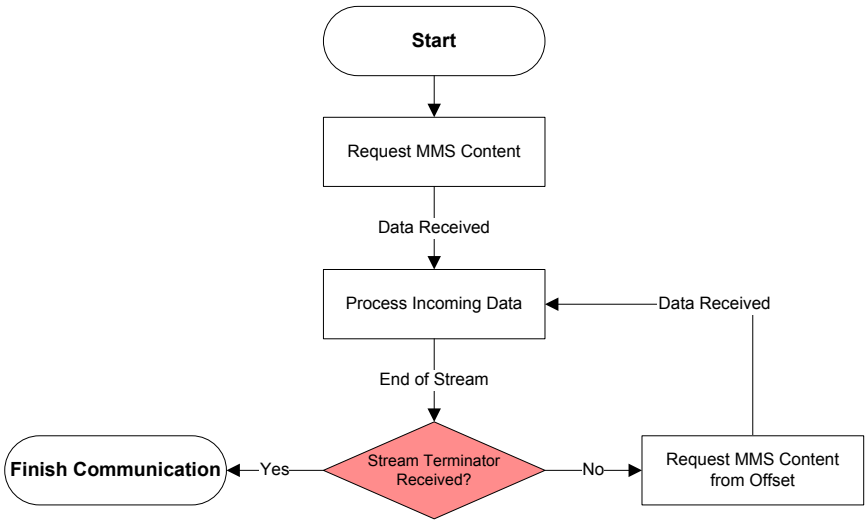

Figure 66 – MMS and Second Life Communication Process

to fall within the Linden Scripting Language size limits, with larger data being split over several requests. Each request is sent to the receiving service sequentially as an HTTP POST request, with the receiving service providing confirmation of receipt.

When importing data, which could be any length in size, it is not possible for Second Life to circumvent the limitations of Linden Scripting Language alone. As multiple requests may need to be made to receive all data within a stream, Second Life and the sending service cooperate, with the sending service accepting as an argument an offset which allows Second Life to request data from a specific point in the stream. As shown in Figure 65 a stream is broken down into a series of chunks, with a pre-defined terminator. If, after receiving a response, Second Life fails to detect the terminator, a second request is made with an offset argument being passed to the sending service. The response will then include data from this offset until the end of the stream. If no terminator is detected, Second Life will make a further request. This process will continue until such time as the terminator is detected by the Second Life client. A flowchart depicting the process is shown in Figure 66

These two approaches, when taken together, provide support for two way communication between Second Life and external services. However as Second Life clients cannot listen for connections, the communication is event based with the Second Life client responsible for initiating the process as required.

4.11 Chapter Summary

This chapter has presented and analysed a substantial case study which demonstrates how learning environments can be enhanced through the integration of gaming methods and technologies in order to facilitate support for exploratory fieldwork. Furthermore this chapter shows that this integration is technically feasible and has significant educational benefit. The objectives addressed by the LAVA excavation simulator are highlighted, with some of the challenges often associated with the teaching of archaeology in a classroom environment discussed.

In contrast to other work in this domain, this work started with a set of pedagogical goals which the framework was designed to address. A significant investigation into the domain to be used for the case study, namely archaeology, was then undertaken. This showed that there is a substantial and real gap between the theoretical and practical aspects of the subject, something that LAVA bridges. The specific excavation used in the case study was analysed and shown to be of significant educational and research interest. Through an overview of the history of the basilica and the excavation work which has been undertaken, the existing archaeological questions that remain are identified, thereby placing the site in a wider academic context.

Having set the framework and provided the background and motivation for the case study, the rest of the chapter goes on to present the design adopted and the solutions developed to meet the educational objectives set out in this and other chapters within the dissertation.

Through the introduction of the LAVA case study, a detailed outline of the excavation simulator has been provided from a student perspective, outlining the activities that are undertaken through the interfaces provided. The user's perspective is a key part of the design. It is shown that gaming methods, in particular the use of goals, levels and chance all regulate the progress users make through the system and develop engagement. The progressive revealing of artefacts as an excavation progresses is consistent with the goal of supporting exploratory learning. What is more, the linking of the excavation simulator with a reconstruction of the basilica and visitor centre brings together the functionality of 2D and 3D distributed systems so that the educational experience is maximised.

The discussion in this chapter has considered some of the key components of the framework as well as their functionality within the system. A service based approach is advocated by this work. This aids communication between learners and lecturers and provides a structure through which anytime access, self-paced learning and groupwork can be supported. The excavation logic provides the central module which mediates communication between users, institutional learning environments, the excavation learning environment, and Second Life. Although the case study is specific to an individual excavation, it has been shown that the structure used is generic within the domain of exploratory learning about environments which may be inaccessible for a variety of temporal, financial or other reasons, for example: history, geography, architecture and space travel.

The design decisions highlighted in section 4.9 demonstrate that significant and systematic investigatory work has gone into the design of the system. In particular the establishment of a functional division of labour between 2D and 3D user interfaces significantly influences the overall design. This section provides insight into the implementation process that has been adopted, as well emphasizing the student focus which has been adopted with respect to the implementation of the simulator.

Finally the chapter concludes by considering some of the key implementation activities which have been undertaken in order to provide a fully functional excavation simulation operating over several discrete systems.

Chapter 5 – Evaluation

5.1 Introduction

In this chapter the archaeology case study instantiated by LAVA is evaluated from both a systems and user perspective. The main contributions of this work focus on extending learning environments to provide additional support for exploratory learning scenarios. As Chapter 4 describes, a system which supports these types of learning interactions has been developed and deployed for student use in a real classroom environment.

This deployment process has successfully delivered a usable system which is able to validate a number of the contributions of this work by confirming the feasibility of the approaches and contributions described in Chapter 3 and Chapter 4 of this work. In addition, the deployment of LAVA to students provides an opportunity to evaluate the system under real world usage. Not only does this confirm the validity of the system by confirming LAVA's fitness for purpose within a classroom environment, but it also allows network traffic measurements to be made in order to characterise the nature of the communication exchanges generated when users interact with LAVA. This characterisation serves two purposes: firstly, making it possible to gain an understanding of the networking issues which will need to be considered when deploying LAVA on a large scale, and secondly providing an opportunity to examine the way in which client-server communication is managed within the system. By understanding the types of communication taking place and analysing the traffic patterns generated throughout each evaluation session it is also possible to develop an assessment of the approximate bandwidth required by each connecting client. Not only does this enable optimal network requirements to be determined: for example, levels of throughput, latency, loss, etc., but it also makes it possible to assess the likely quality of service achievable by different categories of networks: for example, Ethernet, Wi-Fi, 3G, analogue dial up, etc.

Before detailing the evaluation process adopted, this chapter begins by outlining the qualitative and quantitative research methods applied in the evaluation process, with their relevance to the evaluation of LAVA identified. Following this, the methodology informing the evaluation of the system is introduced. Dealing with human and systems issues separately, the evaluation process is separated into two sections, with the first providing an evaluation of the user experience provided by LAVA, whilst the second considers the performance offered by the system, and thereby its suitability for deployment within different educational contexts.

In order to identify strengths and weaknesses in the approach adopted by LAVA, simulations based on an archaeology case study were used to obtain real world usage data over several testing and evaluation sessions. Focusing on the level of usability and educational value provided by LAVA, the user evaluation process considers several human computing factors: for example, interface issues, usability,

reliability etc., whilst also assessing the level of engagement achieved between the system and its target audience – undergraduate students reading archaeology at university level.

When evaluating the performance offered by the system, several deployment scenarios were considered. A variety of secondary data sources were used to obtain system performance data, with direct stress testing undertaken in a lab environment and targeted user focussed system testing carried out over wide area network links being used to contribute primary data to the evaluation process. During this process a variety of system factors were considered including: reliability, request processing time, connection throughput and response delays.

Based on evaluation data provided by domain experts and students who participated in group and individual evaluation processes, the first part of the results section focuses on user evaluation, summarising the main themes of the findings with respect to the degree to which the implemented LAVA simulation meets the aims and objectives identified in Chapter 4. The second part considers LAVA from a systems perspective. Focussing on the performance offered by the initial system implementation, the system performance evaluation is used to determine the suitability of the system for production use, with its ability to service multiple simultaneous accesses from a variety of local and remote sites being considered.

After reviewing the results of the evaluation processes, the key findings are presented in summarised form, with their implications with respect to the use of LAVA in an educational context being considered. The chapter concludes by summarising the main issues raised by the evaluation process and highlighting the ways in which they impact on the deployment of LAVA simulations.

5.2 Research Methods

To provide a balanced evaluation which takes account of both system performance and user preferences and impressions, a double headed approach is adopted, with quantitative data generally used to evaluate important aspects of system performance whilst qualitative data focuses on issues relating to user preferences and the levels of user engagement offered by the system. However, this division is not strictly enforced. When it is cogent to do so, qualitative and quantitative data are combined in order to develop a broader understanding of the merits of LAVA; an example of this would be the use of expert opinion, in which qualitative expert opinion data and quantitative data from other sources is combined to develop a more detailed understanding of the properties of the system by considering contextual information associated with its deployment. Within the evaluation process expert opinion plays an important role, with domain experts from different disciplines providing input; from the field of archaeology domain experts assess the quality and presentation of subject matter provided to students by LAVA, whilst experts from the field of computer science review and examine the architecture of LAVA, identifying features which can enable generalisation, thereby supporting the application of LAVA to alternative educational scenarios.

Before continuing to describe the methodology adopted during the evaluation of LAVA described in this chapter, we examine the main differences between qualitative and quantitative research methods and subsequently the role that each has with respect to the LAVA evaluation process.

5.2.1 Qualitative Research Methods

Qualitative research methods involve the collection, analysis and interpretation of data that are not easily reduced to numbers. The aim of qualitative research is to construct a complete, detailed description of a subject based on a collection of individual interpretations. There is a strong case to suggest that all research is based on qualitative groundings [225], as qualitative methods are often used during the early stages of research in order to shape and define the subject domain [226], with qualitative methods providing flexibility in their approach, owing to the way in which their application can change as the evaluation process unfolds [227].

Often considered to be highly subjective, individual interpretations can feature prominently in qualitative research methods. Routinely used in social sciences and the applied fields that derive from them, the benefits of qualitative research methods are well established, with their importance and validity widely acknowledged [225, 226, 228]. Often taking the form of words, pictures or objects which relate to the social world and the concepts and behaviours of people within it [228], qualitative data can be time consuming to analyse, with the resultant findings difficult to generalise and apply to alternative scenarios [227]. Given these attributes it is important that the methods implemented during the analysis of qualitative data take account of individuals' interpretations and the contexts within which qualitative data was obtained.

5.2.2 Quantitative Research Methods

In contrast, quantitative research methods deal with numbers and anything that is measurable. Counting and recording values are common forms of quantitative methods that are frequently implemented in systems evaluation work [229]. The aim of quantitative research is to classify features, count them and construct statistical models in an attempt to identify trends and explain observed phenomenon.

Quantitative methods are designed to be precise and specific [227, 229]. Unlike qualitative data there is little room for interpretation, with quantitative data obtained using a variety of direct and indirect methods, the result of which is a number, or a series of numbers to which meaning can be ascribed. Comparisons between different subsets of qualitative data can be used to identify trends and patterns of behaviour which change in the features being measured over time. In order to enable comparison of datasets it is important that all aspects of a quantitative study are carefully designed ahead of time; as quantitative data contains little or no contextual information, changing collection parameters within an experiment makes comparison between datasets difficult to reliably undertake.

The numerical results of quantitative research methods are usually presented in tables and graphs and analysed for further meaning using a variety of statistical methods [230]. When dealing with

quantitative methods it is often possible to automate the processing of data collected, with the results being particularly useful in determining the validity of specific hypotheses. One of the side effects of this type of processing is that it is possible to lose some contextual detail associated with the data, so, as with qualitative research methods, one needs to be mindful of the limitations of quantitative methods and ensure robust and clearly defined techniques are used to collate and analyse data [227]. In addition, in order to ensure confidence in any conclusions drawn from the processing of quantitative data, it is important that any statistical methods employed are well matched to the properties of the data being analysed [230].

5.2.3 Qualitative versus Quantitative Research Methods

In the physical and biological sciences, the use of both quantitative and qualitative methods in an evaluation process is uncontroversial, with each method being used where appropriate [227, 231]. In the social sciences, particularly in sociology, social anthropology and psychology, this use of mixed methods has become a contentious issue, with particular schools of thought within each discipline favouring the adoption of one method over the other. Advocates of quantitative methods argue that only by using such methods can the social sciences become truly scientific; advocates of qualitative methods argue that quantitative methods tend to obscure the reality of the social phenomena under study because they underestimate or neglect the non-measurable factors, which may be the most important factors within the experimental process [232, 233].

Within a systems evaluation process, both quantitative and qualitative results are important [234]. If only one approach is adopted, there is a risk that the evaluation process will develop into a pseudo-scientific approach which fails to provide a meaningful outcome. Such an evaluation process is clearly not going to help to develop a measure of the fitness for purpose of a given system. Whilst it is true that quantitative results are excellent indicators of system performance, they are less useful when attempting to evaluate the interactions between the system under evaluation and those using it, hence the need for meaningful qualitative data to provide contextual information regarding the nature of the user interactions being undertaken. However, qualitative data in isolation can often be discounted as largely anecdotal in nature. In order to avoid such a situation it is important that any findings from qualitative data are not overstated, with the collection of such data undertaken in a systematic and rigorous manner [227].

In this work we argue that there is, within a balanced evaluation framework that analyses system performance and user engagement, a place for both quantitative and qualitative evaluation techniques. Quantitative evaluation can work well when reviewing system metrics relating to performance: for example, average response times, processing delays, etc. However one needs to be careful not to introduce meaningless metrics into a system – sometimes it is simply not possible to define a sensible and meaningful metric for a specific measurement. For example, when considering user engagement, it does not make sense to define an engagement metric which measures the amount of time a user spends with a certain page on display. Whilst this metric may initially appear to provide data relating to user

engagement, in reality it merely confirms the length of time that a given page was displayed on screen – unless extended to consider other factors (for example, activity within the page, etc.), it provides little or no evidence of the level of user engagement achieved. Instead of relying solely on a questionable quantitative metric, qualitative data should be introduced into the evaluation process, thereby allowing user responses and quantitative data to be used to build a comprehensive evaluation of the aspects of a system most related to user engagement. For example, the quantitative data collected with respect to the amount of time a page is on the screen can be combined with qualitative data obtained through questionnaires and interviewing techniques to determine the level of user engagement achieved.

The overriding goal of this chapter is to provide a systematic evaluation of LAVA. To this end, the evaluation process has been designed to use research methods that provide reliable results which can be used as the basis for meaningful conclusions. Given both the social and systems related aspects of LAVA, the sensible tendency seems to be to use a mixed approach comprising both qualitative and quantitative methods as appropriate. In this way, quantitative methods can be used to focus on specific system behaviours within a global qualitative timeframe which considers contextual information surrounding the use of the system. In addition, it may prove fruitful for qualitative methods to be used to ascribe meaning to the numbers produced by quantitative methods. Using quantitative methods in this way it therefore becomes possible to give precise and testable expressions to qualitative ideas and concepts [227, 229].

Throughout the evaluation work undertaken in this chapter, the aim is to use the most appropriate research methods for the task in hand, with qualitative and quantitative research methods both afforded equal weighting within the evaluation process. Given this, the decision governing the adoption of qualitative or quantitative approaches to specific areas of the evaluation process is made on the basis of whether the approach considered is likely to provide useful insight into the system. Due to this overriding approach, there is some degree of overlap in the evaluation process, with qualitative approaches being used to clarify or set the research question, whilst quantitative approaches are used to further refine the process and to provide descriptive information and understanding of the context within which LAVA is deployed. This approach follows the evaluation patterns described in detail in [231] and provides the opportunity to systematically evaluate all aspects of the system.

5.3 Methodology

As an instantiation of a framework designed to support the integration of gaming methods and technologies with learning environments, the evaluation of LAVA has been designed to consider two aspects of the implemented system: the generic functionality that the framework provides to learners, and the properties and performance metrics of the specific implementation of the framework being evaluated. In this way the evaluation process separates attributes which are applicable to the overall approach being adopted by the framework from those caused by LAVA specific implementation details.

Within LAVA, the 2D components of the system that are responsible for delivering the majority of the user experience are developed on top of MMS, so the processing overhead and system resources required to support simultaneous student access are well understood [235]. In contrast, the requirements of the 3D components within the system are less clearly defined owing to their innovative nature and shorter period of development. Due to this, the evaluation process applies a different approach to each section of the system, with hands on user evaluation featuring more heavily in the evaluation of the 2D aspects of the system, whilst systems performance evaluation and stress testing forms the bulk of the evaluation of the 3D aspects of the system.

Given the existence of performance evaluation work which has been carried out on MMS [235] and a similar project, FINESS [236, 237], it is evident that the 2D aspects of LAVA will be able to support the numbers of simultaneous accesses required to support a class of students simultaneously accessing their excavation scenarios. Due to this, an emphasis is placed on evaluating users' perceptions of the value of such interactions, with the usability, educational value and reliability of the 2D interfaces being important aspects of the system which need to be evaluated.

When considering the 3D aspects of the system, the performance issues associated with multiple students accessing the system are less well understood. As a technology, Second Life is being aggressively developed by Linden Labs. This fast paced development environment causes a degree of uncertainty, with parts of the system routinely being upgraded to improve the overall MUVE experience. Given this, it is important that the evaluation process is able to measure how Second Life copes with multiple simultaneous accesses by a class of students. With this in mind, a systems based evaluation of the 3D aspects of LAVA is undertaken. Not only does this allow the feasibility of deployment in a classroom environment to be assessed, but it also allows the scalability of the system to be evaluated, with hardware requirements and network traffic measurements providing detailed indicators of system performance under different loading factors.

5.3.1 Aspects and Metrics

During the evaluation process there were three aspects of the system which were focused upon: system usability, educational value and system performance. Of the three aspects, the assessment of educational value is applicable to any implementation of LAVA, with the evaluation of system usability and system performance being specific to the current implementation of the system.

Given the user centric nature of LAVA, the evaluation process placed a strong emphasis on user feedback, with the corresponding data obtained acting as the basis of the analysis. To support this feedback, qualitative data was used to provide a general context within which to analyse the feedback, with quantitative metrics of specific properties of the system adding detail to the evaluation process. For each of the three aspects, this general approach was adopted, with some minor variations being applied in order to present as much detail as possible, the details of which are outlined below:

- **Educational Value (Applicable to Framework):** By educational value we refer both to the value that participants prescribe to their use of the system and also to the value that domain experts prescribe to a student's use of the system. When dealing with perceived educational value, user responses were captured using a Likert scale [238, 239] multiple choice questionnaire designed to be similar to the Digital Equipment Corporation System Usability Scale (SUS) [240, 241]. These responses provided the quantitative data for this aspect of the evaluation process, with expert opinion being used to provide qualitative contextual data with which to frame the analysis.

- **System Usability (Implementation Specific):** With respect to system usability, the evaluation process again makes use of user feedback, with the SUS providing a quantitative measure of LAVA's usability. Although comparable with other systems, the SUS score alone fails to gauge usability. To address this issue, qualitative data was obtained during evaluation sessions using techniques such as group observation, structured interviews and discourse analysis [225, 226, 228, 242, 243]. This double-headed approach provides context to the SUS score obtained through user feedback and helps to identify specific areas of the system which impact on usability, thereby enabling future development work to focus on improving specific components within the system.

- **System Performance (Implementation Specific):** In evaluating the performance of the implemented system the main objective was to validate that it was suitable for concurrent use within a classroom or lab environment. To this end a small amount of instrumentation was added to the customised client browser used during the evaluation process in order to determine how students interacted with the system. Specifically recording response times reported by the client browser it was possible to gain an indication as to how long users were required to wait for system responses. Log file analysis was used to identify usage occurring outwith scheduled evaluation sessions, with the properties of each request being analysed to determine how users were interacting with the system. In addition to this quantitative data, qualitative data was obtained through interviews and group observation during evaluation sessions. This provided a context within which to evaluate the quantitative metrics obtained.

5.3.2 Evaluation Techniques

Given their unbiased position, evaluation participants are uniquely placed to provide valuable feedback which can be used to evaluate the effectiveness of LAVA. As such their responses to interactions with the system formed a large part of the evaluation process. With such a strong focus on obtaining information about participants' interactions with LAVA it was important to minimise any reactivity, experimenter or observer effects [244-246] introduced during the evaluation sessions which could adversely impact the internal validity of the evaluation process. The first approach adopted to achieve

this was the application of several evaluation techniques at each stage of the process, as described below

- **Questionnaires:** A summary of the properties offered by questionnaires is provided in Appendix G.1. With respect to the user evaluation process, anonymised questionnaires were used at the start of each session in order to obtain a standardised set of demographic data for the purpose of characterising the participant population. Within each session, questionnaires were used to allow participants to consider their responses without interference or feedback from evaluators. Comprising a mixture of multiple choice and open ended unstructured questions, questionnaires were used to solicit participant responses relating to specific components within the system. This approach allowed multiple datasets to be obtained and analysed in a uniform way, thereby providing detailed evaluation of several areas of the system. It was also an ideal way of soliciting and exploring user perceptions with regards to the usability of the software and the perceived realism of the archaeological excavation scenarios presented. Owing to the difficulty associated with analysing the responses of open ended questions [247], their use was minimised within questionnaires, with alternative techniques being used to solicit more detailed participant responses.

- **Structured Interviews** [248] were used to explore, in more detail, specific areas of LAVA that had been highlighted in group evaluation sessions or responses to participant questionnaires. Given the properties of the interviewing process, as summarised in Appendix G.2, the emphasis that structured interviews place on active participant involvement was used as an opportunity to solicit participant opinions regarding the user experience provided by LAVA. Participants were asked open ended questions, with the evaluator following up on initial responses in order to gain detailed insight into user behaviour whilst using the system. On some occasions, participants were interviewed whilst actively engaging with a LAVA simulation. The interviewing process helped to provide an overview of the system and highlighted areas that participants perceived to be performing well and areas that were perceived to be lacking. This feedback was used to determine future priorities during the development process, as well as being fed back into the evaluation process to ensure problem areas were re-examined following updates and enhancements applied during the development cycle.

- **Individual and Group Observation** techniques, as summarised in Appendix G.3, were used to analyse the way in which particular tasks within LAVA were approached by users. By following participants' progress through excavation scenarios, valuable usage data was obtained by the evaluation process. As with structured interviews, this data was able to highlight areas of LAVA that were performing well and areas that required further development work. When undertaking individual observations, talk aloud protocols [249] [250] were used to encourage participants to verbalise their thought processes whilst

interacting with LAVA. Conversation [251] and discourse analysis [242, 243] were both used in group settings, again to analyse how participants' approached each excavation scenario. Unlike talk aloud protocols, discourse analysis does not require participants to actively verbalise their actions as they work, but instead relies on analysing the natural communication which occurs when cooperating within group environments. In this way discourse analysis is less intrusive and less likely to introduce experimenter or Pygmalion effects [252, 253]. However, as participants are not actively verbalising their actions, analysing data obtained through discourse analysis is more time consuming owing to the need to infer meaning from user behaviour, something which would otherwise have been made explicit by participants if they were using talk aloud protocols.

- Closely linked to individual and group observation, **Co-Participation** techniques [254], the properties of which are summarised in Appendix G.4, were used in group evaluation sessions to encourage participants to verbalise to fellow group members, in a natural way, their interactions with LAVA. By encouraging users to verbally dissect their rationale and approach, co-participation provides evaluation data outlining the ways in which group members organise their interactions with the system. Through verbalising their thought processes, users are able to reveal to the evaluation process the aspects of LAVA which support and encourage their engagement with the system as well as the aspects which cause confusion, frustration or difficulty when engaging with the excavation process.

- **Written records** were also maintained for each evaluation session by domain experts, tutors delivering the archaeology content in the session, LAVA developers and evaluators. This approach was adopted in order to provide a review of each evaluation session from several perspectives, allowing each to be analysed and considered in the evaluation of the overall suitability of the framework. The soliciting of several different perspectives also added clarity to the evaluation process, with feedback from domain experts and course tutors helping to shape the timetables followed in future evaluation sessions.

In an effort to encourage frank and truthful responses, in all evaluation activities a separation between the evaluator and the LAVA software was emphasised to participants. It was also made clear to participants that their actions were not being evaluated, but that it was LAVA and the way the software handled participant interactions that was of interest in the evaluation process. This separation was adopted to minimise the possibility of the Pygmalion effect [252] affecting participant behaviour.

To further reduce the risk of observer effects, standardised documentation was used throughout each evaluation session. In this way experimenter bias [255] could be more carefully managed, with all session instructions being carefully drafted to ensure an unbiased approach throughout each of the sessions. Not only did this approach ensure that participants were not given any indicators as to how

they should respond during the evaluation process, but it also facilitated comparisons between evaluation sessions owing to the standardised organisation and timing allocated to each activity.

When considering structured interviewing, experimenter effects were more difficult to manage owing to the interactive nature of the interviewing process. In an effort to minimise the possibility of introducing bias, interviewees were encouraged to be the most active participant within the session, with interviewers acting as a facilitator, introducing topics and prompting for further detail from the interviewee when appropriate. In recognition of the fact that the interview process was more susceptible to experimenter effects than other aspects of the evaluation process, interview data was used primarily to corroborate and add context to data obtained through other channels, thereby reducing the possible impact of experimenter bias on the validity of the evaluation process.

5.3.3 User Evaluation

For learning materials to provide any positive educational benefit a level of engagement needs to be achieved with learners, as the discussion in Chapter 2 shows. Given the key role that LAVA plays in the delivery of learning materials, it is important that users feel willing and able to interact with the system, as these interactions are essential for learning to occur. Given this, the user evaluation process considers the educational value and usability of LAVA by soliciting user opinion and observing user behaviour whilst the system is in use.

When the subjective nature of the user data collected is coupled with the lack of easily defined metrics against which to evaluate the system, accurately measuring and recording user perceptions becomes increasingly important. As opinions at the extremes of the spectrum can easily skew results and distort findings, it is important that any subjective data is analysed in context, with evaluator bias which can affect the data collection process minimised wherever possible.

As discussed in section 5.3.2, in order to apply balance to the process of evaluating user perceptions, several investigative approaches are adopted, with some obvious to evaluation participants owing to their involvement (for example structured interviews and questionnaires) and some less intrusive, with participants' behaviour monitored from a distance: for example, group observation, and discourse analysis. As previously discussed, the variety of data collection methods makes it possible to obtain a range of qualitative data points against which to evaluate LAVA, with each of the different approaches focusing on different aspects of the system.

User evaluation sessions were undertaken over the course of three academic years. During the first and second year, group evaluation sessions were undertaken in order to obtain a wide spread of data. In the third year, individual evaluation sessions were used to focus on specific aspects of LAVA and provide additional targeted user responses. The structure of each type of session was standardised to provide a similar evaluation environment over consecutive academic years.

Stage	Timing	Activity
1	5 minutes	Check that all participants can log in to the PC Classroom system and access the MMS resources required. Demonstrators available to diagnose and resolve any issues that arise.
2	10 minutes	Gather participant demographic information through the electronic questionnaire system.
3	5 minutes	Participants shown a walk through of the system by a demonstrator who remains available throughout the evaluation session to answer questions and troubleshoot system problems.
4	75 minutes	Participants separated into groups of 2 (or possibly 3 where groups of 2 are not possible). Each group is provided with a worksheet which outlines a series of objectives that each group should aim to achieve within the session. During the session, a team of two evaluators monitor user interaction with the system and mingle with the groups to obtain more detailed user feedback.
5	10 minutes	The participants are issued with a set of guidelines and asked to review how well they feel the system conforms to these guidelines. This feedback is gathered electronically, with the questionnaire asking participants to categorise their responses using a 5 point Likert scale. Participants are also given the opportunity to provide more in depth feedback in an open question section at the end of the questionnaire.
6	5 minutes	A post evaluation session briefing is given to inform participants of the ongoing evaluation work. During the briefing, the aims and objectives of the evaluation work are reiterated, with participants made aware of the data processing that will be undertaken on the data collected during the evaluation session. This briefing is used to provide an opportunity for queries from participants to be addressed by the evaluators, with longer queries being answered offline after the session.

Table 10 – Group Evaluation Session Timetable

Group Sessions

For most participants, group sessions were the first opportunity for them to engage with LAVA. The main focus of each group session was to gain an understanding of the ways in which users made use of the system whilst attempting to undertake their virtual excavation work. In order to investigate how the users interacted with the system, a six stage process was undertaken as shown in Table 10. To ensure that each group session provided similar opportunities to explore the system, a standardised timetable was adopted, with strict timings enforced for each stage of the evaluation process. This standardisation ensured that participants were given opportunities to familiarise themselves with LAVA at the beginning of the session and ask questions relating to the evaluation process at the end of the session.

At the start of each group session, participants were given printed instructions to guide their exploration of the LAVA software. They were also given a detailed description of the evaluation process before being asked to complete a short 13 question questionnaire, as shown in Appendix C, which was designed to obtain some basic demographic information about the evaluation participants. The majority of the questions within the demographic information questionnaire focused on evaluating participants' educational background, archaeology experience and computer literacy.

Following this, participants were introduced to the members of the evaluation and demonstration teams. During this introduction, the roles of the evaluation and demonstration teams were outlined in a bid to ensure that participants knew who they could ask for help when using LAVA, and who would be

observing their interactions with the system. Participants were then given an introduction to the system and encouraged to follow a brief familiarisation exercise which was presented by the main session demonstrator. This approach was adopted to ensure familiarity with the main components of the LAVA software that the participants would need to use during the evaluation session.

During the initial stages of each session, participant groups were closely monitored by the evaluation team. As problems arose, the demonstrators were called in to ensure that all groups had access to their own excavation simulation as quickly as possible, thereby reducing the amount of time wasted during the session. Within the main working phase during stage 4 of the evaluation session, participants were given free access to explore the virtual excavation site as they wished whilst completing a series of objectives provided on the information sheets. Participants were given opportunities to ask questions throughout the session, with evaluators and demonstrators available to assist as required.

As each session progressed, demonstrators continued to handle queries relating to LAVA whilst evaluators only answered questions relating to the evaluation session itself. This approach ensured that throughout each session, evaluation staff would not be seen as stakeholders in the LAVA system by those participating in the evaluation process. To emphasise the importance of impartiality, if evaluators were asked questions relating to the operation of LAVA, demonstrators were called in to respond directly to the participant's query, with the exchange between the participant and demonstrator observed and recorded by the evaluator.

Whilst interacting with LAVA, participants were organised to work in pairs (or groups of three). In each session there were several groups working simultaneously, with each accessing an isolated instance of the Sparta basilica excavation simulation. This approach was adopted for two reasons:

1. Pair/group working allowed the evaluators to assess the working dynamics of each group by listening to conversations between subject pairs/groups who were asked to follow a talk aloud protocol [249, 250] during the session.

2. As other research has suggested [54, 256, 257], collaboration can facilitate successful performance and encourage reflection on learning objectives:

    a. Groups can often solve more interesting and complex problems than individuals working alone [257].

    b. Students working in groups need to articulate designs, critiques and arguments to other group members. This encourages the kind of reflection that leads to meaningful deep learning [256].

To obtain data relating to usage patterns, group observations were made by the evaluation team, with a single evaluator randomly choosing a group to observe throughout stage 4. To maximise the value of data obtained, a constructive interaction evaluation methodology [168, 258, 259] was adopted by the group under observation. In this form of user testing, the following principles were applied:

- Both users within the group were provided with a scenario containing several tasks which needed to be met.

- Participant A was asked to lead the scenario whilst collaborating with participant B (and possibly C if working in a group of 3).

- The participants were asked to think aloud and verbalise their thought processes as they tackled each scenario. Evaluators monitored progress from a distance, noting down the approaches adopted and thought processes verbalised by the group.

- It was assumed that the users had no prior knowledge of, or experience using, LAVA. In addition no domain specific knowledge, other than that delivered during the AN3020 module, was assumed.

- Where possible, the interaction between the evaluator and participants was minimised whilst participants worked to complete their objectives. Following the completion of each task, evaluators briefly discussed progress with the group in order to solicit user opinion to provide context to the observation data already obtained.

The approach adopted enabled evaluators to record the actions and verbal feedback of participants as they engaged with the system. This provided information on the way the overall scenario was approached, as well as the individual tasks within it. By focusing on the team dynamic, the constructive interaction methodology allows the evaluation process to focus on the collaborative aspects of the system, allowing the evaluators to analyse the ways in which teams use the collaboration tools within the system. Whilst recording the verbal feedback provided by users, evaluators were asked to consider a number of questions concerning the interactions under review. Listed below, these questions were designed to prompt the evaluator to focus on user activities whilst encouraging them to record contextual information surrounding the interactions between the users and the system:

1. How did users navigate through a scenario?

2. How quickly did users complete each task within a scenario?

3. How did the users cooperate within their teams?

4. Did the users identify areas in which LAVA hindered their efforts to meet their objectives?

5. Do users approach each task presented to them in LAVA in a uniformed manner?

This approach made it possible to develop an overview of participant engagement throughout the entire evaluation session. Other evaluators, who moved between groups, were then used to obtain more detailed participant responses whenever an objective was met, an error encountered, or a milestone completed. When combined, these two methods provide both detailed data relating to the entire evaluation session, as well as multiple snapshot reports detailing significant events encountered by several groups during each session.

Following the hands on session with LAVA, the subjects were asked to break from their groups to individually complete a post-session questionnaire in stage 5 of the evaluation process. Containing 29 questions spread over three sections, as shown in Appendix D, the questionnaire solicited user opinion with regards to the following areas:

- **Section A – System Usability Scale:** Consisting of ten standardised questions as defined in the Digital Equipment Corporation System Usability Scale, a full discussion of which can be found in [241].

- **Section B – Educational Considerations:** Consisting of fifteen multiple choice questions in the same format at those in section A:

    1. I feel that I have learned something by using this system.

    2. The excavation simulation reveals believable information.

    3. I found it difficult to find out information about the archaeological site.

    4. The quality of the material presented was consistent.

    5. I believed that all the artefacts I discovered could have been located within the region of the excavation.

    6. I feel that using this system helps develop my understanding of fieldwork methods and techniques.

    7. I found the system educationally stimulating.

    8. I was able to easily identify material culture.

9. The tools provided by the system allowed me to practice the theory that I have learned relating to managing an excavation.

10. Working in a group helped me understand the excavation process.

11. I found it useful to be able to identify where finds were located within the site.

12. The descriptions of the artefacts I found were reasonable.

13. The flow of the excavation made sense to me.

14. I was able to find the tools and information I needed to maintain my context sheets.

15. I would have preferred to work individually using the system.

The focus of these questions was on the educational motivations behind the system, with the questions designed to solicit participants' perception of the educational value of the simulation they engaged with. These questions were designed to elicit participant perceptions in relation to educational value (questions 1, 6, 7, 9), realism (questions 2, 4, 5, 12, 13) and value of groupwork (questions 10, 15). Students were asked to indicate their support for the above statements on a five point Likert scale. Using an approach similar to the one used to analyse the SUS scale results, a weighted sum of answers was calculated with the result ranging from 0 to 100, with a result of 50 indicating a neutral response.

- **Section C – Free Form Questions:** Consisting of four open questions designed to allow participants the opportunity to provide feedback on aspects of the system not covered in sections A and B.

By obtaining data relating to participants' perception of the usability of the system and the perceived educational value of LAVA, the final questionnaire allowed for a review of LAVA's comparative performance to be undertaken. In addition, the metrics were also useful in inferring properties of system attributes which were otherwise be difficult to measure: user engagement and perceived educational value being two examples.

Of course, as the questionnaires were not primarily designed to solicit data relating to user engagement, the inferences drawn from the questionnaire data were only used to corroborate existing findings from interview and group observation activities. However, as participants are more likely to be aware of these activities, there is a strong possibility of introducing experimenter effects, with users attempting to pre-empt the outcome of the evaluation process by indicating levels of engagement higher than

would normally be achieved by the system. Hence, using user responses relating to usability and educational value provided a valuable counter to these possible experimenter effects, with the combination of direct observation and interview data with secondary questionnaire data strengthening the findings of the evaluation process by highlighting cases where participants were reporting unduly high levels of engagement.

In terms of inferring levels of engagement from the usability and educational value results, an assumption was made that participants who actively engage with the scenarios presented by LAVA were far more likely to report high levels of educational value than those who do not take an active role within the system. The rationale for this being that those who do not engage with the system are less likely to enjoy using it, and are thus less likely to progress to a stage where they are able to experience the more advanced, and thus educationally stimulating, elements of the excavation simulation. In contrast, those who do take the time to engage with the system are far more likely to become accustomed to the user interface, thus allowing them to develop familiarity with the system, which in turn may lead to more positive usability feedback than from those participants who did not engage with the system as fully and who thus are unable to develop the same level of familiarity with the system.

Individual Sessions

Within the evaluation process, individual sessions were used to gather detailed data relating to problems highlighted during the group sessions. Given that the participants of individual sessions were volunteers obtained from the group evaluation sessions, most were familiar with LAVA and had previously engaged with the system. This made the individual sessions a good opportunity to trial updates to LAVA prior to them being rolled out for general use.

Each individual session was scheduled to last for between 30 and 45 minutes depending on the aspect of LAVA being investigated, with the timescale of each session agreed with the participant in advance. Given the prior exposure to the evaluation process, a minimal amount of time was spent on familiarisation exercises at the start of each session, with participants briefed as to the objectives of the session and asked to complete a demographic questionnaire, as shown in Appendix C.

Once the preliminary questionnaire had been completed and the participant briefed as to the nature of the evaluation session, individual sessions were run using a mixture of observation and structured interviews. As with the group sessions, participants were provided with a worksheet to guide their progress throughout the session. Owing to the tailored nature of the individual sessions, these worksheets were not standardised as in the group sessions, but instead listed a customised set of objectives based on the area of LAVA under investigation. Participants' interactions with LAVA were observed throughout the session by an evaluator. When each objective was met, the evaluator engaged the participant in a semi-structured interview in order to examine the approach adopted by the participant and any problems that they encountered.

Throughout the session, participants were encouraged to describe their thought processes as they progressed through the system, engaging in dialogue with the evaluator as and when they wished. If participants were naturally vocal, then the evaluator took a predominantly passive role, allowing the participant to lead the discussion. In cases where specific issues needed to be discussed, or when the participant was not forthcoming in beginning discussions, the evaluator took a more active role, introducing cues to encourage dialogue.

Unlike group based sessions, within the individual evaluation sessions only a single evaluator was present. In this arrangement, the roles of demonstrator and evaluator were undertaken by the same person. Whilst this approach reduced the protection from experimenter bias causing distortions to findings, it was felt that presenting the evaluator as someone able to assist with both technical issues related to LAVA and procedural issues relating to the evaluation process was of greater benefit – not only encouraging participants to report problems, but also encouraging them to explore possible workarounds with the evaluator, thereby revealing more details of the thought processes guiding their interactions. This arrangement also reduced the problems associated with overcrowding the evaluation session; with fewer people present it was less likely that the participant would feel overwhelmed by the evaluation process, thereby encouraging them to voice their thoughts and opinions freely.

After the completion of the objectives listed on the session worksheet, participants were asked some open questions relating to their use of LAVA as shown in the post task questionnaire provided in Appendix E. These questions were designed to give participants the opportunity to discuss different aspects of the system in use during the evaluation session. They also encouraged participants to raise other aspects of the system about which they had an opinion, thereby encouraging a broad discussion of the entire LAVA system. To add to this data, the standardised usability and educational value questionnaires (shown in Appendix D) were also completed by the participant in order to obtain more generalised data relating to the participant's perceived educational value of the system.

5.3.4 System Evaluation

As discussed in Chapter 4, LAVA provides two interfaces: one that is presented in 2D using Web technologies, and one that provides a 3D virtual environment using MUVE technologies. Both of the interfaces in use provide users with a viewpoint onto a common dataset, with LAVA adopting a model-view-controller architecture to manage the dataset independently from the interfaces. Reflecting this architectural design, the system evaluation process is split into two independent stages which consider:

1. The functionality within LAVA which supports the delivery of the 2D user interface.

2. The functionality within LAVA which supports the delivery of the 3D virtual environment.

When combined, the outputs of these two strands can be used to determine the fitness for purpose of the entire LAVA system.

	Mac OS	Sun Solaris	Windows
Submit Time	0	0	0
CGI Run Time (Server Processing)	26s	22s	18s
Network + Client Processing	34s	23s	20s
Total Time (CURL)	60s	45s	38s

Table 11 – CURL Constituent Timings in Seconds for Single Client Access

2D User Interface

Extensive evaluation of the 2D user interface has been undertaken, with deployment of LAVA for user evaluation sessions providing the opportunity to evaluate the performance of the system when in use by multiple simultaneous users. The fact that the system was able to support this usage scenario is of significance as it shows that the underlying performance of the network and systems running LAVA are sufficient to reliably support multiple users engaging with several virtual excavations simultaneously. In addition, the fact that LAVA sustained this engagement over an extended period of time goes some way to validating the approach adopted by this work with respect to the contributions outlined in Chapter 1.

In many respects this result is as expected, however this does not diminish its significance. The 2D interface provided by LAVA is delivered using a collection of Java Servlets [260] running on an Apache Tomcat Servlet container [261] with a known performance history as noted in [262, 263]. In this vein it is therefore as expected that the underlying system was able to maintain multiple simultaneous user connections. However, when dealing with the dynamically generated content delivered by LAVA, servicing user requests becomes more complicated, with multiple elements including request time, server processing time and response time all impacting on the time taken to service a user request, or to adopt the terminology of [264], the time taken to provide Closure over a URL (CURL).

Table 11 (adapted from [264] and [265]) shows the total time taken to receive a user request, process it and in response dynamically generate, transmit and display an HTML table which lists current stock prices. The table, which is around 180 Kbytes in size, contains 7 rows and approximately 1,000 columns, giving a total of around 7,000 cells with dynamically updated content. As can be seen from the table, once the client processing overhead is removed from the total time taken for a request to be fulfilled, the next largest component of delay is caused by CGI Run Time (i.e. Server processing). Whilst the Web server will be responsible for a small part of the overall server processing delay [237, 266], the majority is attributable to the act of performing the processing required to dynamically generate the 7,000 cells of data to be displayed. Thus, if it is possible to ensure that LAVA's overall server processing overhead is sufficiently small enough to generate content in a timely fashion to multiple users, then it becomes feasible for the system to be used in a production environment.

When considering LAVA, the server processing delay relates to the amount of time that is required to process a user action, update the underlying simulation state and communicate any resultant changes

	Total	Second Life	TCP
Bytes	3720.964KB	3209.310KB	511.654KB
Packets	18072	16657	1415
Bits/Second	155.852Kb/sec	134.421Kb/sec	21.431Kb/sec
Number of Connections	62	1	61

Table 12 – Summary Statistics for Second Life Traffic Trace

back to the user. Given the fact that LAVA has been able to reliably service a class of students simultaneously undertaking their excavations during several evaluation sessions is significant. Not only does it show that the performance offered by LAVA is of the order required to provide meaningful and timely responses to multiple simultaneous users, but it also shows that the underlying network infrastructure is able to support the volumes of traffic generated.

3D Virtual Environment

Analysis of network traces undertaken by [221] provides a good indication of the characteristics of the quantity and type of traffic generated by Second Life, the MUVE used to deliver the 3D aspects of LAVA simulations. With over 450 different types of data packet, Second Life makes use of both TCP and UDP protocols to transfer data, with application level 'circuits' established on top of connectionless UDP transfers to allow Second Life to monitor packet loss and provide a degree of reliability to the data transfer process. In this respect it quickly becomes apparent that Second Life employs communication protocols which are far more complex than those implemented by HTTP. However, despite the added complexity, as [221] discusses, by analysing Second Life traffic traces captured using TCP Dump [267], it is still possible to quickly gain an insight into the nature of the traffic generated by Second Life and how it relates to the tasks or activities being undertaken in the virtual environment.

In order to determine the amount of bandwidth required by each avatar, a simple test was conducted in which an avatar logs in to Second Life and flies around the LAVA Island before logging out. As shown in the summary statistics presented in Table 12, during this short lived connection the average throughput was calculated at 155.852Kb/sec, with a total transfer size of 3720.964KB spread over a single Second Life circuit and multiple TCP connections. According to Linden Labs, these findings somewhat overestimate the bandwidth required for a connection, with the Second Life wiki [222] reporting typical traffic rates of between 20 and 50Kb/sec in non-busy areas of the Second Life world. However, our higher throughput readings may be attributed to our experimental design, in which the avatar flew around an environment with a number of substantial and complex 3D reconstructions of Byzantine architecture. Additionally, the Second Life client was configured to ignore any bandwidth caps set in the preferences section, therefore enabling it to consume as much bandwidth as required throughout the connection, subject only to the limits of the underlying network supporting the communication; in our case a 100Mb/sec Ethernet LAN connected to a 1Gb/sec WAN link providing Internet connectivity via the University link to the FATMAN network [268]. Given the significant resources aimed at developing academic network links within the UK, the bandwidth available over this connection is significantly higher than that normally available through home DSL or Cable Internet

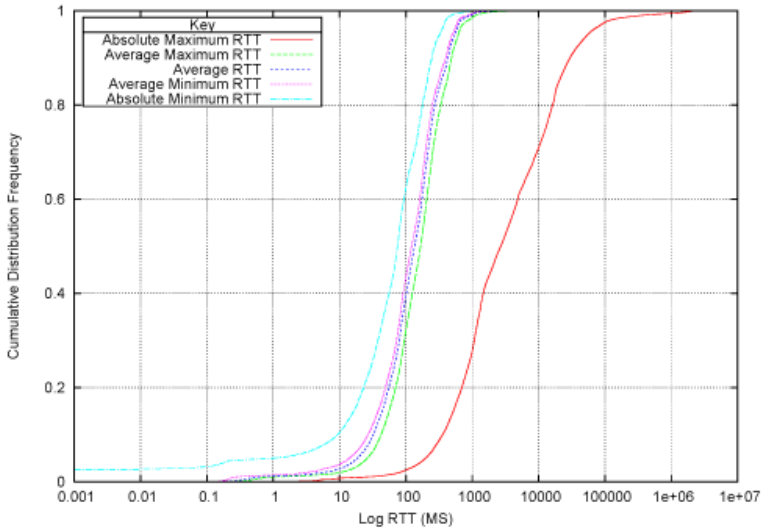

Figure 67 – PlanetLab Round Trip Time Distribution

connections. The availability of bandwidth may have encouraged higher bandwidth utilisation by the Second Life client in order to present a more feature rich user experience. Irrespective of the difference, transfers of the scale reported by both Linden Labs and our investigation can be easily accommodated on links of around 1Mb/sec-2Mb/sec and as such it is feasible that students will be able to access Second Life over a wide variety of connection types ranging from low end DSL links and possibly even 3G mobile data cards currently being sold as mobile 'broadband' connections [269].

In order to determine the feasibility of using Second Life reconstructions over a wider area (for example between continents), we made use of the all pairs ping [270] data gathered on PlanetLab [271, 272] which, as discussed in [273], provides a useful indicator of the characteristics of connectivity between a variety of Internet locations. At its most basic, PlanetLab is a collection of Internet connected machines that are distributed over a number of geographically distributed locations. Each machine in the PlanetLab overlay network is accessible to all other member organisations for various development, testing and deployment purposes. At the time of writing, PlanetLab consisted of 916 nodes located at 473 sites, with each node running a common software package based on the Fedora Linux distribution with the addition of several management tools that monitor important node metrics pertaining to system health, auditing and system control. The overriding goal of PlanetLab is to become a microcosm of the next Internet by supporting the continued research of emerging technologies, with the testbed expanding to reach a target of 1000 geographically distributed nodes, all of which can be accessed by member organisations. To support this objective, PlanetLab has been developed to consider key design decisions that are used to shape the overlay network, but which do not dictate specific implementation policies:

- **Distributed Virtualisation:** The ability to define a number of geographically distributed virtual machines (VMs) and then treat the entire group as an accountable entity afforded protection from other accountable entities hosted by the platform.

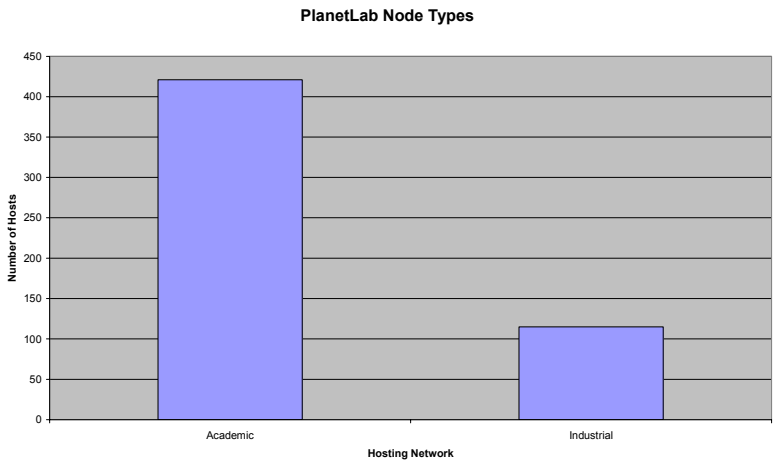

Figure 68 – PlanetLab Node Types

- **Distributed Control of Resources:** The testbed has two distinct user groups: Researchers who want to develop applications and dictate how their work is deployed, and Clients who want to decide what services can run on their nodes. Thus some form of decentralised control structure is desirable in order to allow the preferences of both groups to be accommodated more easily.

- **Unbundled Management:** Allowing independent development and deployment of both application and infrastructure-level services. This should allow different organisations to deploy system management and control services which may then compete with each other, encouraging innovation and evolution.

Generally this policy appears to be successful in delivering a usable testbed environment, with nodes primarily located in North and South America, Europe and Asia. This distribution of nodes reflects the connectivity seen on the Internet at large, with the main hubs of connectivity found throughout North America, Europe and Asia.

As shown in Figure 67, inter-nodal connectivity between PlanetLab machines is generally very good with around 75% of node pairs reporting round trip times (RTTs) of approximately 200ms, which, for a wide area connection over the Internet, represents a link with low latency. Whilst the absolute maximum and minimum values shown on the graph indicate more variable results, these metrics are easily skewed by a single rogue data point. As such, more emphasis should be placed on the relatively compact nature of the average minimum and maximum RTTs reported which are less susceptible to skewing by rogue results. According to the Second Life wiki, links with latencies of this order are likely to provide a smooth Second Life experience so long as the bandwidth available is around 20-50Kb/sec [222].

One point to note with respect to PlanetLab's node distribution is the proliferation of nodes hosted by academic networks. As shown in Figure 68, the majority of PlanetLab notes are hosted by academic

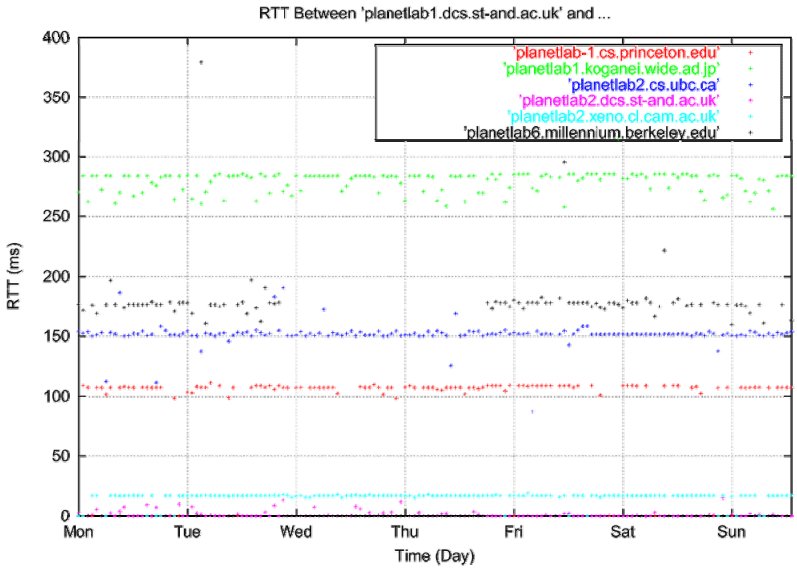

Figure 69 – Sample PlanetLab Round Trip Times between Europe, North America and Asia

institutions and as such nodes located within commercial networks are relatively under-represented. As this work is concerned with the deployment of an academic tool, this distribution does not pose a huge problem, with the findings remaining valid for our purposes, providing a reasonable indication of the likely network characteristics between different academic institutions.

When considering specific links between academic institutions located within Europe, North America and Asia, Figure 69 shows some encouraging results. Of the routes depicted in the graph, intra-European traffic (the link between St Andrews, UK and Cambridge, UK) routinely achieved round trip times of less than 25ms. When extending the distance from St Andrews to cover the east and west costs of the USA (Princeton, NJ, USA and Berkeley, CA, USA respectively), the round trip times recorded were in the region of 110ms and 175ms. Canadian links also performed well, with traffic between St Andrews and the University of British Columbia, BC, CA achieving round trip times of approximately 155ms. In all these cases, the degree of variability (jitter) between measurements was very small as shown by the graph. When considering connectivity with Asia, a higher degree of jitter was experienced. On the link between St Andrews and a PlanetLab host maintained by the WIDE project [274] in Japan, performance was still generally good, with round trip times of around 280ms reported.

Through the test connection and analysis carried out in [219] and [221], we are able to estimate the characteristics of the traffic likely to be generated when users connect to the LAVA Second Life Island and engage in meaningful activities, with each connection maintaining a small number of TCP connections and establishing several UDP 'circuits' throughout the session. From this we can therefore establish a baseline of network characteristics that a users' network should provide in order to maximise their experience when connecting to Second Life: with low latency (RTT in the region of 150-250ms) and bandwidth of around 50Kb/sec desirable. In addition, as we know the capabilities of the underlying PC classroom network we can also estimate the numbers of simultaneous users that it is

likely to support. However, this figure is likely to differ from the maximum number of users who can be present in the LAVA virtual environment simultaneously.

As users can connect to LAVA from a variety of locations, it is more likely that the server hosting the LAVA Second Life region will introduce the limiting factor which restricts the number of concurrent clients active in the virtual environment. As discussed in [275, 276], the server limitations restricting the number of avatars within a single Second Life region are still not entirely understood, with many factors including the complexity of the virtual environment and specification of the server hosting the Second Life region having an impact on the maximum number of support connections. Irrespective of these unknowns, the limitations introduced by the hosting server is an issue of hardware and software performance. As such, the impact is likely to become less pronounced as hardware capabilities increase in line with Moore's Law [3, 65] (see Chapter 2) and the software used to host Second Life matures. In addition it is worthwhile noting that these performance issues are not specific to the approaches advocated by this work and adopted in LAVA in general, but are instead specifically related to the choice of implementation platform.

In summary, the fact that the system has been deployed and used in a classroom environment is significant. Not only does this deployment validate the approach advocated by this work, but it also provides a reference instantiation confirming the technical feasibility of the architecture adopted.

5.4 Analysis of Subject Demographic

Carried out over three academic years, the participants in the evaluation process were all undergraduate students at the University of St Andrews, educated to at least GCE A-Level or Scottish Highers level. All participants were in either their second or third year of an undergraduate programme of study and had volunteered to take part. Most participants were enrolled in a degree programme which paired archaeology with either ancient or medieval history, with only one student enrolled in a programme with no archaeology weighting. The majority of participants had not previously been exposed to either MMS or LAVA and for those students participating in evaluations conducted in years 2 and 3 of the trials, none had participated in any previous years.

At the start of each evaluation session, prior to any activities being undertaken, all participants were asked to complete a pre-session questionnaire which included questions relating to education, background experiences and IT competency. An example pre-session questionnaire is included in Appendix C. A summary of the responses obtained during the evaluation of LAVA is presented in Table 13. As can be seen, the age distribution of participants in the three evaluation sessions undertaken falls firmly within the 19-21 age range, as expected given their status as undergraduate students. Nearly 70% of the participants, in either their 3rd or 4th year of a 4 year course of undergraduate study, evaluated themselves to have an intermediate level of IT competency as shown in Figure 70, with 23% assessing their skills to be at a novice level and just under 8% assessing their skills to be advanced.

Age Range	Number of Participants (%)
<17	0
18	0
19	15%
20	61%
21	12%
22	8%
23	0
24	0
25+	4%

Table 13 – Evaluation Exercise Age Distribution

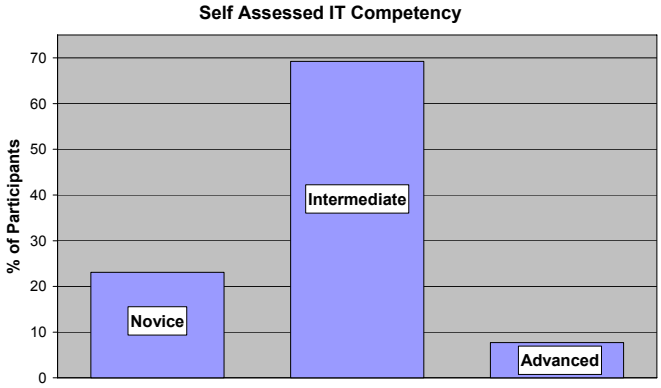

Figure 70 – Self-Assessed IT Competency of Participants

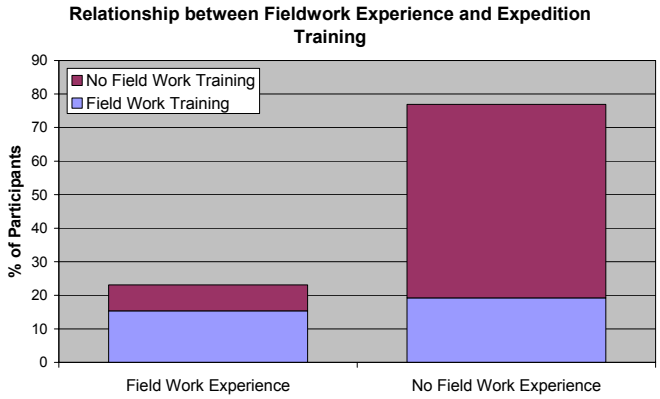

Figure 71 – Relationship between Fieldwork Experience and Expedition Training

As shown in Figure 71, of those who participated in the evaluation process, just over 23% had gained some form of fieldwork experience, with approximately 35% of the sample having undertaken some form of organised fieldwork training. Of the participants with fieldwork experience, 66% also reported that they had undertaken some fieldwork training. As expected, this result is far higher than for those participants without fieldwork experience, with only 1 in 4 subjects in this category reporting that they had undertaken any fieldwork training. This could be indicative of a general trend, with opportunities to undertake fieldwork training nearly as difficult to come by as opportunities to undertake fieldwork. Alternatively, it could be that those who secured the opportunity for fieldwork experience were more likely to actively engage in preparatory work prior to attending an excavation site. Either way, this difference is noteworthy and should be subject to more detailed investigation, albeit outwith the scope of this work.

The properties of the sample used in this evaluation process seems to broadly support the lack of opportunity to engage in fieldwork training and onsite excavation work that others have previously discussed [161, 277], with the low take up rates possibly indicating a lack of available training and fieldwork opportunities amongst the sample population. Certainly given the educational background of the sample and the relatively high levels of IT competency reported (with 3 out of 4 participants reporting either intermediate or advanced IT skills) it seems reasonable to suggest that the sample were reasonably self-motivated and keen to further their education. Given this, one could reasonably expect the sample population to report higher levels of fieldwork and fieldwork training experience were opportunities to engage with fieldwork projects and training sessions more widely available.

Rather interestingly, of those participants who reported being involved in some form of fieldwork, 33% had, by their own admission, received no periods of formalised fieldwork training prior to joining an excavation team. This result is surprising and seems to indicate that there are a significant number of fieldwork participants who are ill equipped to benefit from their own site excavation experiences. This could indicate that participants deemed formalised training to be of only limited value, or could otherwise indicate that few opportunities were available for them to undertake any training prior to their involvement on site.

Previously, it has been suggested that prior knowledge and training in the field improves an applicant's chance of being involved in an excavation project [161]. This view is supported by the findings in this sample population, with significantly higher numbers of students who reported fieldwork experience also reporting fieldwork training than those who reported no fieldwork experience. Given this, it seems surprising that nearly 1/3 of those who were able to gain fieldwork experience were given their opportunities without any prior training activities.

5.5 Analysis of Results

When reviewing the results of the group evaluation sessions, all participant groups completed at least one of the excavation scenario stages, with most groups making considerable progress through the simulation. In each year, a small number of groups stood out due to their ability to rapidly move through the excavation scenario by quickly identifying the types of skills and equipment that they needed to select in order to meet the objectives of each level and progress through the scenario. Each year a small number of groups struggled to completely grasp the concept of fulfilling objectives, with at least one group, who attended the group evaluation session held in year 1, spending over 90 minutes of the allotted time attempting to complete stage 1 of the scenario. To prevent a recurrence of this type of difficulty, demonstrators in subsequent sessions spent more time ensuring groups were able to understand the link between fulfilling objectives and progressing through the system, thereby encouraging them to investigate how their decisions could be altered in order to improve their rate of progress through the excavation scenario.

5.5.1 Year 1

During the first evaluation session, a team of demonstrators and a team of evaluators were deployed to monitor participant progress. As has been previously discussed, the roles of demonstrator and evaluator were split in order to encourage frank and open discussion about the positive and negative aspects of the LAVA. When considering usability and educational value, the first evaluation session provided the following outputs:

Usability

In year 1, 17 of the 18 session participants filled in the SUS section of the post session questionnaire, with all respondents answering all questions. A full breakdown of the results is provided in Table 14, with a summary graph in Figure 72. For this evaluation session, the SUS score returned for the system was approximately 65. As the scale runs from 0 to 100, with 50 being neutral, this gave LAVA a firmly positive usability score, which seemed to be in agreement with the number of usability issues reported during the evaluation session. As shown in Figure 72, of the results returned, 3 subjects returned usability scores below 50, with the remaining 14 participants who completed the questionnaire returning scores over 50. The lowest absolute score reported was 37.5, with the highest being 87.5.

In terms of the responses to individual questions, the highest ratings were in response to the question:

> "I would imagine that most people would learn to use this system very quickly"

Whilst the lowest scores were in response to the question:

> "I found the various functions in the system were well integrated"

This finding appears to indicate that whilst the subjects were able to use the system, they were aware that it was not as cohesive and polished as more mature systems. Given that the year 1 evaluation exercise was the first widespread use of LAVA, this response from the users was seen as broadly encouraging.

Of the usability problems encountered when interacting with the 2D interface, most related to the way in which the interface was arranged. 7 of the subject groups cited at least one problem either understanding what the user interface options meant or how the user interface worked during the session. Of these groups, 5 were able to rectify their misunderstanding without seeking demonstrator support. When encountering errors, most users reported that the error messages and the steps suggested by the system to resolve problems were useful.

Participant	SUS Score	Educational Value Score
1	67.5	38.3
2	47.5	51.6
3	65	73.3
4	45	33.3
5	87.5	71.6
6	75	76.6
7	62.5	73.3
8	65	55
9	872.5	66.6
10	70	60
11	62.5	48.3
12	70	85
13	65	60
14	65	66.6
15	72.5	65
16	72.5	63.3
17	37.5	73.3

Table 14 – Year 1 Participant SUS and Educational Value Scores

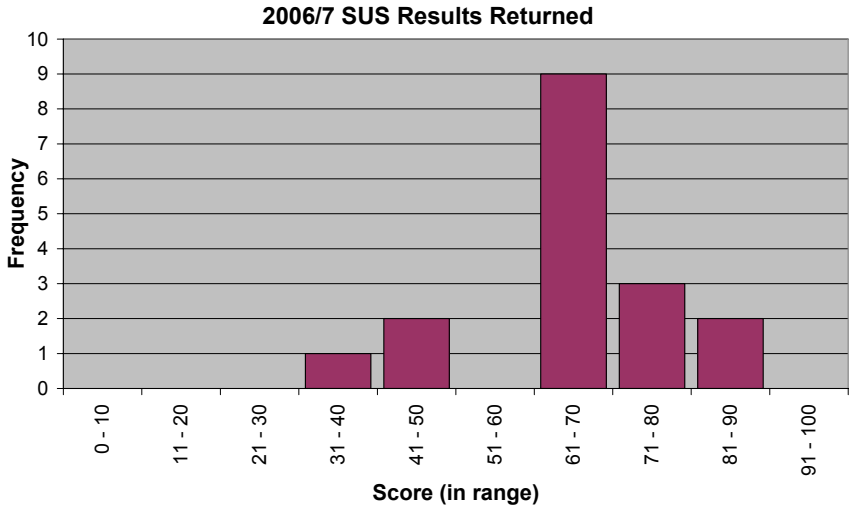

Figure 72 – Year 1 System Usability Scale Scores

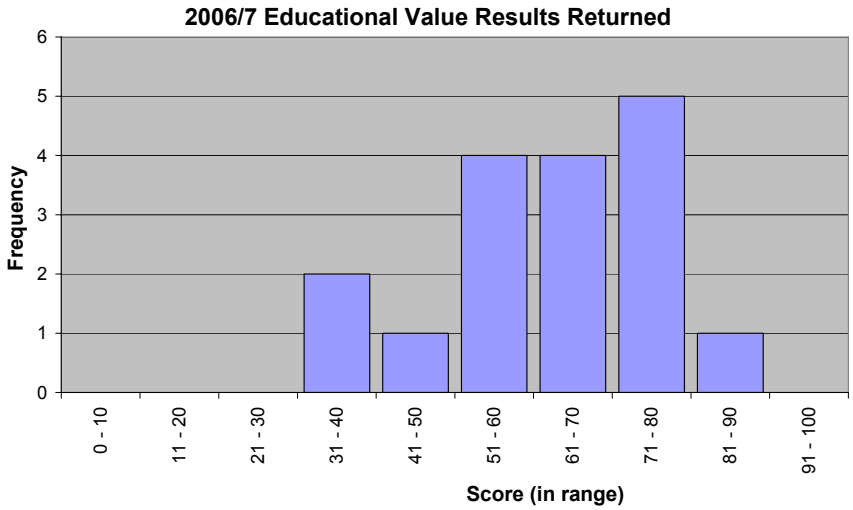

Figure 73 – Year 1 Educational Value Scores

Educational Value

All participants who completed the SUS section of the questionnaire completed the educational value section too, with all respondents answering all questions. A summary of the results is shown in Figure 73, with Table 14 providing the raw values. For this evaluation session, the educational value score returned was approximately 62. As the scale ranges from 0 to 100, with 50 being neutral, the score returned is broadly encouraging and provides an indication of the level of engagement and value that participants apply to LAVA. When compared with the SUS dataset, the educational value results show a similar spread which ranges from a score of 33 to 85. However, unlike the SUS dataset, the educational value distribution features a greater number of scores towards the lower end of the distribution, thereby producing a small peak at the lower end of the score spectrum. This is countered by a strong skew to the right, with a notably higher number of participants returning scores between 51 and 100. Overall the distribution reflects a broadly positive outlook, with significantly more results returned in the 51-100 range than in the 0-50 range (14 participants in the 50-100 range versus 3 participants in the 0-50 range respectively). This is again very encouraging and shows that the majority of participants placed a positive value on their use of LAVA.

In addition to these quantitative results, a number of comments were made by participants. These again support the broad approval for LAVA indicated by the educational value scores:

> "The personal touches to the employable individuals added a friendly, approachable touch to the system"
>
> "Enjoyable session with insight into the excavation process"
>
> "I liked the photographs of artefacts and gradual revelations made by each stage"
>
> "Helpful to understand what is needed in an excavation"
>
> "I liked the fact that it was interactive"
>
> "I think it's some way off being a polished application but I think it has serious potential"
>
> "The program takes a lot of what we've learnt and gives it a bit of substance and that's got to be good"

The following is an account of one of the observers of the session. It suggests that students found the system engaging and helps to provide context to the way in which the evaluation sessions were undertaken:

> "At the start of the evaluation session, once the users were logged in to the system the noise level in the room got louder and louder as the groups began to communicate with each other across the lab. The AN3020 lecturer kept trying to bring the noise level down, however these efforts were in vein. The noise level maintained a consistent plateau as the groups continued to communicate verbally. When the first group to complete stage 1 were shown

> the artefacts that they had discovered they boasted and the room went silent, all of the groups focused on what the group to complete stage 1 had done, and then a wave of excitement and activity rolled over the lab as the other groups, spurred on by the outcome, began to try to complete the stage with renewed interest".

5.5.2 Year 2

The evaluation approach adopted in year 2 followed the model applied in year 1, with the exception that all participants were asked to complete questionnaires electronically. A total of 14 participants were involved in the second evaluation session, with all volunteering their time to participate.

During the session, at one point there were some minor technical problems with the server hosting LAVA. Groups were notified of these issues during the session, and they were very quickly resolved. These issues were commented upon by two participants in their questionnaire responses, with both showing frustration at their investigation work being interrupted:

> "It kept logging us out, so we had to keep starting over, which was highly frustrating"
>
> "On first attempt to open a hotspot, had to log in again and received another error message (can't remember) and took a couple of tries to load"

From the participant responses there was frustration at the problem encountered. Whilst only 2 participants out of a group of 14 noted this issue in their questionnaire responses, a number mentioned the issue during the session. When considering usability and educational value, the following results were returned.

Usability

In year 2, all of the 14 session participants filled in the SUS and Educational Values sections of the post session questionnaire. All respondents answered all questions, with many providing additional comments on their impression of the evaluation session in the open ended section of the questionnaire. A summary of the results returned for the SUS and Educational Value multiple choice questions is shown in Figure 74, with Table 15 providing details of the raw scores returned. For this evaluation session, the average SUS score recorded for LAVA was 59. As the scale goes from 0 to 100, with 50 being neutral, this gave LAVA a positive usability score. It is of note that this result is lower than the average usability score of 65 returned during the first evaluation session. The lowest absolute usability score awarded was 30, with the maximum being 82.5. As with the average score, these results show a slight shift to the left when compared with the results of the first evaluation session. However, as 11 of the 14 participants returned scores in excess of 50, the second year results still show a significant number of users rating the usability of the system positively. It is also important to note the reduced sample size in the second evaluation session which amplifies the effect of any outlying results to the

average score calculation. Furthermore, given the technical difficulties experienced at the start of the session, it is likely that participants' opinions with respect to usability would have been negatively affected.

When considering individual questions, responses to the question;

> "I felt the system very cumbersome to use"

solicited the highest number of responses indicating disagreement with the statement, therefore indicating that participants felt that they were able to use the system with reasonable ease. In terms of the lowest scores returned, the question;

> "I found the various functions in this system were well integrated"

faired less well for the second time running, with many participants again indicating that whilst they were able to use the system with relative ease, they were aware that is was not as cohesive and polished as more mature systems.

Throughout the session a number of usability issues were reported, with many being related to the login issue caused by the technical problem at the start of the session. Of the remaining issues, most related to the mechanisms designed to allow groups to investigate separate contexts within the main body of the excavation. Of the three groups surveyed when dealing with contexts, all reported having initial problems, with one group showing complete confusion which led to one participant commenting in the post session questionnaire:

> "What were we supposed to do with the contexts?"

However, the remaining two groups did seem to be able to grasp the concept after two or three attempts, with one group offering the following response:

> "Initially, found contexts a little difficult to fully understand, couldn't tell at a glance how to further explore them"

This seemed to indicate that perhaps the initial instructions were not necessarily helpful in determining how to use this system. This was further confirmed by feedback from another group who commented that:

> "The directions of the program after you start the excavation are not as dire[c]t and not as engaging as one would hope"

Participant	SUS Score	Educational Value Score
1	55	53.3
2	65	60
3	30	41.6
4	45	61.6
5	82.5	65
6	32.5	35
7	62.5	55
8	60	38.3
9	57.5	61.6
10	67.5	53.3
11	77.5	63.3
12	65	81.6
13	72.5	63.3
14	60	75

Table 15 - Year 2 Participant SUS and Educational Value Scores

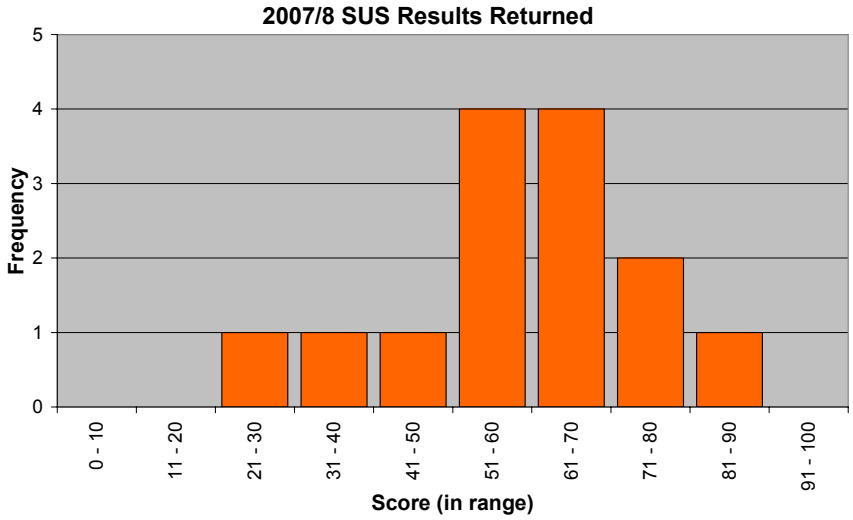

Figure 74 – Year 2 System Usability Scale Scores

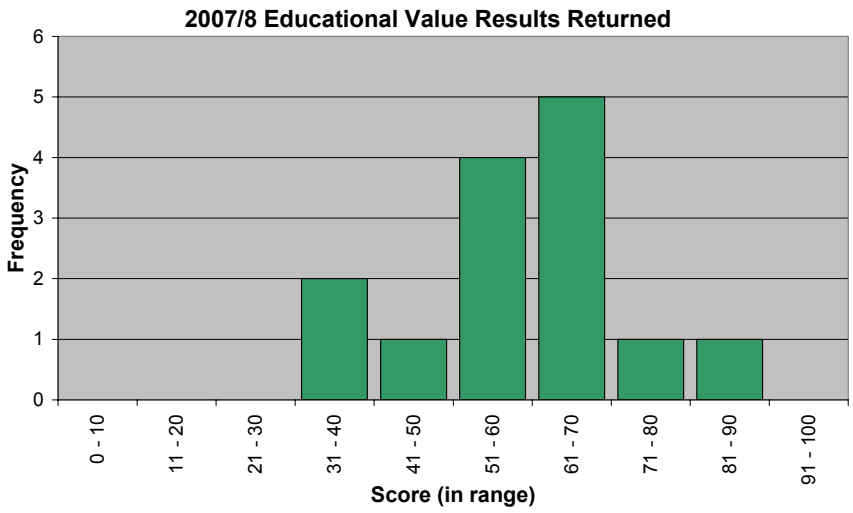

Figure 75 – Year 2 Educational Value Scores

Once clarified, however, the concept of separate contexts within the excavation did appear to be desired amongst the participant groups, with one participant making a note in their post evaluation questionnaire responses that it was a desirable feature which should be present in the system.

> "The ability to pick what tools you use to excavate a certain area was good"

Given this, it seems as though many of the problems associated with the contexts system are related to the level of instruction and the interfaces provided to manage the functionality, and not fundamental to the approach being adopted per se. This is reassuring and emphasises the importance of redesigning the contexts interface to help develop a more positive user experience.

On the whole, 5 of the 7 groups stated that they found that the visualisations offered by the 2D interface of benefit, with many suggesting minor changes to help further clarify things: for example, using different coloured hotspots to distinguish newly found artefacts from those already discovered and recorded. In addition, one group suggested that replacing the site maps with more detailed site photographs would be beneficial as this would make it possible to show the different stages of the excavation more clearly, i.e. before and after clearing the top soil etc. One participant commented that this type of feedback would be useful when determining whether to finish or continue a line of investigation:

> "It was unclear when to progress as basic pictures do not show the entire site [soil, etc.], which is necessary when you need to know when to continue"

Given the design of the system, this adaptation could easily be accommodated if there were existing photographs showing the details required.

Educational Value

All participants completed the educational value section of the post session questionnaire, with all respondents answering all questions. A summary of the results is shown in Figure 75, with raw values provided in Table 15. For the second evaluation session, the educational value score returned was approximately 58, which is slightly lower than that returned in the first evaluation session. However, as the scale ranges from 0 to 100, with 50 being neutral, 58 is still broadly encouraging and provides a positive indication of the level of engagement and value that participants apply to their use of LAVA. Despite a slightly lower average, the range of scores returned in the second session is similar to that of the first evaluation session, with a low of 35 and a high of 82 returned.

The spread of scores is skewed slightly to the left as shown in Figure 75. However, with most scores falling in the 51-70 range (9 of 14) the effect of the skew is limited. As with the results from the first evaluation session, the overall distribution of scores reflects a broadly positive outlook; with

significantly more results returned in the 51-100 range than in the 0-50 range (11 participants in the 50-100 range versus 3 participants in the 0-50 range respectively), participants associate value with their use of LAVA. Given that the effect of the technical problems experienced early in the session cannot be quantified, it is encouraging to see that participants still return broadly positive results which show a promising reaction to their interactions with LAVA.

Of the feedback obtained through the open questions included in the post session questionnaire, participants made the following encouraging comments which again seem to backup the conclusion that, in general, the user response to LAVA is positive:

> "The pictures and artefacts were good"
>
> "The simplicity of the program is appreciated as it makes the [excavation] process simple"
>
> "It sounds complicated, but very simple to pick up once you start, and the prompts (with one day penalty) for missing skills [are] very useful to remind/teach you what you need. Also enjoyed the witty remarks on the staff! Based on real life examples?"
>
> "Being able to investigate the finds was useful to understand what was there [on the excavation site]"
>
> "A great tool to help people who might not have the opportunity to dig to actually understand the processes and demands of an excavation - as organiser or grunt [student?]. Relatively easy to grasp, teaches a lot, and interesting"

5.5.3 Year 3

In order to focus on development issues, the evaluation session undertaken in the 2008/9 academic year differed from those previously undertaken. Instead of evaluating with a large group of participants simultaneously, a small number of participants, some of whom had used LAVA in previous evaluation sessions were invited to attend individual evaluation sessions. As discussed in section 5.3.3, individual sessions were scheduled to last between 30 and 45 minutes, with each focusing on a specific aspect of LAVA. In total 8 individual evaluation sessions were undertaken, with the focus of each as shown in Table 16:

Each of the individual sessions were designed to identify strengths and weaknesses in the current implementation of LAVA by examining different aspects of the system. Two types of objectives were used:

- **Fixed** objectives which have a firm set of steps needed to be completed in order for the objective to be met.

- **Loose** objectives which are less prescriptive in their approach, with participants' responses to the environment being of interest.

Session	Focus Topic	Objective	Type
1	Identifying the equipment and personnel required to meet objectives and progress through a level.	Identify the equipment and personnel required in order to reveal a minimum of 10 artefacts/features in stage 1 of the excavation.	Fixed
2	Navigating through the artefact interface.	Use the artefact interface to find information about previously found artefacts.	Fixed
3	Completing context sheets – including bookmarking and navigating artefact interfaces.	Use the context sheet functionality to record artefact information and add your own notes about an artefact.	Fixed
4	Using the context interface to manage subsections of the excavation process.	Open and explore a context independently from the main excavation process.	Fixed
5	Completing a stage using the 2D interface.	Complete stage 1 of the excavation process, using the team, equipment and artefact management interfaces as necessary.	Fixed
6	Completing a stage using the 2D interface.	Complete stage 2 of the excavation process, using the team, equipment and artefact management interfaces as necessary.	Fixed
7	Examining the basilica in the 3D environment.	Log in to the 3D environment and explore the basilica reconstruction.	Loose
8	Critique process, examining the use of audio and text chat.	Log in to the 3D environment and guide the other in-world avatar around the basilica reconstruction.	Loose

Table 16 – Individual Evaluation Session Focus Topics

Sessions 1-6 were designed using a fixed objective to be achieved by the participant. Sessions 7 and 8 followed a less rigid structure and employed a loose objective with participants being asked to explore and guide others through the virtual environment respectively. This mixture of fixed and loose objectives was applied in order to more closely mirror the type of interactions students would have when using LAVA for academic purposes – with the 2D environment being used to drive forward the excavation through a fairly well defined structure of interactions whilst the 3D environment allows for more reflective and explorative activities.

In addition to providing feedback through interviews and observation by evaluators, participants in the sessions which had fixed objectives were also asked to complete a short post task questionnaire as shown in Appendix E. As can be seen by the responses recorded in Table 17 and shown in Figure 76, participants generally performed very well, with all but one evaluation session seeing the participant successfully complete the objectives set. The majority of participants responded positively when asked about the ease with which they were able to complete their objective, as shown in Figure 77, and most said they were happy with the way the system provided them with information as they progressed, as shown in Figure 78. However, as shown in Figure 79, three of the participants commented that they felt that the system had, in some way, hindered their progress as they worked to meet their objective, with five participants indicating that the did not feel their progress was obstructed. Upon further investigation by the interviewer, the cause of these less favourable responses was determined to be due to interface design issues in two cases, with users receiving results other than expected, and a lack of feedback in the remaining case, with users unsure whether the system had processed their requests.

Question	Response		
	Easy	Neither	Hard
How easy was it to find out how to use the system to perform the task?	5	2	1
	Yes		No
Did the system hinder your progress in achieving the task?	3		5
Were you happy with the way the system provided you with information relating to your progress through the task?	6		2
	Yes	No	N/A
Did you achieve your task successfully?	5	1	2

Table 17 – Individual Evaluation Session Responses

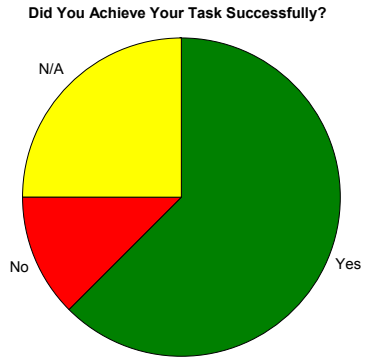

Figure 76 – Year 3 Task Completion Rate

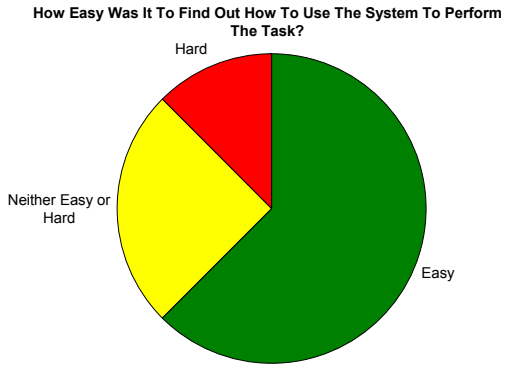

Figure 77 – Ease with which Year 3 Users were able to Comple The Tasks Set

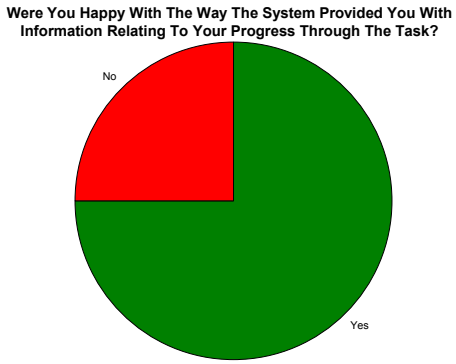

Figure 78 – User Opinion of LAVA Progress Reporting

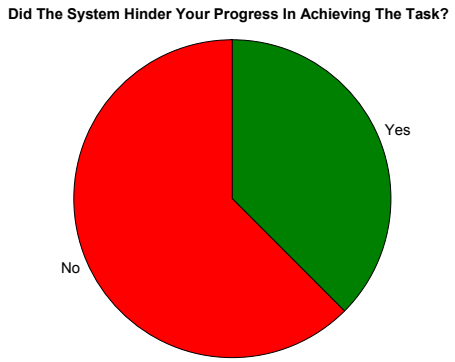

Figure 79 – User Opinion of LAVA Progress Management

Whilst the quantitative data obtained from the individual sessions provides a useful indication as to the nature of the interactions that the participants had with LAVA, the main benefit is the qualitative data obtained. Not only does this help to reveal the approach adopted by participants whilst using the system, it also helps highlight aspects of the system where the intended use (and therefore system design) differs from the way the system is actually used.

As an example, initially the bookmark interface provided by LAVA had a checkbox called 'bookmark' which was designed to allow participants to decide whether to bookmark an artefact or not. However, the subtlety of this checkbox was overlooked by users who simply entered text into the bookmark notes and then clicked the OK button to close the window. The assumption of the participants was that any data entered would be saved in the bookmark. However, as the system was designed to use the 'bookmark' checkbox, if this was not ticked, then bookmark data was simply discarded. Given the

differences in the designed use of the interface, and the actual use adopted by participants, this interface proved problematic in the initial version of LAVA. Through detailed feedback provided by participants through individual sessions, however, this problem was identified and subsequently dealt with – the redundant 'bookmark' checkbox was removed, with the system instead checking for bookmark notes and saving the data automatically as required.

In addition, participant feedback during individual sessions also helped to redevelop the personnel and equipment management interface, with initially unfavourable responses leading to the redesign of the interface to allow personnel and equipment to be searched for based on their skill set and/or application (i.e. searching for the skill of digging would reveal all personnel who were able to dig and associated equipment, e.g. spades, trowels, JCBs etc).

Another area in which the individual evaluation sessions excelled was in the testing of system feedback. During the group evaluation sessions, users were often left confused by seemingly inaccurate or conflicting error messages or system feedback messages. In order to address these issues, as individual session participants progressed towards their objectives they were asked to specifically comment on ways in which feedback could be given to users. As a direct result of this evaluation process, the method of notifying (and penalising) users who had not provided the correct equipment to complete a stage of the excavation was updated. Initially users were provided with a message saying that they had not identified and provided equipment and personnel to meet every skill required for a stage. However, individual session participants commented that this approach made it trivial to cheat through the excavation by making multiple attempts to guess the correct mixture of personnel and equipment without actually determining the skill set which needed to be fulfilled by the excavation team. Following this feedback several penalty systems were investigated and trialled, until the current system was reached whereby more detailed user feedback is given in the form of an error message, with a day knocked off the excavation time limit for each attempt to complete a stage without providing the correct mix of skilled personnel and equipment.

5.5.4 Summary

To summarise, in each of the evaluation sessions, participants showed enthusiasm and interest in LAVA. The mixture of mediums provided a varied and novel viewport to the excavation simulations which participants adapted to quickly. Groupwork arrangements functioned well, with participants seemingly undisturbed by the evaluators observing the sessions. Each session was lively throughout, with participants actively engaging with the system. Analysis of the server access logs shows that this interest continued for some time after each evaluation session, although not on a large scale.

To evaluate the usability of LAVA and provide comparisons relative to other systems, the SUS was used during each session to monitor changes to users' perceptions of LAVA as additional development work was undertaken on the system. The graphs below show a comparison of the SUS scores (see Figure 80) and Educational Value results (see Figure 81) returned during each evaluation of LAVA, as

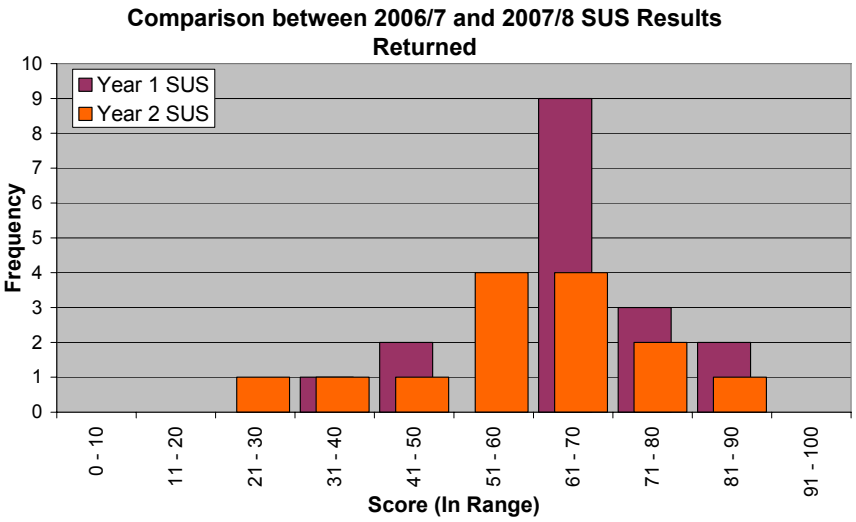

Figure 80 – Comparison between 2006/7 and 2007/8 SUS Results Returned

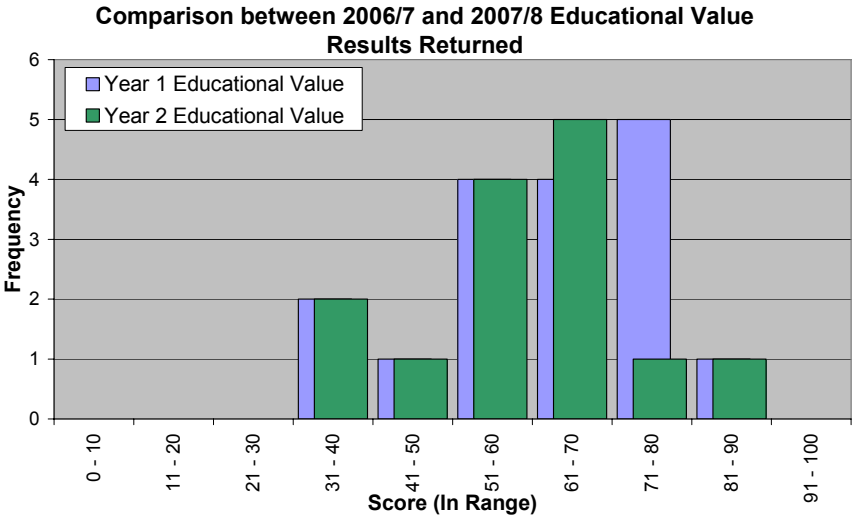

Figure 81 – Comparison between 2006/7 and 2007/8 Educational Value Results Returned

recorded over the two consecutive group evaluation sessions. The similarity between the scores is visible in both graphs. This is encouraging as it shows a degree of consistency with respect to the way in which the usability and educational value of LAVA has been perceived by users over two academic years. Given how the system development has seen the addition of a number of more complex features it is also encouraging to note that the average SUS score has not been adversely affected, thereby indicating that, despite the addition of new functionality enabling more complex interactions with the excavation, the base level of usability provided by the system remains broadly high. In addition, the similarity between the spread of usability scores between the first and second year of evaluation is also encouraging. With respect to the educational value results, both the 2006/7 and 2007/8 dataset show promise with a similar spread and slightly more compact distribution being returned in the 2007/8 result set. Whilst the difference in distribution is minor in nature, it is nevertheless encouraging to see the lower end educational value scores being upgraded to indicate higher levels of perceived educational value.

During the evaluation sessions a number of issues were detected with respect to the functionality offered by LAVA. These findings had a direct impact on the development work being undertaken. The approach of using evaluation session feedback to help focus development effort has provided benefits, with the results obtained during the second year of the evaluation process showing improvements. Many of the problems recorded during the first year which related to the equipment and personnel management systems were resolved through redesign, with individual focus groups providing data that was used to guide the development of both systems between each group evaluation session.

However, time constraints meant that not all issues could be addressed. As such certain aspects of the 2D interface remained problematic throughout each of the group evaluation sessions, despite significant development effort, with the context management system being notable as receiving the highest number of participant problem reports. Whilst the results indicate that the overall usability of LAVA has not been significantly affected by the inclusion of new functionality, the complexity associated with managing the excavation and each context which branches off into a separately managed miniature excavation, does require significant effort to understand. Given this, the high number of problem reports obtained by the context management tool is not surprising, although it does highlight it as an area of the 2D interface which requires additional developmental effort, with associated interactive help being a useful feature to include.

Between each evaluation process, a number of procedural aspects were altered to account for issues uncovered during the previous session. For example, during the first evaluation session a participant group began to collaborate whilst recording their responses to the post-session questionnaires. This happened despite participants being asked to complete their feedback responses independently. To address this issue, in future group evaluation sessions participants were asked to complete the questionnaires electronically, with groups physically separated at the start and end of the session to reduce the opportunity for accidental collaboration. This arrangement worked well and led to a 100% completion rate for the questionnaires during the group evaluation session in year 2 and individual evaluation sessions in year 3.

Despite physically separating the groups, the results for the second evaluation year continued to show a strong degree of correlation between group members. Given that collaboration was minimised as much as possible during the completion of the questionnaires, this finding seems to indicate that group members were forming a shared view of the system based on their experiences using it as a team. This phenomenon is broadly in keeping with our discussion of collaborative learning in Chapter 2, and provides an interesting avenue of future evaluation work to investigate how the team dynamic during the evaluation session impacts on the SUS and Educational Value scores returned by group participants.

5.5.5 Implications with Respect to LAVA Framework

The LAVA simulation system has been developed as part of a project aimed at allowing students to develop an understanding of practical archaeology skills. The need for a virtual excavation stems from the fact that real-world fieldwork projects can be expensive to attend and are often heavily oversubscribed, thus limiting the number of students able to be involved. In addition, there are a number of accessibility issues which can often prohibit the inclusion of real-world excavation activities in the curriculum: excavation sites are frequently in-accessible to physically disabled people and so it becomes difficult for the general curriculum to include excavation site experience without unfairly discriminating against those who would be unable to navigate around the environment. Through the evaluation activities undertaken it has been possible to determine the effectiveness with which the current implementation of LAVA fulfils these needs.

As an excavation simulator, LAVA is not designed to replace the physical processes associated with undertaking an excavation, but is instead designed to prompt users to consider the issues and problems which must be addressed when carrying out an excavation project. Through the development of the simulation based on the excavation of the Sparta acropolis basilica located in the Sparta region of Greece, LAVA provides opportunities for students to actively engage with these issues in a realistic environment. This simulation does not suffer the same physical and financial restrictions of a real world excavation. However, for the LAVA virtual experience to be meaningful it is important that students are exposed to environments in which they must consider the issues and problems associated with excavation work. In order to achieve this, the development of LAVA has followed four key objectives, with each virtual simulation aiming to provide:

- **Learner Engagement:** It is important for the system to engage with students and encourage them to explore the subject matter.

- **Groupwork and Collaborative Working Practices:** The motivation for the LAVA system to support collaborative learning is two fold:

    a. Real archaeological excavation projects involve a high level of collaboration and so it is important that this collaboration be mirrored in LAVA simulations.

    b. Groupwork is an important transferable skill which is often underdeveloped within traditional educational contexts, especially within the domain of practical archaeology.

  Whenever students use the LAVA system they are organised into groups. This strategic groupwork forces students to adopt cooperative learning strategies and thus emphasises the importance of collaboration within real world excavation scenarios.

- **Realism:** When undertaking a virtual excavation, students should be faced with realistic scenarios which accurately reflect real-world working practices. This realism should also be extended to include realistic outcomes based on the activities undertaken by the students, thereby reinforcing their theoretical knowledge of practical archaeology. Realism is achieved in two ways:

    a. LAVA is based upon a real archaeological site. All electronic resources presented to students are based on original excavation data and are organised both geographically and temporally so that learners may engage in sequenced activities, with realistic, real-world inspired results.

    b. Excavation information is presented to students using a variety of complementary technologies ranging from text to provide contextual information, 2D maps to define geographical context, photographs to provide high fidelity imagery of the region, and 3D collaborative environments to provide a sense of spatial relationships.

- **Accessibility:** LAVA has been developed to run alongside an existing archaeology module within the School of Classics. It is intended that groups will work with the LAVA system collaboratively within the university PC Classrooms as well as individually on private computers. Given this varied usage, LAVA has been developed to allow students to access and interact with the system from anywhere at anytime. To facilitate group access, management tools are provided by MMS to allow student groups to manage and coordinate their progress through the excavation in a distributed way.

Through the evaluation process we have identified significant levels of user engagement, with a majority of participants providing positive feedback in both the SUS and Educational Value components of the evaluation process. In addition, the observations from evaluators and domain experts point to positive learning experiences by many participants, with active engagement apparent in all evaluation sessions. Having said this, as a developing system, some aspects of LAVA still require additional work – something that has been made clear by the evaluation process. Participant feedback in relation to system interfaces and the feedback offered have been invaluable in identifying aspects of the system in need of extra development work. In many cases, this participant feedback has helped to directly determine the development priorities of LAVA.

Overall the evaluation of LAVA has been a worthwhile exercise in determining LAVA's fitness for purpose. User feedback has broadly indicated a positive response to the system and its aims and objectives, with the deployment and use of LAVA in a classroom environment being vital in proving the technical feasibility of delivering simulated excavations to multiple simultaneous users.

Looking forward, the evaluation process has helped to identify aspects of the system which would benefit from further development work. The results of the evaluation process show initial promise, with the usability and educational value of LAVA reported as broadly positive by evaluation participants and domain experts. However, given the reliance on user opinion, the true value of the interactions that students have with LAVA can only really be determined by collecting more usage data through the deployment of the system over an extended period of time.

5.6 Chapter Summary

In this chapter we describe how the core of the LAVA system has been deployed and evaluated over three consecutive academic years. We outline how students in honours level archaeology modules have participated in virtual excavations both as part of a team and also individually. The trials, usually undertaken during class hours, have been voluntary, with students able to opt out as they wish. The uptake and completion rates of the trials have been high, with a sizeable number of volunteers completing their participation in individual evaluation sessions focussing on specific components of the LAVA system.

When evaluating the system as a whole, a two pronged approach focussing on the usability of the system and the educational benefits that it offers has been adopted. The opinions of student participants have been collected using questionnaires broken down into three sections that included questions on system usability using the SUS, educational aspects of the system and open questions designed to allow respondents to provide feedback on any aspect of the system. In addition, group observations and individual interviews have been conducted to gain more specific information about key aspects of the system.

The initial findings of the evaluation process have been positive, with responses to the educational value and SUS sections of the evaluation indicating a broadly positive response to the system which has been consistent over each of the three years of evaluation. In addition, several encouraging user responses have been obtained which go some way to identifying specific aspects of the system that participants found engaging – the graphical and realistic nature of the visualisations presented being most noteworthy.

Domain experts in the fields of archaeology and computer science agree that LAVA has been well received by students, with many showing high levels of engagement with the scenarios presented. Indeed, many student respondents have indicated that they feel that LAVA was easy to use and that it had a positive impact on the courses in which they used it.

It is promising that the initial findings indicate that the adoption of gaming methodologies can have a positive impact on the educational benefits of a course. In addition, it is important to note that the evaluation process has played a significant role in shaping the instantiation of the system, with user feedback directly affecting the priorities adopted during the development process.

Given the heavy reliance placed on user opinion and other types of qualitative data, the evaluation process acts as an indicative guide to the applicability and suitability of LAVA as a teaching tool, with the process of deploying the system providing more concrete evidence of LAVA's fitness for purpose – the deployment and use of the system in a classroom environment proves the technical feasibility of the framework, architecture and current instantiation of LAVA.

In summary, this chapter describes a systematic evaluation of LAVA and explores areas of further research and evaluation which may be beneficial when further considering the impact of LAVA on the curriculum. The evaluation process identifies areas of positive response from participants and has helped further the development of the system. The deployment investigates and provides evidence to confirm the technical feasibility of the system, with opinions from domain experts and evaluation participants providing extensive qualitative data to support the educational value offered by the system.

Chapter 6 – Related Work

6.1 Introduction

Throughout this dissertation, reference has been made to a variety of work from both the educational and technological sectors. This chapter considers the technological work which has informed the development of LAVA, with Chapter 2 outlining much of the educational theory that has guided the development of the system.

By identifying the learning technologies routinely deployed within the educational sector, as well as those that have been superseded or fallen out of use, this chapter not only considers the current state of the art, but also examines the historical context surrounding the development of educational software. As such, this chapter discusses the impact that both past and present educational technologies have had on the development of LAVA, thereby situating the work in a wider educational context.

Focusing on five key areas of related work, this chapter examines working software systems as well as standards based approaches to the development of educational software, including:

- **Web-Based Virtual Learning Environments** (section 6.2).
- **e-Learning Standards** (section 6.3).
- **Edutainment** (section 6.4).
- **Gaming and Serious Games** (section 6.5).
- **Multi-User Virtual Environments** (section 6.6).

In addition to identifying mainstream educational software presently in use (predominantly in sections 6.2 and 6.4 which relate to Web-based virtual learning environments and edutainment respectively), the chapter also considers the role played by standards in section 6.3 and the use of computer games as a tool with which to present learning scenarios in section 6.5. It examines the degree to which other works have successfully married the properties of games to the processes of teaching and learning. Furthermore, the role of an emerging class of 3D multi-user virtual environment technologies is considered in section 6.6, particularly with respect to the support offered for constructivist based approaches to learning.

Throughout the review a staged approach is adopted, with the underlying objective of each area of related work being identified before the chapter continues to consider the generic functionality provided to both learners and educators. After introducing and discussing specific implementations of each category of work, the chapter proceeds to discuss their relevance to LAVA. In each of the five

areas of discussion, an evidence based approach is adopted, with representative examples being examined and discussed.

With a focus on a wider educational context that considers how best to meet the specific educational objectives set out in Chapter 2 (i.e. the development of scenarios which allow learners to apply conceptual and procedural knowledge); this chapter focuses predominantly on the similarities between LAVA and related work. Additionally, the technical aspects of the related work is considered, as well as its applicability for use in alternative educational settings.

By considering the strengths and weaknesses of each area of related work, as well as their uptake within the educational sector, this chapter demonstrates an understanding of the purpose of each approach, whilst also highlighting the degree to which it has had an impact on the development of software within the educational sector.

6.2 Web-Based Virtual Learning Environments

Web-based virtual learning environments are so widely deployed in higher and further education that they have become synonymous with e-Learning in general. Whilst this ubiquity may have lead to the two phrases often being used interchangeably, they are in fact significant differences between e-Learning and Web-based virtual learning environments:

- **E-Learning** has a wide scope of definition, referring as it does to the general approach of using technology to support the teaching and learning process. As an approach, e-Learning considers the pedagogical aspects of a teaching and learning exchange, with technologies adopted that are sympathetic to the pedagogical goals of the exchange [278].

- In contrast, **Web-based virtual learning environments** are a specific class of software system designed to facilitate the administration of a variety of teaching and learning processes which take place over local and wide area networks. Originally created to support distance learning over the Internet [279], Web-based virtual learning environments are now frequently used in higher educational institutions as a means by which to supplement traditional face to face learning activities [280, 281].

6.2.1 Objectives and Functionality Provided

Focusing on the administrative aspects of teaching and learning, Web-based virtual learning environments aim to simplify the management and deployment of electronic learning resources, thereby enabling non technical teaching staff to make use of the Internet as a distribution medium.

The main objective of a Web-based virtual learning environment is to provide a range of services which can be used to store, manage, distribute and control pre-existing resources that are maintained by the system. Web-based virtual learning environments do not natively provide or facilitate the

development of new educational content, and as such do not explicitly dictate a specific pedagogical approach. However, owing to the way in which learning materials are organised by Web-based virtual learning environments, there is an implicit reliance on the information transfer paradigm, with the Web being used as a means by which to reproduce didactic approaches to teaching and learning.

From an institutional level there are benefits to the use of a Web-based virtual learning environment. Owing to their centralised position within an organisation, it is possible for standardised approaches to the delivery of learning materials to be adopted, thereby allowing a host organisation to apply institution wide policies to the delivery of learning materials in order to help ensure compliance with any regulatory, statutory or copyright holder requirements [282].

Given the focus on the Web as a medium for delivery, Web-based virtual learning environments often provide additional tools to support interactions between physically separated users. As such, many systems provide a collection of tools which can be used to enable a wide variety of activities to be undertaken online, including:

- The uploading, management, organisation and delivery of learning materials.
- The submission, assessment and grading of work.
- Administration of students and groups.
- Synchronous and asynchronous communication between students and teachers.

6.2.2 Specific Implementations

The ubiquity of Web-based virtual learning environments within the higher education sector has prompted significant development of both commercial [41, 89] and open source [104, 145] offerings. As such, this is one sector of educational software in which there are a significant number of competing products. Below is a summary of the seven of the most widely used systems.

Modular Object-Oriented Dynamic Learning Environment (Moodle)

Moodle [145] is a course management system (CMS) developed to help educators create online learning communities. Supporting a social constructionist [283] inspired approach to education, Moodle facilitates the development of courses that encourage learners to become involved, to question and to build their own understanding of the materials presented using a variety of different interactive exercises in a collaborative setting (as shown in the activities window highlighted in Figure 82).

As an open source project, Moodle supports a wide range of standard formats including SCORM [140] and can import content from a number of commercial environments including the market leader,

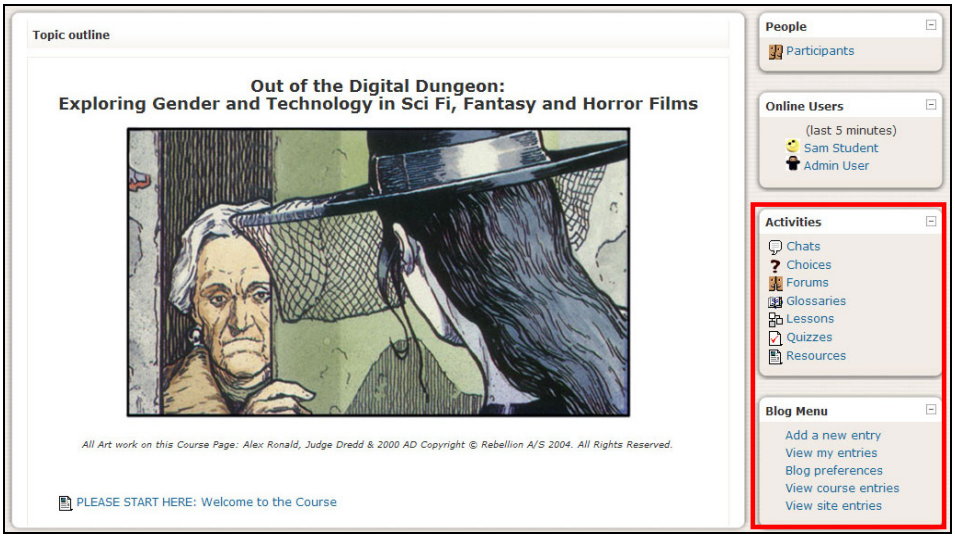

Figure 82 – Moodle Interface with Interactivity (Activities and Blogging) Tools Highlighted

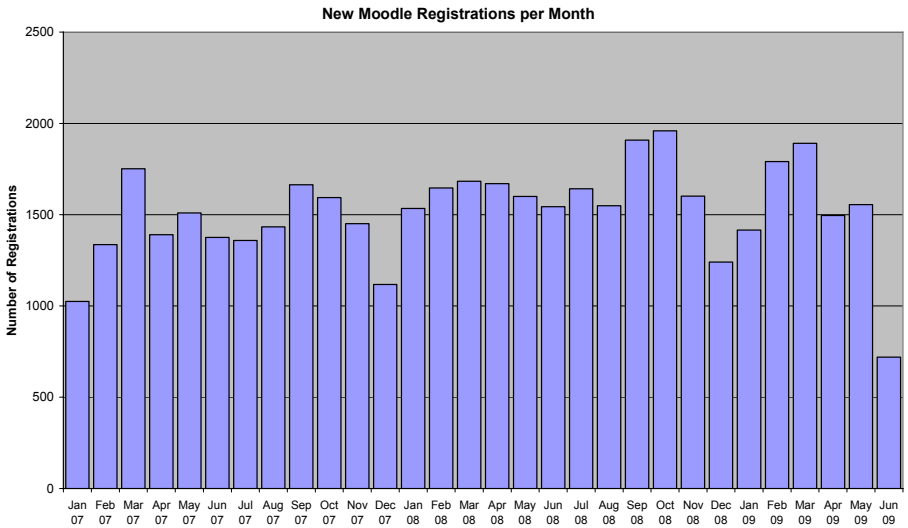

Figure 83 - New Moodle Registrations per Month (2007/8/9)

Blackboard [89] and the discontinued WebCT [41] product line. Moodle provides simplified management of many course, user and group management activities within the administrative interface and allows users to build personalised profiles based on their module assignments and personal preferences. With support from the open source community as well as a number of larger educational organisations in the UK and abroad, a number of modules have been developed for Moodle to promote synchronous and asynchronous interactions between learners. Using the standard installed modules alone, Moodle is able to provide support for synchronous chats, asynchronous forums and notice boards, lessons, quizzes, surveys and module wikis.

Developed as a scalable system, Moodle is able to support many users simultaneously. This scalability is seen as one of Moodle's major benefits and, when coupled with Moodle's support for a wide variety of authentication systems and its ease of integration into existing learning infrastructure, Moodle has quickly become popular amongst the higher education sector, with around 1400 new registrations each month (as shown in the graph in Figure 83). Worldwide Moodle is used in over 200 countries, with

around 35,000 organisations hosting nearly 25 million users [284]. Used by both small and large scale organisations, Moodle software has been put into production in a number of local education authorities and large UK organisations including the Open University [285, 286], with around 450,000 users [284], and the University of Glasgow [287, 288], with 12,000 Moodle users [284].

Bodington

Bodington [104] is a learning environment that provides all the tools necessary to provide role based access to learning materials. By modelling an institution's organisational structure, Bodington makes it possible to quickly develop resources and provide access to specific audiences using already familiar organisational roles. To extend this familiarity, Bodington makes use of a metaphor of buildings, and within these buildings, floors and rooms [289]. These physical representations are analogous to directories and folders, with the metaphor being of particular value to institutions where the students and staff identify materials and resources with specific physical locations. By tying the physical location of information in the real world with the organisational structures within Bodington, the building metaphor promotes familiarity amongst users and provides an organisational structure which is customised to the institution's requirements.

By facilitating the management of both static content: for example, lecture notes, student handbooks, course manuals, etc. as well as interactive content: for example, multiple choice tests, online surveys, logbooks and diaries, Bodington makes it easy to develop a comprehensive online course portal using a single set of tools. Comprehensive import filters make it possible for content stored in other systems to be imported into Bodington.

Bodington has been developed and deployed within a number of institutions worldwide and is fully accessible and strictly adheres to UK accessibility legislation. Within the UK, Leeds University [290, 291], the University of Oxford [292, 293] and the UHI Millennium Institute [294] all maintain large production systems alongside a second learning environment based on the commercial Blackboard Academic Suite [89]. Both Oxford and Leeds currently have plans to focus their Web-based learning provision on the Blackboard system, with existing Bodington services ceasing in 2012 [295, 296].

Learning Activity Management System (LAMS)

LAMS is a tool for designing, managing and delivering online collaborative learning scenarios [146]. With a strong focus on the sequencing of learning activities into a series of stages, LAMS differs from the majority of Web-based virtual learning environments in supporting and encouraging high levels of user interactivity. Separated into four main areas, LAMS provides different role-based perspectives on the learning process:

- The **Authoring** area (shown in Figure 84) provides the tools and interfaces required to enable teachers and other content developers to design, construct and sequence their learning

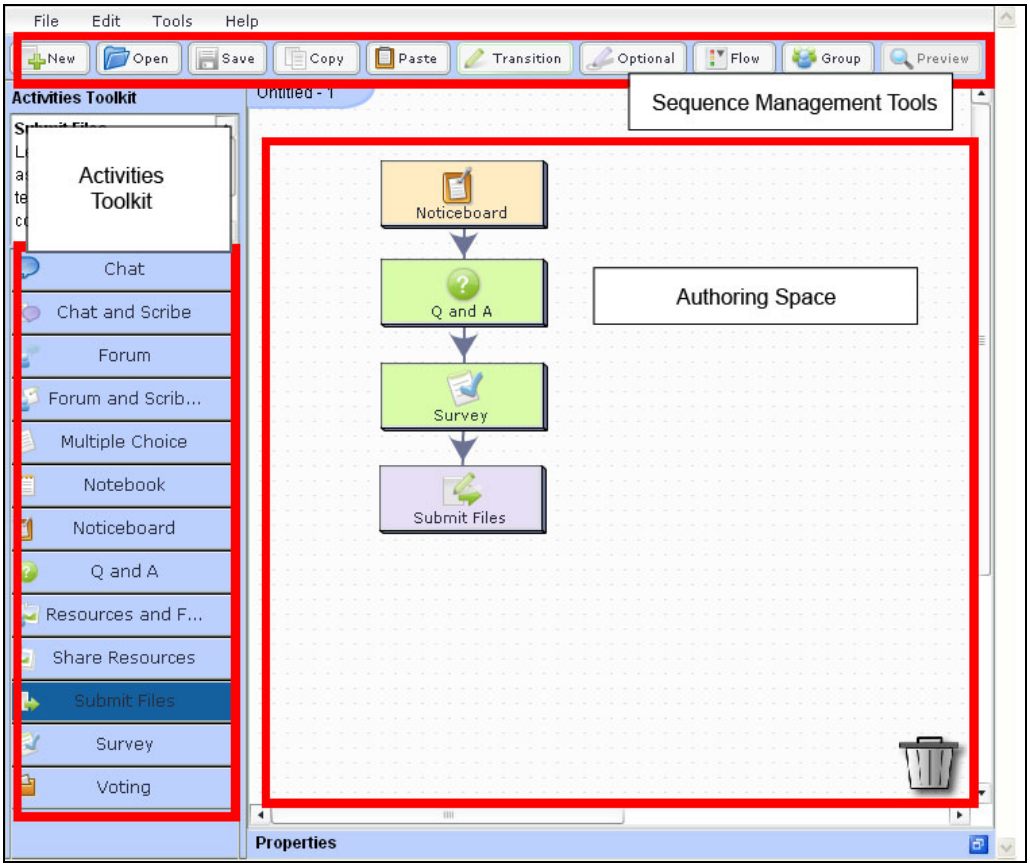

Figure 84 – LAMS Authoring Area Interface

materials. Once completed, the individual learning materials can be stored in a sequence repository and used in multiple learning scenarios.

- A **monitoring** interface is provided to allow teachers and others involved in module delivery to assign a sequence to a learner and monitor their progress through it.

- The **learning** area (shown in Figure 85) is the interface used by students. Within the learning area, groups of students are able to access the activity sequences assigned to them either individually, or as larger groups. Learners can monitor their progress through an activity by following the timeline and making notes as they wish using the notebook feature.

- An **Administration** area provides all of the tools required to maintain and administer the LAMS system. This interface is separated from the authoring, monitoring and learning interfaces in order to maintain a distinction between roles.

LAMS makes extensive use of Adobe Flash and Java on the client side, with a strong focus on collaborative activities. Within the visual authoring environment, learning resources can be designed and sequenced. To assist in the development of content, several templates can be used, including voting forums, notice boards, synchronous chat areas and question and answer boards. LAMS is IMS LD Level A [139, 297, 298] compliant and is published as an open source application. To facilitate

Figure 85 – LAMS Learning Area Interface

integration with existing virtual learning environments, a number of extensions have been developed to allow LAMS learning sequences to be directly incorporated into other learning environments and content management systems including WebCT, Blackboard, Moodle and Microsoft SharePoint [299].

As part of a JISC supported trial, LAMS was evaluated by 40 respondents in 24 institutions throughout the UK [300], 35% of which were involved in the higher education sector. During the trial, 54 courses were developed, with 14 being rolled out to students. Of the courses rolled out for student use, the uptake by students was generally positive, with most respondents to the survey indicating that the use of LAMS had a positive effect on student motivation. One of the biggest concerns reported by the trial relates to the increased administrative duties associated with the development of a LAMS course – of those who developed and rolled out courses for student use, there was a wide consensus that the use of LAMS increased the administrative duties associated with course delivery considerably.

The Module Management System (MMS)

The MMS system has grown out of the TAGS system [103, 301] which was designed to support the delivery of interactive learning resources and management of educational groups. Within MMS the module (i.e. class, course etc) is a key concept in the organisation of the system, with the first page after login listing all of the modules that the user has a stake in (either as a student or member of staff) as shown in Figure 86.

Each module comprises a number of resources that provide tools and services to users. Providing the functionality to support basic management functions, including: coursework submission, marking and feedback, exam reporting, and returning module grades to the institutional registry has been a major focus of MMS, with the intention of streamlining the administrative burden associated with managing course modules so that academics are afforded more time for teaching and research activities.

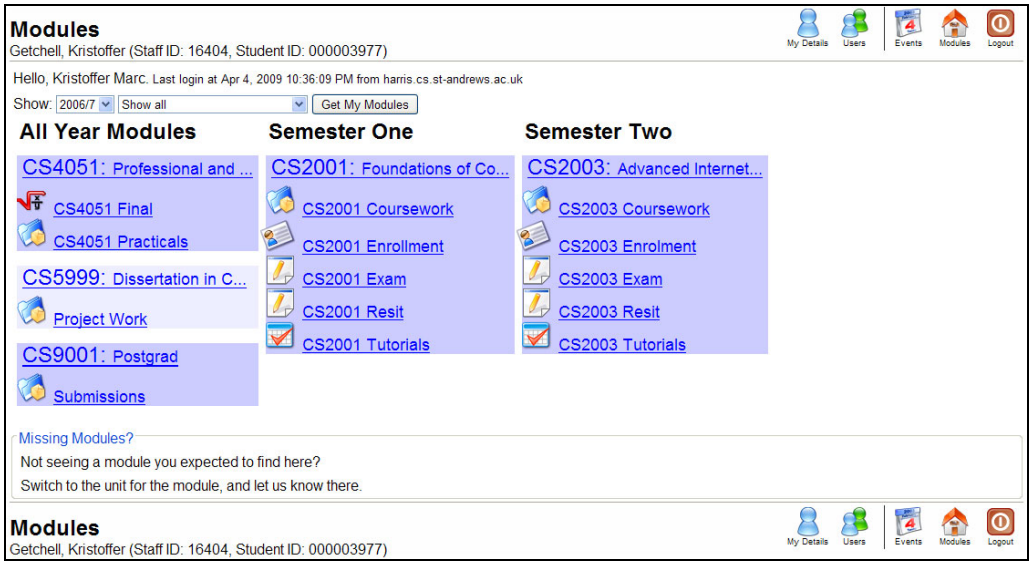

Figure 86 – The MMS Module Listing Page

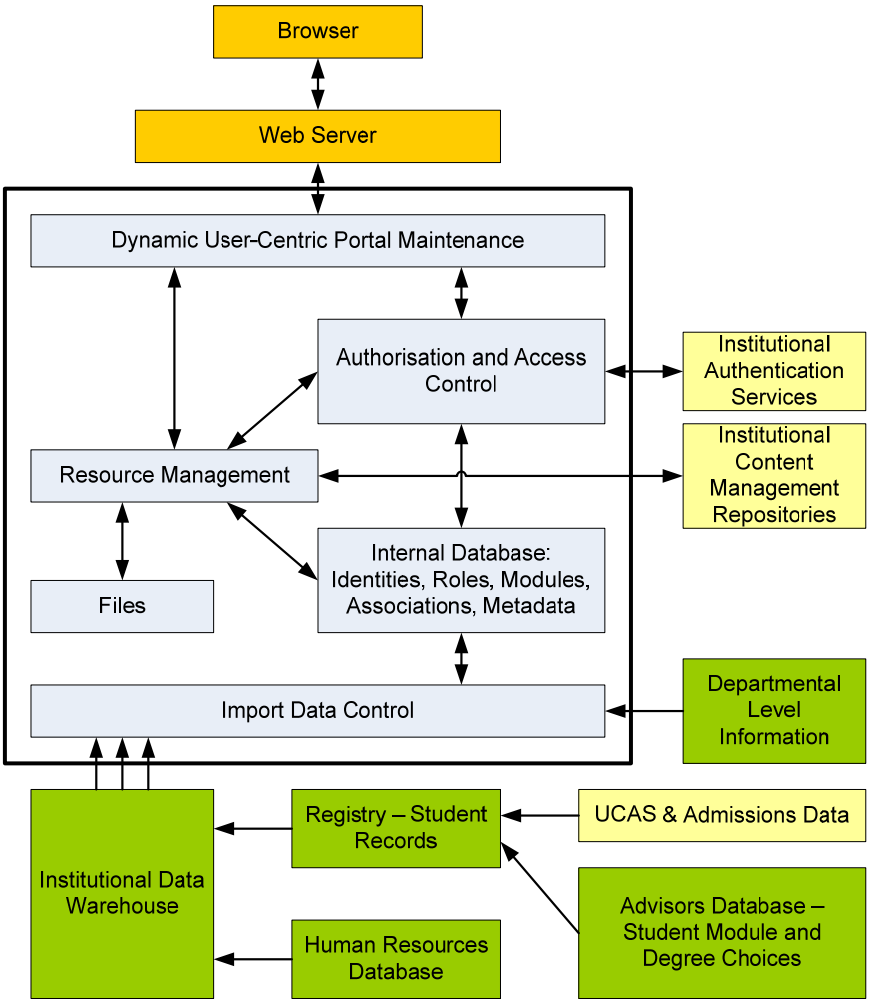

Figure 87 – MMS Integration with Existing Institutional Infrastructure

Through the use of a published API, additional resources can be developed and integrated into MMS, thereby extending the functionality offered by the system. This API has been used to introduce a number of innovative learning facilities, from the early spin-off Finesse [236, 302], a stock market portfolio management tool using live data from Reuters [303], to support for problem based learning using Robocode [304].

By integrating with existing institutional infrastructure, MMS provides single sign on support, with institutional users able to access resources using their standard login credentials. Roles are assigned to users on a module by module basis, therefore allowing varying levels of access to modules based on the needs of the institution. Given the fine granularity of the authorisation system, MMS makes it possible for a user to be treated as a student in one module, but as academic or administrative staff in another. Institutional data is also used to populate module information, with an understanding that any data exported from institutional data sources may be stale (and/or inaccurate), in which case it can be overridden locally in MMS with any changes replicated back to the original data source if required. Figure 87 gives an idea of the general interactions MMS undertakes with other data sources within an institution.

Given the capabilities and flexibility of resources, MMS can also be used for other functions, with the attendance monitoring and reporting resource being used frequently to track lecture and lab session attendance at the University of St Andrews. By providing swipe card monitoring of designated lectures, lab sessions and tutorials a user can quickly access a calendar of their academic schedule, as well as a summary of their attendance to date.

WebCT and Blackboard

Initially two separate products, WebCT and Blackboard are slowly being merged into a unified learning architecture targeted at both business and educational institutions. The underlying objective of the merger of WebCT and Blackboard is to provide a wide range of tools aimed at enabling institutions to develop, manage and deliver their curriculum objectives using a variety of online technologies.

As one of the most popular commercial learning environments, uptake of the Blackboard Academic Suite has been high. With the takeover of WebCT in 2005 [305], the Blackboard product line is a market leader. Within the UK, Blackboard's position in the market is well recognised, with JISC developing a number of regional user groups to support the development of best practice approaches to the deployment of Blackboard and WebCT products in the UK.

The Blackboard Academic Suite [89] is available in different versions based on the size, user base and requirements of an institution. At the heart of all versions is a closed source course management framework based on an architecture called Building Blocks. Building Blocks can be used to extend the functionality of the core system using third party components which adhere to the Building Blocks standard. Blackboard, third party developers, and educational institutions are all able to make use of

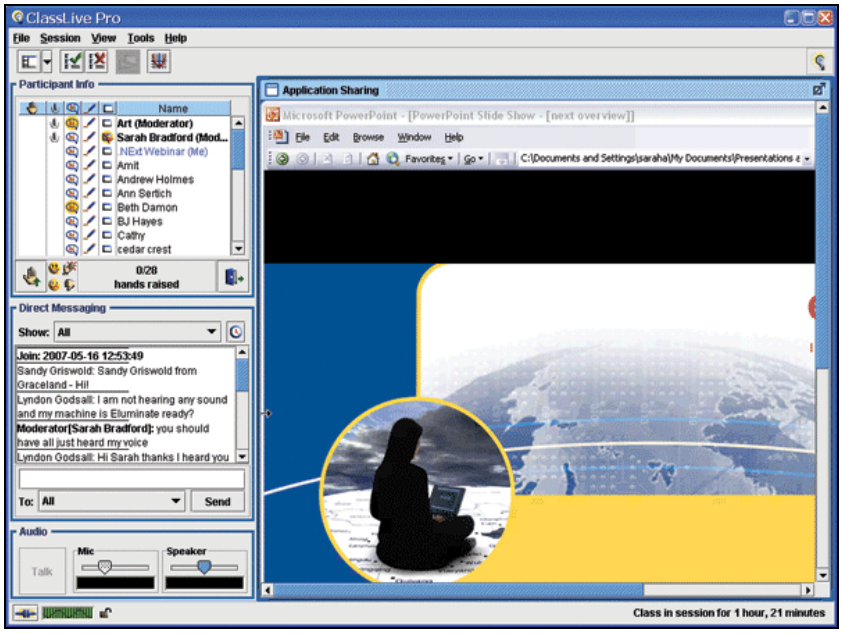

Figure 88 – eCollege Class Live Pro Whiteboard and Video Conferencing Tool

the Building Blocks technology to develop and deploy a wide selection of extensions and ready made content to enhance the Blackboard Academic Suite.

eCollege

eCollege is a Web-based virtual learning environment used predominantly in higher educational institutions and secondary schools. Unlike other environments which are generally hosted and maintained on local servers, eCollege adopts a third party hosting model, with all aspects of the delivery of the service managed on behalf of the purchasing institution. A dedicated eCollege site for each institution is created on eCollege's network, with direct links into the client's Web infrastructure. By moving the hosting into a managed environment, eCollege is designed to be easy to deploy and maintain, with centralised monitoring, software updates and backups carried out by the vendor.

As with other Web-based virtual learning environments, eCollege provides a wide selection of tools to assist educators and learners alike. In addition to the asynchronous communication facilities commonly offered by Web-based environments, eCollege provides a suite of Java powered applications (as shown in Figure 88) which enable real time audio and video conferencing between users as well as the ability to work on shared whiteboard space.

Import and export of data is facilitated through a series of standardised file formats, with flat files (Comma Separated Values) and the IMS Enterprise Specification 1.1 [306] format being supported. eCollege supports bi-directional integration with existing institutional systems using either batch mode secure FTP transfers or real time SOAP Web service [307] transactions, thereby enabling organisations to integrate eCollege data with existing institutional infrastructure.

Each eCollege instance may be branded to match the client institution, with a number of template roles making it possible for institutional customisations to be made. As a hosted application, extensive modifications to the underlying platform are difficult for an institution to undertake alone, however eCollege provides a number of support and consulting services to facilitate changes of this nature.

Angel Learning Management Suite

The Angel Learning Management Suite [308] has evolved from research and teaching experience gained during the development of the OnCourse [309] course management system at Indiana University. Following the commercialisation of the Angel Learning Management Suite, it was provided as a service to end users in much the same way as eCollege. As with Blackboard products, the Angel Suite supports the development of third party add-ons, with integration possible through the use of the Web service API built directly into the architecture. In addition, the Angel Suite also offers an Objects and Extensions Framework which can be used to integrate new learning object types and extend the underlying platform.

In much the same way as the Blackboard Academic Suite, the Angel Learning Management Suite provides a wide variety of tools for both educators and students. One noticeable difference between the two offerings is the availability of import filters. Unlike the Blackboard Suite, the Angel Suite is not a market leading product and so a much wider collection of import filters are provided in order to enable existing content from competitor products to be imported into Angel, with Angel also providing standards based export filters to further enhance content portability. As a member of the IMS Global Learning Consortium [310], Angel Learning have contributed to, and developed products which conform to, a number of learning standards including:

- **IMS CC – Common Cartridge Support [311]:** An open standard for delivering course content in a standardised format.

- **IMS QTI 2.1 – Question and Test Interoperability [312] and IMS TI – Tools Interoperability [313]:** All assessment content and tools developed within the Angel Suite are built to be compliant with openly published IMS standards. All assessment exercises within the Angel suite are developed and delivered using an assessment engine built to QTI 2.1 specifications, with all tools supporting tool interoperability standards to ensure seamless integration and single sign on across a variety of third party Web applications.

- **IMS Content Packaging Information Model 1.1.4 – Content Interoperability [314]:** Angel interoperates with instructional materials developed in accordance with the IMS Content Packaging Information Model structure.

- **ADL Sharable Content Object Reference Model (SCORM) [315].**

- **IMS ACCLIP – Access for Learner Information Pages [316]:** Angel is the only learning environment that supports ACCLIP, allowing Angel to adapt to a learner's specific accessibility needs and preferences before or after they login to the system. Because it is standards based, students who have defined accessibility needs in other systems can seamlessly import this data directly into their Angel profile.

As of May 2009 it was announced that Blackboard and Angel Learning would merge to form a single organisation [317], further strengthening Blackboard's dominance in the educational sector. As the merger has only recently been announced, no visible changes are apparent in the Angel Learning Management Suite at the time of writing.

6.2.3 Relevance to LAVA

Whilst each of the examples offers a different approach to the presentation and management of the learning process, all provide tools and services to allow learners to access and interact with learning materials as well as other learners. In addition they provide a number of features designed to ease the administrative burden associated with the development, maintenance and control of Web-based learning materials. These features are relevant to the development of archaeological excavation simulations and as such have informed the approach adopted by LAVA.

When considering the drawbacks of existing Web-based virtual learning environments, the most striking issue relates to the focus of the systems, with a concentration on the management of the learning process, thereby neglecting to fully consider the pedagogical approaches they implicitly encourage. Given the transactional nature of the Web, there is a strong tendency for Web-based virtual learning environments to focus on the information transfer paradigm as a means by which to present learning materials. Whilst additional tools are generally provided to encourage an element of learner interactivity, they are largely extraneous to the learning process, and certainly not central to it.

Both LAMS and MMS take significant steps to provide support for more interactive pedagogical approaches to be developed. In the case of LAMS, an approach focusing on collaboration and constructivism is supported through the provision of tools which allow learners to work in groups throughout the learning process. In MMS, educators are provided with further scope for development, with an API provided to make it possible for extensions to the system to be developed. Through these extensions it is not only possible for the behaviour of MMS to be tailored, but for specific learning processes and pedagogical approaches to be supported. However, development of MMS resources is not trivial, requiring knowledge of the Java programming language.

When considering the extensibility of the commercial and hosted environments (i.e. Blackboard/WebCT, eCollege and the Angel Learning Management Suite) there are issues relating to extensibility. Whilst Blackboard/WebCT, eCollege and Angel all support a degree of customisation,

without access to the source code of the software, any extensions are naturally limited by the capabilities exposed through the respective plug-in interfaces. In addition, when considering the need to support different pedagogical approaches, the suitability of the hosted environments (Angel Learning Management Suite and eCollege) again raises some serious considerations. Not only are the hosted environments shared amongst several users (this alone could become a significant limiting factor), but they are also designed to be managed and maintained by a third party vendor, thereby adding an additional layer of complexity when developing extensions to the underlying system.

Given the restrictions associated with commercial offerings, the use of an open source Web-based virtual environment seems, in principle, to offer the best opportunities for the development of tools and mechanisms to enhance the support for alternative pedagogical approaches to the teaching and learning process. As such, LAVA has been loosely coupled with MMS to take advantage of the management functionality and extensible API that it provides.

In summary, whilst Web-based virtual environments offer support for the administration and management of learning resources, their focus on didactic approaches mean that the types of interactivity that they can support are limited in nature. Whilst providing useful functionality which LAVA capitalises on (for example, the integration with existing institutional identity management systems), the functionality of Web-based virtual environments is largely orthogonal to this work.

6.3 e-Learning Standards

Within the educational sector the Blackboard and WebCT product lines have, through their widespread adoption, quickly become a de facto standard (i.e. the Proprietary standard) which dominates the e-learning sector. As the discussion in section 6.2 shows, Blackboard's continued expansion and acquisition of competing products is only set to further reinforce this dominance. Whilst this consolidation is good for the purposes of ensuring continuity of products and familiarity amongst users, the lack of any clearly defined, published standards for interoperability raises the barriers of entry into the marketplace with new products struggling to interoperate with existing ones. This makes the adoption of new products both costly and time consuming as existing materials must be adapted before they can be used in new systems. This further entrenches the dominance of existing market leaders by stifling competition and innovation within the market.

An alternative to the proliferation of a single, dominant vendor is the development of open, freely accessible standards to which all competitors adhere (i.e. the Community standard). In this model an underlying set of standards emerge from within the community, with a working group often established to maintain them. Individual products are developed by a variety of organisations, all of which work within the guidelines of the standards. In this way, interoperability is promoted and users can move between systems with relative ease. A good example of this approach is the development of the HTML standard for Web pages [318] as managed by the World Wide Web Consortium (W3C) [77].

As the dominant standard for the mark-up language used to create Web pages, HTML makes it possible for authors to develop pages which can be displayed in a variety of applications that support the HTML standard. In order to allow authors to describe the structure of text-based information within a document, HTML associates meaning with a pre-defined series of tags which denote text as certain elements within the document, including links, headings, paragraphs, lists, etc. as shown in blue below.

```
<?xml version="1.0" encoding="utf-8"?>
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.1//EN"
"http://www.w3.org/TR/xhtml11/DTD/xhtml11.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
<head>
<title>This is a Simple HTML Page</title>
</head>
<body>
<h1>This is a Title</h1>
<p>This is a paragraph <a href="link.html">with a link</a></p>
</body>
</html>
```

Over time HTML standards have become more robust, transitioning through a variety of versions from HTML through to XHTML [318-321] (eXtensible HTML) which allows for extensions to be defined in additional namespace and document type declarations (i.e. the lines at the start of the document which precede the `<head>` tag). Of course, in practice very few applications fully support the HTML standards; however, most provide support which is adequate to enable the same document to be rendered reasonably consistently across applications, thereby providing users with reasonable levels of interoperability between systems.

Finally, an alternative to both approaches is the adoption of standards which are carefully designed and planned by standards institutions charged with developing and maintaining key standards to support interoperability (i.e. the Standards standard). Unlike the Proprietary and Community standards, Standards standards are designed using a top down approach. As such they can sometimes be rather delayed in receiving final ratification, with the resulting standards often less relevant to current practice than Proprietary and Community standards which are often developed based on real world practice.

6.3.1 Objectives and Functionality Provided

Within the e-learning sector, the development of standards has been somewhat piecemeal, despite the involvement of a number of Standards bodies. At a high level, the development of a standard is undertaken in order to provide an ordered and uniformed approach to a specific activity. Standards are designed to allow interoperability, with every product that conforms to a given standard being interoperable [322, 323].

Historically standards and standards bodies have been very important, with standards often being developed in response to a specific need (i.e. interoperability in an environment when multiple systems need to communicate) [323]. Standardisation allows the creation of common approaches which facilitate interoperability between standardised components. They can also provide quality assurance,

with standards guaranteeing that compliant systems will provide certain levels of functionality and performance. If one considers the widespread use of electricity, or the use of the Internet, the power of standardisation quickly becomes apparent – without widely agreed and accepted standards neither would be routinely used as it is now. If we consider electricity, the use of standardised plugs and voltages has allowed electricity to be used in a vast array of devices for all manner of purposes worldwide. A similar trend can be seen with the Internet - the adoption of TCP/IP [215], HTTP [223, 224] and HTML has paved the way for uniformed access to a wealth of information hosted on Web servers globally.

Within the e-learning sector, the development of standards is undertaken with the aim of providing benefits to both educators (who develop and maintain learning content) and students (who consume and otherwise interact with learning content). Of the myriad of standards that exist within the education sector (many of which are defined by the bodies discussed in section 6.3.2), many aim to promote interoperability [313], encourage platform independence [311] and allow learning materials to be shared, managed and maintained for use in a variety of educational scenarios [314, 315].

Of the current standards, those that are most relevant to current practice relate to the ways in which learning materials are packaged and maintained so that resources can be reused in different learning environments. From an educator's perspective this is desirable. Not only does it reduce the amount of time spent modifying resources for specific learning environments, but it also provides opportunities for resources to be used in several courses and, if appropriate, shared with the wider community. This has the effect of creating a wider market for learning materials which, whilst designed for a specific course or module, can be shared and traded across departmental or institutional boundaries. Of course, for interoperability of this nature to be realised, learning environments also need to conform to a standardised approach in their handing of learning materials. As such, standards governing this aspect of e-learning also exist [311-313].

6.3.2 Specific Standards Bodies

Despite the increasing use of computers in the delivery of learning materials, at present there is no single set of standards adopted by all vendors in the educational sector. Whilst the open source community and commercial developers are working towards standards compliance for issues such as data description, content packaging and content interchange, the sector is still very much filled with proprietary data formats. Although there are four key organisations pushing forward the agenda for a single set of commonly adopted standards, the adoption of standards is likely to be consumer-led, with end users ultimately favouring a subset of standards based on the products that prove to be most popular.

Learning Technology Standards Committee (LTSC) of the IEEE Computer Society

Many groups creating learning materials for e-learning choose to adopt IEEE LTSC P1484 [324] as a way to define and describe their learning materials in an accessible way. With standards covering a

wide variety of topics including learning object metadata, student profiles, course sequencing, computer managed instruction, competency definitions, localisation, and content packaging, IEEE LTSC has published extensively within the educational domain. It is envisioned that much of the work of the IEEE LTSC will be internationalised by the International Organisation for Standardisation (ISO) [325] through the ISO Joint Technical Committee 1 Sub Committee 36 on Learning Technology.

Advanced Distributed Learning Initiative (ADL)

The work done by the US Federal Government ADL initiative [326] on the Shareable Courseware Object Reference Model (SCORM) [315] provides a good example of the application and integration of learning standards. SCORM guidelines provide a foundation for how the US Department of Defence uses learning technologies to build and operate in the education sector. The US military, be it Navy, Air Force or Army, can all use, exchange, manage, track, and reuse their learning content and data irrespective of its source or authoring application. Moreover, the adoption of a uniformed set of standards allows the US Government to avoid vendor lock in, with the ability choose any vendor that complies with the IEEE LTSC standards and the SCORM specifications.

Instructional Management System (IMS) Global Learning Consortium

The IMS Global Learning Consortium develops and promotes open specifications for facilitating online distributed learning activities such as locating and using educational content [314], tracking and reporting learner progress [312], and exchanging student records [316] between administrative systems [327]. IMS has two key goals:

1. To define the technical standards for interoperability of applications and services in distributed learning.

2. To support the incorporation of IMS specifications into products and services worldwide.

IMS is a global consortium with members from educational, commercial, and government organisations. IMS generates the majority of its funding through membership fees and freely distributes its specification documents online via its website [328] for anyone interested in developing or contributing to them.

One notable exception from this list is the International Organisation for Standardisation (ISO) [325], an international non-governmental organisation with approximately 158 national members tasked with developing and ratifying global standards. ISO has three membership levels:

- **Member bodies** are generally countries with their own standard bodies and have full rights to participate in and follow the ISO standards development process.

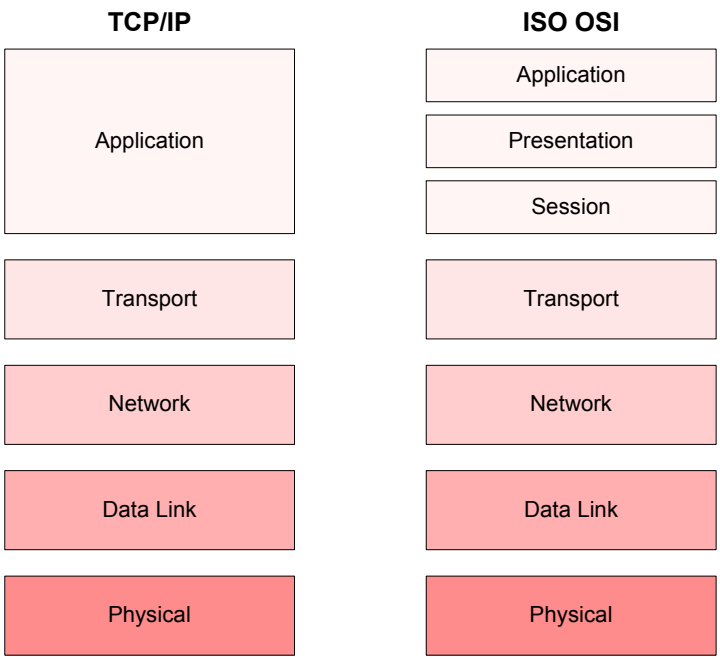

Figure 89 – Comparison between TCP/IP and ISO OSI

- **Correspondence members** are usually countries with no national standards body. Members at this level have rights to follow the ISO standard development process but cannot actively participate in it.

- **Subscriber members** are frequently countries with small economies. In exchange for a reduced membership fee, subscriber members can follow the development of new standards but cannot actively participate in the development of them.

The ISO have a single subcommittee of the Joint Technical Committee 1 dedicated to developing, maintaining, promoting and facilitating standards for Information Technology for Learning, Education and Training – subcommittee SC 36. It is anticipated that the specifications and standards developed by IEEE LTSC will be submitted to ISO for internationalisation. However, at present, ISO are not actively promoting or developing any relevant standards in the educational sector.

6.3.3 Relevance to LAVA

Within the educational sector the dominance of Blackboard as market leader has created a de facto standard which poses a significant challenge to the adoption of open standards like those published by IMS and ADL. One of the problems associated with the development of standards is ensuring their uptake within the wider community. With products from Blackboard often failing to offer support for open standards it becomes very difficult for them to become established within the sector, irrespective of any improvements that they may be able to provide. The failure of the ISO Open Systems Interconnect (OSI) Reference Model [329] as an alternative to the TCP/IP protocol stack is a prime example of such failure, with the easier to implement TCP/IP protocol stack becoming dominant over the ISO OSI model due to its simplicity, efficiency and existing level of adoption. A comparison between the ISO OSI and TCP/IP approaches is shown in Figure 89.

When considering the ISO OSI versus TCP/IP example, the outcome was for the community to adopt the existing TCP/IP approach as the mechanism through which to effect computer to computer communication. As part of this process, TCP/IP in effect became a standard in its own right [215, 330], albeit one which was not originally planned and designed to be a standard as carefully as the ISO OSI model was. This also highlights another important point, demonstrating that free and open standards can, with enough backing, become dominant within a given domain.

When considering the community practice and the focus of many e-learning standards, it can be argued that a disconnect exists, with community practice favouring an approach which leads to the development of systems that are able to perform defined academic objectives. In contrast e-learning standards often concern themselves more with processes and designs which have little or no bearing on the ability for a system to meet any academic objectives. As such, this work concludes that in general standards need to grow out of the best practices found in the community if they are to become successful and widely adopted.

In keeping with this discussion, LAVA has adopted an approach which seeks to support a specific pedagogical approach to solving a real world problem, with a focus on the provision of tools and functionality designed to meet these needs. As such, the structure and layout of LAVA has been predominantly dictated by pedagogical concerns and not by standards compliance. However, this does not mean that standards were not considered during the development process. The Web-based components of LAVA are designed to be fully compliant with the APIs provided to support extensions to the MMS system.

6.4 Edutainment

The combination of education and entertainment is often referred to as edutainment. Typically designed so that educational content is embedded into enjoyable entertainment scenarios, edutainment can take many forms, with film [331, 332], television [333, 334] and radio programmes [335] as well as computer games (discussed in more detail in section 6.5) and other types of entertainment software [336, 337] featuring widely. Outwith the electronic environment, the increasingly popular educational play facilities featured in many museums are also a form of edutainment, with the London Science Museum's Launchpad Exhibit [338, 339] and Sydney's Powerhouse Museum [340] being prime examples of how to communicate scientific principles in an interactive and entertaining setting.

Whilst edutainment has a broad spectrum of supporters, it does not enjoy universal approval. The increasing use of edutainment within museums is often cited as problematic, with claims that the entertainment and enjoyment aspects of an exhibit are given preference over the historical and educational content being presented [341]. As such, critics of edutainment argue that it devalues the quality of education that can take place, with museums placing too much emphasis on developing interactive and entertaining exhibits which are superficial in the content that they present [341].

Within the education sector, edutainment has been met with mixed success amongst different age groups. Early childhood has generally seen positive results with Reader Rabbit (software) [342], Magic School Bus (books) [343] and Maths Blaster (software) [344] all successfully creating enjoyable and educational experiences. When considering older age groups, there are fewer reports of successful uses of edutainment. This may be due to the fact that there has been no sustained exploration of how to create more sophisticated educational experiences for late adolescents, or it could be indicative of older age groups becoming aware of crude attempts at embedding snippets of educational content into entertainment scenarios [345]; for edutainment to be truly successful it needs to form an integral part of the content being presented [345], with hospital dramas such as Grey's Anatomy [346] and Casualty [347] being examples of how to convey factual information relating to medical issues in an entertaining way.

6.4.1 Objectives and Functionality Provided

The overarching objective of edutainment is to provide an environment in which it is fun to learn, thereby encouraging learning to take place. Taking many forms, edutainment considers the way in which educational content is presented, with a strong emphasis on drawing out the interesting and exciting aspects of a subject area. An interactive, hands on approach is often adopted, with learners encouraged to become active participants in the learning process. In this way edutainment encourages a very social approach to learning, with groups often forming part of the overall process.

Edutainment does not necessarily require the use of electronic resources or materials and is frequently applied in pre-school and infant classrooms, with teachers encouraging learners to ask questions, give opinions and provide answers. Often props are used to encourage participation and attract the attention of learners.

When considering the use of edutainment in films and television programmes, it is important that the educational content is an integral part of the storyline. In this way educational content can be discreetly delivered to learners, thereby maintaining the integrity of the entertainment value associated with the media. In general this is achieved well, with many examples of informative broadcasting for a variety of age groups as discussed in the previous section.

Within the software sector, edutainment titles aimed at younger children have generally fared well, partly due to the use of interactive animations, audio and video to attract and engage the learner's attention. This success, however, has not been achieved in the software packages aimed at late adolescents, with many attempts finding it difficult to create discreet learning scenarios which are able to attract the desired level of continued interest from their target audience [345]. In many ways these failures are not surprising, with many edutainment titles aimed at older children adopting a rather crude approach to the introduction of learning materials which often sees a poor attempt at a modern computer game spliced with segments of educational materials. As such, for edutainment to appeal to older audiences it is important that the educational content being presented is not simply surrounded by fun activities, but is instead designed as an integral part of the entertaining content being presented.

6.4.2 Relevance to LAVA

As educational tools, the methods and techniques implemented in edutainment titles are of relevance to LAVA. In some ways LAVA shares similarities with the approaches adopted by edutainment products. As discussed in Chapter 4, LAVA emphasises the use of realistic data obtained from real excavation sites, with the content of the excavations being central to the simulations presented in much the same way that the learning content contained within edutainment films and television programmes is central to the underlying storyline being presented.

In addition, LAVA also shares the approach advocated by some types of edutainment software with respect to encouraging engagement. When considering the role of the learner in edutainment software, their interactions are of primary importance, engaging with the content at frequent intervals. Within LAVA a similar trend can be seen, with learners required to make decisions and attempt to solve problems in order to progress through the excavation simulation.

Furthermore, the social aspects of LAVA have been informed by the social aspects of edutainment, with learners in LAVA often collaborating and working as a group in order to solve problems; an approach adapted from reviewing the ways in which multiple learners interact with hands on museum exhibits.

However, there are also a number of key differences in the approaches adopted by LAVA and edutainment. Unlike edutainment, LAVA's main focus is on academic validity. As such, educational content is not simplified or abridged in order to maintain a sense of entertainment. LAVA's primary objective is to provide an educationally stimulating environment which simulates that of a real world excavation site. This is reflected by both the detail and presentation of the educational content delivered by the system.

6.5 Gaming and Serious Games

The computer games industry has grown enormously in recent years, as has the cost associated with the development of modern games [348]. As part of this expansion there has been a significant shift in the structure of games, with the industry moving from a monolithic structure to one which is modular in nature. This transition has allowed game makers to introduce a separation between the game content (i.e. the logic, graphics, storyline, methods of progression, etc.) and the underlying game engine (i.e. the software which controls the visual and audio output, handles network communication, and user input, etc.). This separation of engine and content has made it possible for multiple titles to be developed using the same underlying technologies, thereby reducing the costs and lead times associated with the production of a new game. In addition it has opened up a new revenue stream, with game developers able to sell the rights to use their game engines to third parties. As such, the possibility of putting gaming technologies to other uses has significantly expanded.

In addition to opening up game engines for use in different titles and across several platforms, the modular separation adopted by game engine developers has also made it possible for comprehensive

game modifications (or mods) to be developed by the gaming community. Not only do these mods extend and enhance existing game play and features, they can also be used to develop additional game scenarios and, in some cases, alter the underlying game objectives and logic, with many online communities established to develop, publish and support such modifications [349-352]. Developing game mods has also won wide support from the developers of game engines, with many official and third party tools being released to allow game mods to be developed. Indeed both id Software and Epic Games have produced official map and texture editing applications designed to allow the gaming community to make customisations to their respective products [353, 354]. In this way, by supplementing existing game content, the development of mods is far less onerous than the approach of developing the entire content for a serious game from scratch. As such, this modding method has been used on several occasions to good effect (see section 6.5.2 for more details).

The ability to gain access to existing engines offers a significant advantage. Not only does it simplify and expedite the development process through software reuse, but it also allows the development of serious games to benefit from the technological improvements that innovation in the games sector brings. However, it is important to note that whilst there are several benefits, the use of commercial game engines can introduce restrictions on educators, with issues relating to licensing, hosting of game services, and the level of interactivity and customisation required needing to be addressed before meaningful learning scenarios can be presented. Whilst licensing and hosting issues are likely to be resolved with time (older commercial game engines are often made available for download under open source licenses as in the case of id Software's Quake Series [4, 141, 355, 356]), the level of customisation required can still pose significant problems for educators looking to develop rich interactivity in their learning scenarios. Oftentimes the level of interactivity offered by games differs from that required by educational scenarios. In addition, the strong goal oriented organisational approach of many games which operate within a closed environment can prove problematic when faced with an educational scenario which requires students to operate freely and explore an open environment in which others are also interacting. As such, for the re-tasking of a game to be beneficial it is important that the pedagogical and educational objectives of the learning processes being modelled are confirmed as being able to be delivered effectively within the gaming environment.

The re-tasking of computer games as a tool for teaching and training is not a new concept. For a long time games have been used for serious purposes, with flight simulators having a long history of use as a means for pilots to refresh their training and practice the skills required to deal with emergency situations [198, 357]. Increasingly games are also being deployed by the Armed Forces as a recruitment and training tool. An example of such application is the use of America's Army [193] by the US Armed Forces as a way to teach and test skills that are difficult to rehearse in real world environments [358] as well as to inspire possible new recruits to join up [359]. Often used as a part of a wider suite of tools, games are frequently combined with other types of real world activities so that the benefits of both the real and virtual worlds can be combined. Whilst games are able to provide simulated experiences, they are not suitable as a direct replacement for real world experience. As such

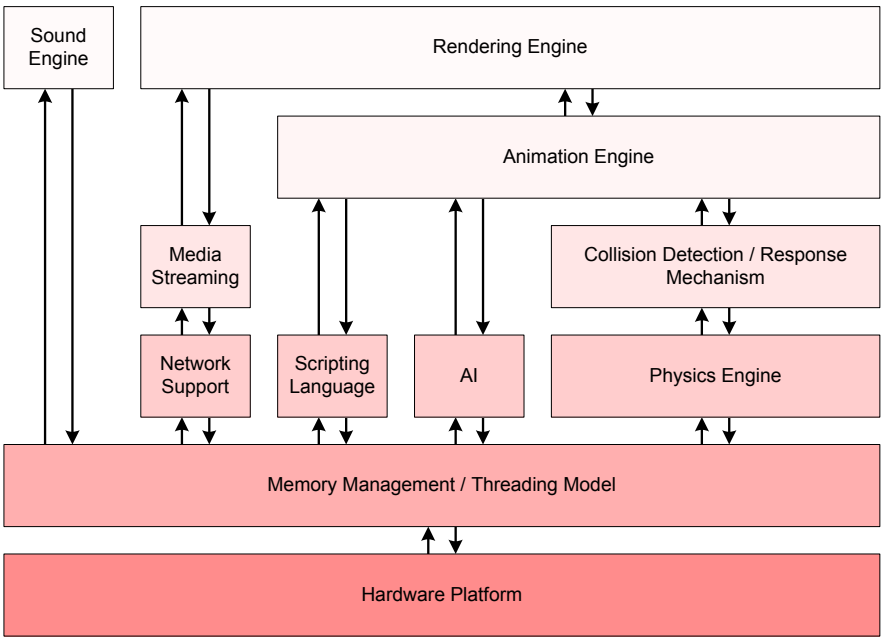

Figure 90 – Exemplar Modular Game Engine Structure

it is important to consider games as an addition and enhancement to existing practice and not simply a replacement of it.

6.5.1 Objectives and Functionality Provided

The overriding objective of a game is to provide an engaging and challenging form of entertainment. In order to do this, game engine designers need to ensure that their engine is able to run on a wide selection of hardware components from a several different vendors. One of the approaches frequently adopted to assist with this compatibility is the use of a modular structure, with loose couplings linking components within a game engine.

At its most basic, a game engine will provide a selection of the following generic features as represented in the example architecture shown in Figure 90:

- A **Rendering engine** to support the presentation of 2D or 3D graphics.
- Support for **sounds** to be generated based on a player's activity within the game.
- A **Physics engine** and **collision detection** (and optionally **response**) **mechanism(s)** to allow realistic in game interactions between players and the surrounding game environment.
- **Artificial intelligence** to allow the behaviour of game actors to be managed so that interactions with players can be developed. This allows the flow of the game to be controlled to a certain extent based on a player's actions and responses, and can also enable an element of storytelling, with game actors being positioned at strategic points within the game. The Grand Theft Auto [176, 360-362] series of games makes extensive use of artificial

intelligence to manage the actions of the people and vehicles which a player encounters during gameplay.

- A **scripting language** to enable players to trigger events within the gaming environment. In addition, scripting languages can be used to control the behaviour of game actors which interact with players as part of the gameplay scenario. Oftentimes scripting languages can also be used to enable players to develop scripts to alter the gaming environment by turning features on and off based on the current state of play.

- A means through which to **animate** activity so that a player's interactions within the environment can be visualised in a realistic way. In addition, animation is frequently used to develop cut scenes which portray a fixed sequence of activities to players. These cut scenes are a key feature of many games including the Grand Theft Auto [176, 360-362] and Quake [4, 141, 355, 356] series of games, playing a crucial role in presenting the underlying story being acted out by players of the game.

- **Networking Support** to enable multiplayer gameplay.

- **Streaming** of media to allow content to be distributed to, and between, players.

- **Memory management** and a **threading model** which allow the game engine to manage the hardware resources provided by the system upon which it is executing.

- In addition, whilst not strictly part of the actual game engine, developers often provide a suite of **development tools** which allow content for the game engine to be created, packaged and distributed to players.

In this arrangement the components in use are interchangeable, thereby allowing the game engine to use different subsets of components based on the hardware platform in use. In addition, a modular approach makes it possible for specific features of the engine to be extended or replaced, with additional components providing extra capabilities as required. This increases the level of customisation supported by the underlying engine and allows game developers to choose the components that best fit the needs of a specific game.

In many ways game engines are similar to the Java Virtual Machine [363], in that they provide a level of abstraction over the underlying hardware of the computer running the engine. This offers a degree of hardware independence, thereby making it easier for games to be ported to a variety of platforms, including mobile phones and Web browsers. Increasingly higher level languages are also being used to develop game engines with Java [364] and C#.NET [365] featuring in many game engines [210, 366, 367]. Whilst higher level languages are often criticised for being relatively inefficient in comparison with lower level languages such as C [368] and C++ [369], these inefficiencies are more than

accounted for by the increases in computing power that Moore's Law predicts [3, 66, 73] (as discussed in Chapter 2). In addition, as higher level programming languages are generally more accessible for humans to read, their use can have a positive effect on the timescales associated with code development and maintenance.

Despite this gradual progression to higher level languages, game engine designers still spend considerable amounts of time tailoring their game engines to maximise performance, as it directly relates to the quality of experience provided to players. One of the largest game development companies, Valve Software [370], frequently conducts hardware surveys as a means by which to gauge the current hardware used by players [371]. This allows them to tailor the Steam engine to be compatible with popular hardware setups and it also offers content designers the ability to assess the capabilities of the target audience's gaming platform in an effort to enhance the gaming experience.

6.5.2 Specific Implementations

There are many examples of games being used as the basis for serious purposes, with the research and training sectors being especially quick at identifying the opportunities provided by re-tasking game engines. Many projects have been successfully undertaken using a variety of different game engines:

- The **Unreal Engine 2.0** [372] has been used as the basis of a virtualisation of the National Institute of Standards and Technology (NIST) Reference Test Facility for Autonomous Mobile Robots (Urban Search and Rescue) [208].

- A virtual reconstruction of the University of Cambridge Computer Laboratory's William Gates Building [373] has been developed using the **Quake 2** engine [141].

- Professor Robert Amor of the University of Auckland [374] has developed a virtual architecture course based on the **Torque** game engine [210]. Students design and construct buildings using the game engine. Each building is then examined by the rest of the class who log in to the game environment in order to be given a tour of a building by its designer.

In addition, several tools have been developed which make it possible for external data to be fed in to game engines in order to allow the gaming environment to reflect that of the real world [213, 375]. In this way it is possible for game engines to be used to develop a blended environment, with game state accurately modelling that of the real world.

Of the different games, the following four examples each highlight a different approach to the use of games for serious purposes, with Championship Manager [206] and Civilization III [376] both presenting a similar management style overview to players, whilst the Gates of Horus [377, 378] example provides a detailed 3D first person perspective. Medieval: Total War [379] adopts an interesting approach in that it combines both styles, with the 2D interfaces used to provide an overview of current game state and tools for players to manage their progress, whilst the 3D interface allows

Figure 91 – 2D Management Interface used by Championship Manager 2007

users to engage at a more detailed level with their activities. In addition, each of the four examples displays a different approach to game content modification, with Championship Manager and Medieval: Total War being used in an entirely unmodified state. Civilization III sports partial modifications, whilst Gates of Horus is an entirely original game based on the Unreal Engine 2.0 which displays custom content designed specifically for educational purposes.

Championship Manager

Championship Manager is a series of commercial games most recently published by Eidos Interactive. Each version of the Championship Manager follows a similar pattern, with players assuming a managerial role of a football team in a variety of football leagues. Early releases of the game used entirely fictitious team and player names. These were later replaced with realistic names based on actual football leagues. A player chooses a team to manage and is responsible for the strategy employed. A multiplayer mode is available, with a turn based system being implemented to allow each player to make managerial decisions.

The overall premise of the game is for a player to develop a successful management strategy which allows their team to win matches and progress up the leagues. Each player is given an initial amount of capital with which to recruit players, develop a football ground and encourage supporters to watch games. Teams earn money by winning matches, with incremental revenue being raised through the sale of tickets as well as match programmes, refreshments, etc. As a team wins more matches, they gain a wider supporter base, thereby increasing sales revenue which facilitates expansion of the club.

Adopting a managerial overview of the progress of each team, players use a 2D interface (as shown in Figure 91) which allows them to fine tune the strategy in place. The interface allows players to control every aspect of the team, both on and off the pitch. The actual process of playing a match is abstracted over, with the player determining strategy before the start of the match and at key points throughout it. During each match the player does not control the individual members of the team, but instead decides

on the strategies that should be adopted. Throughout each match feedback is provided in the form of textual and audio commentaries which are backed by pictures and short video clips highlighting key moments of play.

Whilst there are no official reports of Championship Manager being used as a means by which to train future football managers, a 1990s episode of Football Focus [380] did see Gordon Strachan [381], the then manager of Coventry City Football Club [382], being interviewed with a copy of Championship Manager clearly visible on his office desk! Irrespective of whether the game is actually used by football managers to test their strategies, the game has a serious side which could be used to help players understand some of the intricacies of the business factors behind the football industry. Within the game, players need to consider not only the players and match-time strategies, but must also balance the financial requirements of a team by evaluating options and making decisions based on sound financial evidence.

Civilization III

Civilization is a series of turn based strategy games in which players have to establish a settlement and develop a civilisation which they must then guide through various periods in history ranging from 4000 BC to 2100 AD. The overall aim is for the small initial settlement to grow into a dominant empire within the world. Players can use a variety of strategies in order to compete with other computer based civilisations, using both diplomacy and war to exert their dominance.

Players begin with two settler units which can be used to establish a base from which to grow an empire. Initially a player needs to decide where to settle, identifying areas to explore for sources of mineral wealth which can be used to expand the settlement. As time progresses, players can devote resources to expanding knowledge in an effort to develop modern technologies that they can then use to exert dominance over other civilisations. Throughout the game, players need to devise economic, social and political strategies, with the success of their civilisation directly related to its ability to sustain itself and expand. The game can end in one of two ways, with a player's civilisation being defeated by a competing force, or through the successful attainment of certain objectives including the destruction of all other civilisations, reaching 2100 AD with the highest score, or by winning the space race and reaching Alpha Centauri first.

As shown in Figure 92 and Figure 93, Civilization III uses an interface which presents a simple 2D isometric representation of the world, with the various strategies, wars and diplomatic efforts of the civilisation managed through a system of menus and dialog boxes as shown in Figure 93. During wars, a degree of abstraction is introduced, with players responsible for directing the overall strategy adopted by units of personnel, but not the individual battles between soldiers which may take place. Whilst not as high a level of abstraction as that introduced in Championship Manager, there are distinct similarities between the two approaches, with the focus of the player on the overall progress of their civilisation (or team in the case of Championship Manager) and not on the micro management of individual members within it.

Figure 92 – The Isometric 3D Interface Presented by Civilization III

Figure 93 – Civilization III Menu System for Controlling a Town's Economic Growth

The use of Civilization III in academic subjects such as history, geography and economics has been examined on a number of occasions [383-385] and featured in outputs of the Games to Teach Program [386] undertaken by Massachusetts Institute of Technology [387] in association with Microsoft [388]. A number of educational resources have also been developed for use in Civilisation III, with the Civ World Website [389] providing tutorial materials [390] and six curriculum modules which span the Dawn of Civilization through to the Industrial Age [391].

Gates of Horus

Unlike all other examples in this section, Gates of Horus has been designed as an educational game. As such, the gameplay has been developed specifically to provide an introduction to Egyptian temples [378, 392]. Based on Unreal Tournament 2004 [393], Gates of Horus is a custom level which depicts a fictitious temple which has been modelled on real data obtained from the temples of Horus at Edfu [394] and Medinet Habu [395].

Figure 94 – Gates of Horus 3D Perspective Showing Temple Entrance

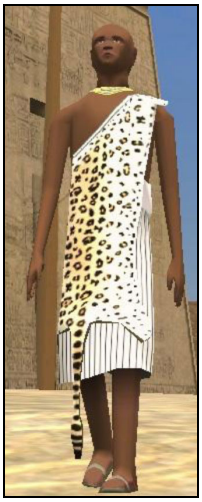

Figure 95 – High Priest

Supporting a single player at a time, Gates of Horus presents a first person perspective as shown in Figure 94. A player's progress through the game is moderated by a high priest (depicted in Figure 95) who is controlled by in game artificial intelligence. This technique, used previously in a reconstruction of Notre Dame Cathedral [396], provides players with a point of assistance whilst also allowing them the freedom to explore at their leisure.

As shown in Figure 96, the temple consists of four zones: the exterior (zone 1), the courtyard (zone 2), the hypostyle hall (zone 3) and the inner sanctuary (zone 4). After completing an initial training programme which familiarises players with the controls and 3D environment, players are free to start their exploration of the exterior of the temple. Within the game there is no concept of the progression of time. As players interact on an individual basis, they are free to explore as they wish. Given this, there is no need to provide a level of abstraction and/or a 2D management interface as is the case with the other examples discussed in this section. Instead players are able to fully focus on understanding the specific details of the content being presented.

Progression is managed by the high priest, who poses a series of questions relating to the current location of the player. For a player to progress further into the temple they need to correctly answer these questions. Should they require additional information, players are able to click on features displayed within the 3D perspective (the clickable areas are highlighted with grey colouring in Figure 96). This prompts the High Priest to provide a verbal explanation of a given feature, thereby allowing the player to gain the required information to correctly answer the questions posed. Winning is achieved when all questions posed are answered correctly.

As Gates of Horus was designed as an educational resource, it has been extensively tested in a variety of environments, with multiple players' progress through the scenario recorded and analysed [378]. In terms of the archaeological simulations provided by LAVA, the method of controlling progress adopted by the Gates of Horus is of significant interest, as is the ability to provide meaningful educational content to learners using only a 3D environment. It is encouraging to note the positive

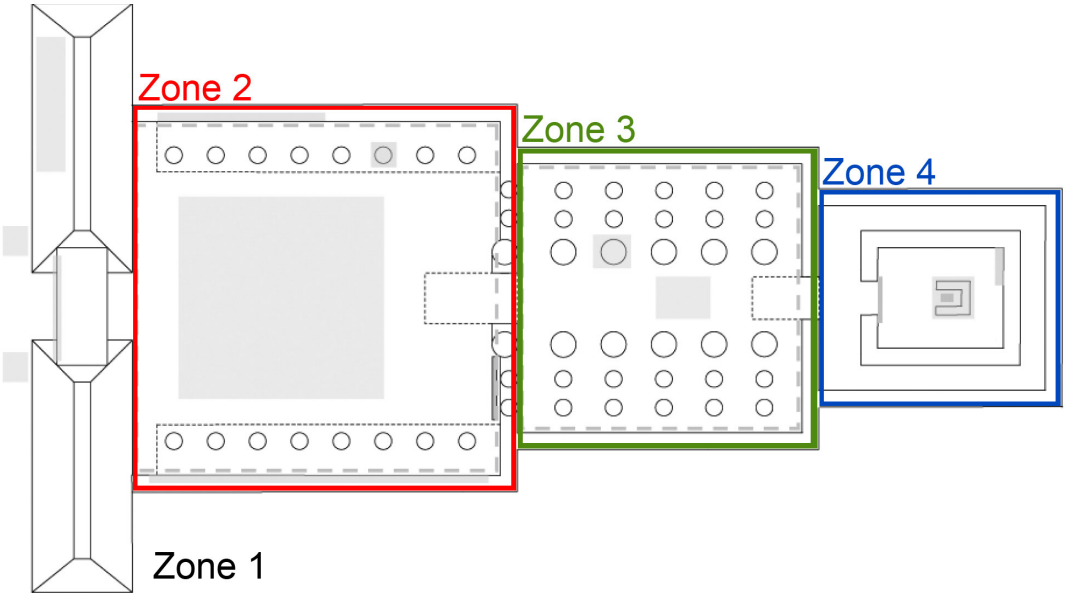

Figure 96 – Gates of Horus Zone Map

results reported by the evaluation of the system [378] given the significant difference in the style of presentation adopted by Gates of Horus when compared to traditional learning environments.

Medieval: Total War

As with Civilization, Medieval: Total War is a strategy game in which players aim to build an empire across Europe, North Africa and the Middle East. Unlike Civilization, Medieval: Total War is set in medieval times with the focus of gameplay on the religion and politics of this fixed timeframe. Players can use a variety of strategies in order to compete with other computer based civilisations, although warfare is the predominant mode of domination offered by the game.

In single player mode a campaign map is provided in a 2D interface (as shown in Figure 97). This allows players to control their armies and manage their diplomatic efforts. Unlike Championship Manager and Civilization, Medieval: Total War provides players with two distinct modes of interaction, switching to a real time 3D battlefield whenever a battle commences. This is significant in that it allows elements of turn based strategy games and first person perspective games to be combined; thereby removing the need to abstract away any details of the underlying activities taking place. Within the 3D interface, players are able to control the members of their army on an individual basis (as shown in Figure 98). Not only does this ensure that players are involved in all aspects of the game, but it also helps to establish a cause-effect relationship, with players experiencing the effects of their decisions first hand.

In addition to the main campaign mode, players can engage in individual battles which are based on a variety of historical campaigns and battles from the medieval period including, the Hundred Years War [397] and the Crusades [398]. Focusing on specific battles or campaigns, players predominantly use the 3D interface when engaging in historical campaigns, with the outcomes dependent their actions.

Figure 97 – The 2D Interface Showing the Campaign Map for Medieval: Total War

Figure 98 – A Real Time 3D Battle Under Way in Medieval: Total War

Players can also choose to play as a variety of historical characters such as Richard the Lionheart and William Wallace.

In multiplayer mode, the concept of progression is replaced with that of winning. Players focus on competing against each other in single battles and tournaments. In this mode the 3D interface is used almost exclusively, with only minor configuration changes to an army being undertaken in the 2D interface prior to the commencement of a battle.

As with Championship Manager, there are no reports of Medieval: Total War being used for serious purposes. However, we contend that the underlying design of the game lends itself to serious applications. In contrast to all other examples discussed in this section, Medieval: Total War provides a blended 2D/3D interface which allows players to engage at all levels of abstraction with their progress through the game. Unlike Championship Manager or Civilization III, Medieval: Total War does not prevent players from getting involved in the minutiae of specific battles, nor does it force players to consider it in isolation as is the case with Gates of Horus (and other first person perspective

Property	Championship Manager	Civilization III	Gates of Horus	Medieval: Total War
Customisation	None	Save Games	Game Level	None
Interface Type	2D Text/Graphics	2D Isometric	3D First Person	2D Isometric 3D First Person
Applicable Subjects	Business Management Economics	Management Economics History Geography	History Archaeology	Management History Geography
Recorded Serious Use	No	Yes	Yes	No
Game Licensing	Commercial	Commercial	Commercial	Commercial
Content Licensing	N/A	Open Source	Open Source	N/A
Specialised Hardware?	None	None	3D Graphics	3D Graphics
Multiplayer Mode	Turn based	None	None	Simultaneous

Table 18 – Summary of Key Features of Serious Games Examples

games). As such, Medieval: Total War is of significant relevance to the combination of management of the excavation process and the minutiae of individual activities that are present in the simulations of the archaeological excavation work presented by LAVA. However, the content of Medieval: Total War does not lend itself easily to adaptation within an educational context owing to its focus on the process of battling an army and not the historically accurate accounts of the background leading up to the battles that can be played out.

Although each of the four examples feature a very different approach to the use of games for serious purposes, all are effective in providing elements of factual information to users. Table 18 provides a summary of the key features of each of the games, whilst section 6.5.3 considers their relevance with respect to the archaeology simulations presented by LAVA.

6.5.3 Relevance to LAVA

Although the examples each provide a different style of gameplay, three common traits can be seen from the examples discussed, with all employing similar techniques to maintain a player's interest:

- A concept of **progression** is the primary approach adopted by games to maintain player engagement and is based on the fulfilment of specific sub-goals and challenges. This approach is widely regarded as an effective way to both challenge and stimulate a player [20, 190], with the smaller objectives acting as training exercises which allow players to develop the skills required to meet the increasingly complex challenges they encounter during the game. This approach is adopted by all four examples, with Gates of Horus explicitly limiting a player's progression until all questions in a specific zone have been correctly answered.

- An element of **random behaviour** within a game's artificial intelligence is frequently used to determine the outcome of a given situation based on the actions taken by a player. Within Civilization III this approach can sometimes lead to counterintuitive results, with the

occasional surprise victory of an ancient army unit (e.g. a spearman) over modern warfare equipment (e.g. battleships, tanks, or fighter planes). Whilst a seemingly impossible outcome, the randomisation in the calculations of the game logic means that if an ancient unit is provided with enough fortifications to protect itself from attack then it can, in a limited number of cases, beat a seemingly superior modern fighting unit. Irrespective of any implementation level issues, the overall purpose of this randomisation is to maintain interest and encourage repeated use. Taking Sudoku [399] as an example, if each puzzle was identical, people would not spend hours playing multiple puzzles, as each would share the same solution thus, after completing one puzzle, there would be no challenge associated with completing further puzzles. By randomizing the initial seed numbers, each Sudoku game is different, thereby offering a challenge to players.

- A policy of **selective revelation** allows game designers to control the rate at which in game information is released to players. Civilization III and Medieval: Total War make use of this approach as a means through which to limit a player's ability to fulfil the criteria required to win in battles against stronger opponents which feature later in the game. This has the effect of forcing players to engage in smaller battles with weaker opponents in order to build up the technical and social knowledge required to overpower larger settlements. The technique is most beneficial in games which have no physical barriers to prevent players from attempting to solve challenges out of sequence; whilst it is still possible for a player to meet the requirements of a later challenge, the likelihood of them doing so is naturally limited if players do not have the prerequisite prior knowledge, skills or equipment.

  The approach adopted by Gates of Horus is slightly different. Within Gates of Horus physical barriers are used to prevent players from progressing past their current level of experience, with selective revelation being used as a device to encourage exploration – players need to examine their environment to obtain clues that will help them answer the questions required for them to progress to subsequent zones.

With the exception of Medieval: Total War, none of the games provide any support mechanisms to enable simultaneous multiuser play. Given that collaboration is often cited as beneficial in terms of encouraging analysis and evaluation of progress amongst learners (both of which are desirable higher order learning behaviours) [32, 257, 300] this was somewhat disappointing and acts to highlight the differences between the gaming and educational communities.

In terms of real world deployment, both Gates of Horus and Civilization III have been used and evaluated in educational contexts [383, 385, 389]. This is encouraging as it is indicative of an increasing awareness of the use of games as serious tools for learning. Of the modifications presented in the examples, the use of customised saved games as a means by which to deliver learning materials in Civilization III is interesting. Whilst the game itself is not customised in any way, specially

designed levels are used to present specific geographical and economic concepts to learners using existing game behaviours. As such, the process of development of these learning materials is relatively easy to undertake, with tools provided directly by the game itself.

Also using customised content, Gates of Horus highlights how game mods can be used to good effect. With the Unreal Tournament 2004 game engine underlying the scenario, it is impressive to see how the customisation of in game artificial intelligence and the development of high quality reconstructions of the temple can transform a first person perspective 'shoot em up' game into a serious educational resource. This shows that it is possible to adapt games for educational use when there is a synergy between the objectives of the game and the educational activity being undertaken. However, in the absence of such an overlap, the challenge of adapting games becomes more problematic. In addition, as games are designed as standalone applications, integration with existing educational systems (for example institutional authentication mechanisms) can be problematic.

From the perspective of academic subjects, it is of interest that management and history both feature in three of the examples whilst economics and geography feature in two. In all of these subjects there is an element of application of knowledge required, occasionally in environments which can be difficult to recreate within the traditional classroom environment. Referring back to our discussion of the challenges associated with the teaching of archaeology in section 4.3, the fact that these challenges have been met, in the case of management, history, economics and geography, through the use of computer games strengthens the position adopted by LAVA, with computer game techniques being integrated into the learning process in order to support learners in applying their knowledge through investigation, experimentation and evaluation. Furthermore, when considering the discussion of Bloom's hierarchy of learning behaviours in sections 2.2.1 and 2.2.2, the use of computers games such as Championship Manager, Civilization III, and Medieval: Total War has a direct effect on the types of learning behaviours that educators can support, with all three games supporting behaviours associated with the application of conceptual and procedural knowledge.

6.6 Multi-User Virtual Environments (MUVEs)

As an emerging class of technologies, MUVEs are relatively new, with some of the more mature examples such as There [128] and Second Life [5] only being released in 2003. By providing a simulated environment within which multiple users can interact through the use of avatars, MUVEs are often used for social purposes.

Within a MUVE, each user has their own perspective on a virtual world, with the underlying environment presenting a consistent state to all users. Unlike games, the virtual environment of a MUVE is not fixed and can be modelled and altered by some or all of the users who inhabit it. In addition, each user's avatar can be customised to portray the personality of the owner. As the environment is persistent, any changes to it, or a user's avatar, remain over time and are not reset each time a user logs in. This allows long term changes to the environment to be retained in perpetuity.

Unlike games, MUVEs do not impose any set rules or objectives which users must follow within the virtual environment. Instead the inhabitants are able to decide what rules and conditions they wish to impose. This makes it possible for MUVEs to be used to host a variety of different activities including music concerts [400, 401], games [402] and university lectures [403]. In addition, the underlying world is not limited in size or the number of simultaneous users, with multiple servers being used to host different regions of the world. This allows the environment to grow in accordance with demand.

In many ways the environment is very similar to that of the real world, with the laws of physics often emulated to provide an environment representative of the real world. As such, some of the behaviours we are familiar with (such as not being able to walk through walls or objects falling towards earth due to gravity) are mirrored in the virtual environment. There are, however, some notable exceptions which are designed to make movement within the MUVE easier; users are often able to fly or teleport to different places within the environment.

6.6.1 Objectives and Functionality Provided

Unlike the games and serious games discussed in section 6.5, MUVEs have no rigidly defined set of goals, but instead aim to enable users to develop their own communities and environments. As such, MUVEs generally exhibit a number of fairly generic characteristics, in order to enable a user centred approach to the development of the environment:

- **Realism:** The environment presented by the MUVE mirrors many aspects of the real world. This ensures familiarity with the environment amongst users, making operation within the MUVE more intuitive.

- **3D perspectives:** Users are provided with a personalised 3D view of the virtual environment.

- **Avatars:** Users experience the virtual environment through their avatar. As the avatar acts as a representation of a given user it is possible for relationships to be formed between users who may or may not know each other outside of the MUVE environment.

- **User control:** There are no predefined goals or objectives in the virtual environments. The users are fully responsible for developing any rules or objectives as they see fit.

- **Mutability of environment:** Users are empowered to create content and edit areas within the virtual environment. Whilst the virtual environment may provide some initial content, users are not confined to using this and may develop new content based on their own requirements.

- **Persistence:** The virtual environment persists over a long period of time, with changes made by one user experienced by all other users within the environment.

- **Distributed environment:** MUVEs have no fixed size, with the environment growing and shrinking with demand. In order to facilitate such expansion and contraction, the underlying environment is often distributed over several servers, with each managing a defined area. From a user perspective this distribution is seamless, with the MUVE client application handling the communication with multiple servers as required.

In addition to these generic properties, MUVE client applications often provide a series of tools which can be used in the virtual environment to allow users to modify the landscape and scenery and construct buildings and areas of shared space such as parks, gardens and neighbourhoods. Many MUVEs also support access controls which allow authorised users to define access restrictions on parcels of land, thereby making it possible for private spaces to be developed within the shared environment. In addition MUVE clients also provide tools to allow users to communicate both synchronously and asynchronously through text (and often audio) messages.

6.6.2 Specific Implementations

Several systems have been developed which can be classified as MUVEs, with each adopting a slightly different approach to the provision of the generic characteristics described in section 6.6.1. Of those currently available, the following are the most widely used:

Second Life

Second Life is a popular commercial MUVE in which anyone can sign up for an account and rent land to build upon. Using the Havok physics engine [404] to provide an approximation of the laws of physics in the virtual world, Second Life presents users with a broadly realistic representation of the real world. With an economy that is tied to that of the real world, Second Life is often used for commercial purposes with residents creating, buying and selling goods in order to earn currency in Second Life that can be exchanged for those of the real world.

Managed and hosted by Linden Labs, the virtual world presented by Second Life is broken up into a series of islands, with up to four separate islands hosted by a single server [219, 221, 275]. Using a client-server model, all of the simulation in Second Life is conducted by the hosting servers, with the client application acting as a viewer which displays the resulting visual scenes. Predominantly open source, the client application has been ported to a variety of platforms including: Windows, Mac OS and Linux.

Within the lifetime of this work, Second Life has been adopted by academia as a tool to support both teaching (as discussed in more detail in section 6.6.3 below) and research. In addition, many institutions use Second Life as a marketing and recruitment tool, with a number establishing sizeable communities in the virtual world [148, 276, 405, 406].

Open Simulator

Open Simulator is an open source MUVE which can be used to create 3D worlds similar to those of Second Life. Using a client-server architecture which mimics much of the behaviour of Second Life and uses the same communication protocols, Open Simulator virtual worlds can be accessed using the Second Life client application.

As the hosting of Open Simulator is managed directly by individual organisations, it is possible for more control to be exerted over the virtual environment. This makes it possible for entirely private virtual environments to be established by an organisation either with or without an economy – something which Second Life cannot support. Furthermore, as Open Simulator provides support for multiple systems to be grouped together into a grid structure, it is also possible for a single virtual environment to span multiple administrative domains, thereby making it possible for multiple organisations to cooperate in establishing a shared virtual world.

Active Worlds

Originally intended as the 3D equivalent of the Web, Active Worlds [24] provides a 3D virtual environment in which users can develop their own 3D presence. Using a structure similar to that of Second Life, the 3D environment presented by Active Worlds is constructed from several constituent worlds, with some controlled by Active Worlds and some controlled by private individuals and organisations. As with Second Life, multiple servers are used host the overall 3D environment, with all systems maintained by Active Worlds.

Within Active Worlds there is no concept of an economy; as such there is none of the direct commercial uses that Second Life boasts. However, Active Worlds is still used for commercial purposes, with businesses establishing a presence as a marketing, sales and customer relationship tool. In addition there is a sizeable educational following, with many personal users maintaining a presence within the environment.

River City

River city is a MUVE specifically designed to teach middle school science using a curriculum centred on the skills of hypothesis formation and experimental design. Set in a city in the late 1800's, students are able to explore various neighbourhoods, industries and institutions such as hospitals and universities.

Student avatars interact with computer based agents (residents of the city), digital objects (pictures, video clips etc) and other student avatars in order to determine the possible causes of an illness within the city. Three scenarios have been developed, with illness passed by water, air or insects [407].

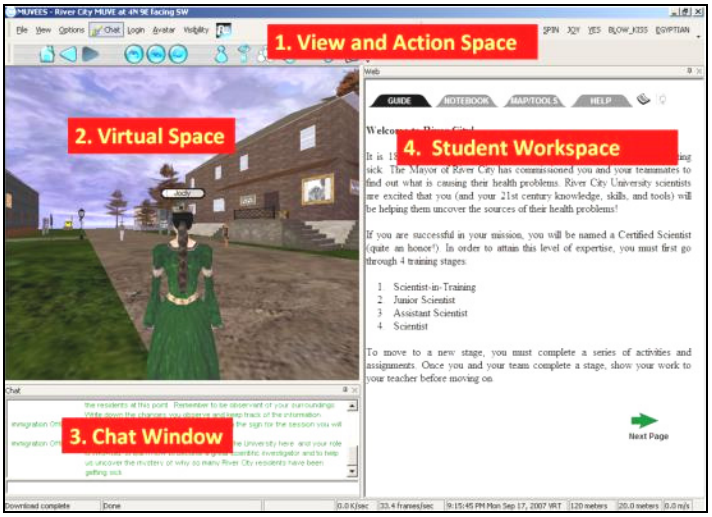

Figure 99 – The River City Project MUVE Interface

The River City client application has four components as shown in Figure 99, with a toolbar to allow users to control their character (1), a 3D view of the virtual environment (2), a text area in which students can communicate with the other students and agents (3), and a workspace window which changes content based on what the student encounters within the MUVE (4).

6.6.3 Relevance to LAVA

Whilst each of the MUVEs discussed is tailored to suit a different model of use, all share a similar capacity for supporting user-led modifications to the virtual environment presented. This adaptability means that MUVEs are ideal as a platform upon which to build 3D educational scenarios. Within the academic community a variety of learning activities have been developed within MUVE environments, including:

- **Virtual Quests:** Similar to Web Quests [408], but based within a MUVE environment. A series of tasks are set, with learners attempting to complete them through a program of independent research using a variety of resources (many of which are sourced from within the MUVE environment).

- **Simulations:** A working model of a real world phenomenon, process or activity [409, 410]. As MUVEs provide an environment in which anything can be modelled, simulations of real world processes can be developed using a variety of scales, thereby making it possible for small items to be enlarged so that learners can see processes which would otherwise be invisible or difficult to witness in the real world.

  An example of such simulation would be the recreation of the combustion engine in a MUVE. By scaling the model to a size that allows Second Life avatars to walk through it, learners

would able to explore the different parts of the combustion engine and witness them in action – something which would be difficult to achieve in the real world.

- **Virtual Laboratories:** Closely linked with simulations, virtual laboratories simulate real world behaviours. Configured to represent the real world using realistic representations (i.e. similar to those found in the real world), or new levels of abstractions, virtual laboratories can enable the exploration of otherwise difficult to examine behaviours.

  Real world representations can be used to model scientific reactions, thereby allowing learners to control and experiment with dangerous chemical reactions, with the effect of any mistakes having no long term effect on the real world.

  Alternative abstractions can be used to represent behaviours that are otherwise difficult to visualise in the real world, with the WiFiVL [411, 412] being a good example of how invisible radio waves can be given a visual representation, thereby allowing learners to visualise the effects of changes in the topology of wireless networks. More recent versions of WiFiVL have been implemented in Second Life (named WiFiSL in Second Life) [413] in order to allow learners to examine the behaviour of wireless networks in 3D spaces.

- **Virtual Fieldwork** activities involve the development of digital representations of real world environments [414, 415]. As such MUVEs provide an ideal basis upon which to develop virtual fieldwork activities. By presenting realistic fieldwork environments, MUVEs can help to overcome the limitations associated with the classroom environment and provide more relevant experience to learners [415]. Several fieldwork projects already exist in Second Life, with LAVA [416] and the Global Outreach Morocco project [417] being examples of how virtual environments can be used to model those of the real word.

- **Role Play/Scenario Re-enactment** – many MUVEs support scripting, therefore making it possible for autonomous virtual actors to be developed. This opens the opportunity of staging accurate re-enactments of real world scenes, with learners participating as an actor within the re-enactment or observing the overall proceedings as a passive audience member. In this way MUVEs can be used to allow learners to explore and engage in the social activities associated with historical scenarios.

As indicated by the already widespread use of MUVEs within the educational sector, the technology offers real opportunities with regards to the development of alternative approaches to learning which centre on the learner. By providing the social and collaborative tools required in order to allow physically disparate learners to communicate effectively using technological means, MUVEs are well placed to support distance and anytime-anywhere learning, thereby empowering the learner by allowing them to decide when and where they wish to learn.

Furthermore, as MUVEs share many of the expressive properties of 3D game environments they are well placed to provide support for alternative approaches to visualisation to be developed, thereby allowing educators to employ new abstractions as a way of depicting complex real world behaviours. With none of the preconceived notions of goals or objectives that games have, MUVEs are somewhat better suited to educational use, with educators able to spend more time focusing on the development of new and innovative learning materials and not on overcoming the inherent limitations associated with the ideas of goals, objectives and progression that a game may impose.

However, it is not the case that the 3D environments presented by MUVEs are suitable for all educational activities. As users are often more familiar with 2D presentation, the use of 2D interfaces should not be precluded. As an example, reading text from a Web page is probably more easily done than reading a similar piece of text from within Second Life. Consequently we contend that a blended approach which uses a mix of 2D and 3D technologies is beneficial.

6.7 Chapter Summary

Within this chapter a number of technologies are examined, many of which have been used in the delivery of electronic learning materials. Throughout the discussion, the dominance of commercial Web Based Learning systems is noted, with the impact of the proprietary formats that they impose considered. It is acknowledged that these commercial systems are beneficial in standardising and simplifying the way in which learning materials are developed, but also recognised as somewhat stifling of innovation owing to their focus and reliance on traditional didactic approaches.

Within the educational sector, the role of standards is often discussed. Section 6.3 identifies three types of standard within the educational sector: those which form following the widespread use of a single piece of software for a particular task (i.e. the Proprietary standard), those which are designed from the top down to address an entire sector (i.e. the Standards standard), and those which are formed by consensus through the development of open standards which address specific goals and objectives faced by the community (i.e. the Community standard). It is recognised that the Proprietary standards approach is dominant within the education sector, with the dominance of BlackBoard and WebCT hampering the uptake of alternative approaches. Whilst there is a sizeable effort from the likes of IMS and ADL to develop Standards standards, these approaches are largely ineffective owing to their perceived lack of relevance to specific educational challenges.

When considering the ways in which technology is encouraging innovation within the educational sector (sections 6.4, 6.5 and 6.6), there is an increasing occurrence of edutainment and the use of games and MUVEs as educational tools. These efforts are broadly unsupported by both Proprietary and Standards standards, and as such provide a real opportunity for Community based standards to be adopted. The use of edutainment itself is subject to considerable criticism on the grounds of over simplification and an overly strong focus on entertainment to the detriment of educational rigor. These

approaches are generally considered to be good at gaining attention, but are otherwise discounted as useful only with younger children owing to their limited ability to convey complex information.

The use of games and MUVEs is somewhat more successful, owing to their ability to present more detailed educational content. This is seen as a considerable benefit, with educators increasingly recognising the value associated with the levels of interactivity and engagement that MUVEs and game technologies can provide. Stemming from the discussion in Chapter 2, we identify an application for this interactivity as a means through which to allow learners to apply their conceptual and procedural knowledge in virtual reconstructions of real world environments. In doing so we strengthen the case for adopting games and MUVE technologies as mainstream learning tools.

In concluding sections 6.5 and 6.6 we recognise the relevance of game and MUVE technologies as a means through which to develop archaeological simulations. As discussed in Chapter 4, the effort required to support such use is significant, with the digitalisation of resources and the development of 3D environments requiring specialised skills. Although both games and MUVEs provide inbuilt tools to assist, their focus is not on educational practice and as such the barriers of entry are notably high.

In comparing game and MUVE technologies, MUVE technologies generally offer a greater degree of flexibility, owing to a lack of any pre-determined goals or objectives. In contrast, games often have an inbuilt concept of goals and progression which educators need to temper (or otherwise match with existing educational objectives). As such, the uptake of MUVEs is somewhat more popular at present, with many different types of learning activity being actively developed in a variety of MUVE environments as discussed in section 6.6.

Chapter 7 – Summary and Conclusions

7.1 Introduction

This chapter summarises the argument put forward by this dissertation and considers the work carried out to support it. In summarising the contributions made, this chapter situates the work in a wider educational and technological context. The main thesis of the dissertation is reviewed, with the strengths of the dissertation considered in respect to the requirements of a PhD.

7.2 Summary of Argument

Whist it is intuitive that interactivity and engagement are desirable facets for learning materials to support, it is often difficult to justify why this is so. It is here that Bloom's taxonomy of learning behaviours is useful. By considering learning as a series of behaviours that learning resources should encourage, Bloom justifies the need for supporting interactivity by citing it as a means through which to advance the learning process.

In terms of the development of knowledge, Anderson's updates to Bloom's work act to clarify the situation. By identifying specific learning behaviours which relate to specific aspects of the learning process, Anderson associates:

- The ability to **experiment** and **explain** as important behaviours in allowing the **application** of conceptual and procedural knowledge

- The ability to **calculate** and **differentiate** as important behaviours in allowing the **analysis** of conceptual and procedural knowledge

Given that Bloom's hierarchy acts as a progressive process, with previous levels of learning behaviours subsumed by those which follow, if learners are to be able to move beyond knowledge and comprehension to synthesis and evaluation, it is important that they show the behaviours of application and analysis. Thus, it becomes desirable to ensure learning environments support such activities. For this to be possible, interactivity and a degree of engagement are essential. However, most commonly used learning environments fail to meet these needs, instead focusing on the provision of tools and services which allow learners to collect knowledge through the information transfer paradigm.

Existing learning environments are well versed at managing the behaviours associated with Bloom's lower level behaviours of knowledge acquisition and comprehension. This work does not seek to replace these, but instead supplement them. By integrating with existing approaches this work extends the capabilities of existing learning environments by adding support for the application and analysis of knowledge, thereby enabling learners to progress to the higher levels of synthesis and evaluation (which, incidentally, our approach can also support).

When considering the types of knowledge presented, a combination of both approaches is beneficial. LAVA focuses on providing support for learners to develop conceptual and procedural knowledge. This is in contrast to existing learning environments which instead focus on the development of factual and conceptual knowledge. Thus, by combining both approaches, this work enhances the overall functionality provided by a learning environment through enabling behaviours that allow the acquisition, comprehension, application, analysis, synthesis and evaluation of factual, conceptual and procedural knowledge to occur. This is an improvement over the majority of Web based virtual learning environments which generally support only a small subset of these behaviours.

From the perspective of usability, the combination of existing 2D learning environments and LAVA's 3D visualisations is also beneficial. In isolation both systems lack the support required to allow learners to be given contextual data as well as detailed knowledge, with 2D systems focused on conveying detailed information, whilst 3D systems provide good contextual data. Through a combined approach which uses both 2D and 3D interfaces, this work allows learners to deal with both the context and also the detail of the knowledge presented.

Throughout this work, three classes of subjects are considered:

1. **Abstract subjects** such as mathematics and philosophy in which application of knowledge can be achieved through thought experiments or within an easily accessible environment.

2. **Skills based subjects** such as carpentry or metalwork in which the application of knowledge focuses primarily on practiced skills.

3. Subjects in which **abstract ideas need to be applied to concrete or physical environments**. Subjects such as archaeology and geography fall into this category.

Of these three subject classes, those which fall within classes two and three are poorly supported by existing approaches. In the case of skills based subjects, there is little point in developing technological support for the application of knowledge, as the development of practical skills is more important than the development of conceptual or procedural knowledge. However, when considering the third class of subjects, there is a significant benefit associated with enabling the application of knowledge. It is this class of subjects that this work has considered, and it is here where advances in technology can enhance the range of educational scenarios which can be supported.

As existing learning environments tend to focus on the use of Web technologies, the types of learning resources that they provide are predominantly didactic in nature. This is partly a function of the technologies employed: Web technologies adopt a transactional approach which favours a process of information transfer. Web 2.0 and 3D MUVE technologies are disruptive to this transactional

approach, offering opportunities for a higher degree of interaction between content and those consuming and, more importantly, creating it. Instead of only information transfer, richer paradigms of interaction are available, with users able to consume, create and modify content. Within the context of this work, these technologies provide the opportunity for alternative approaches to the learning process to be adopted, with environments created that encourage and support learner's efforts to apply, analyse and evaluate their knowledge in realistic, collaborative and reflective environments.

This work has shown that the use of collaborative 3D technologies offers significant opportunities for expanding the range of learning behaviours that learning environments can support. Through the development of a case study based on an archaeological excavation which integrates 3D MUVE technologies and 2D learning environments, we have validated the possibility of such an approach, with the resulting system being subjected to real world use and evaluation. In this process we have uncovered a number of challenges to address and developed a number of solutions to them. These form the basis of the contributions of this work and are discussed below.

7.3 Summary of Contributions

Concerned with both the process of education and the role of technology, this dissertation makes contributions in the following key areas:

- A framework is described which extends the functionality of a Web based virtual learning environment to enable support for exploratory learning scenarios within a variety of 2D and 3D environments.

- The archaeological excavation process is analysed and decomposed into a learning case study containing a number of scenarios that can be used as the basis for learning exchanges which support exploration and modification of the underlying environment.

- An evaluation of the effectiveness of alternative approaches to teaching and assessment has been undertaken, with particular emphasis being placed on interactions which encourage learners to analyse and reflect on their learning through the application of conceptual and procedural knowledge.

The primary contribution of this work is a reference framework which integrates three different technological areas: gaming methods, 3D visualisations and a Web based learning environment. In the development of this framework, a number of innovative steps have been taken which build upon and extend the related work in the field of education.

The educational potential for exploratory learning within the domain of archaeology has been analysed. This was based upon a reading of relevant literature, attendance and participation in AN3020, an honours archaeology module at the University of St Andrews. Interviews and discussion with domain

experts Dr Rebecca Sweetman and Professor Greg Woolf, as well as current and past students, were also undertaken in an effort to identify aspects of the teaching of archaeology that could be improved by altering teaching strategies and the approaches adopted (See Chapter 3 and Chapter 5). As part of this work, a survey of the state of the art in learning design methodologies, such as IMS-LD and SCORM, was undertaken in order to understand how others are managing the increased importance placed on the sequencing and management of distinct learning resources (See Chapter 6).

In terms of developing the excavation simulation, the appropriateness of different categories of 3D technologies for supporting virtual fieldwork has been explored (See Chapter 3 and Chapter 4). In particular the roles that the following technologies have in the development of educationally sound learning scenarios have been considered:

- **3D Modelling and rendering technologies** (3D Studio Max [142] and VRML/Web3D [418-420])
- **Libraries for the creation of 3D environments** (jPCT [143], Java 3D [144])
- **First person shooter genre of games** (The Unreal [23] and Quake [4] series of game engines)
- **Massively multiplayer online games** (World of Warcraft [421])
- **Multi-user virtual environments** (Second Life [5] and Open Simulator [22])

In addition to assessing the suitability of 3D technologies, an investigation into their effect on the perception of scale and depth within a virtual environment has been carried out. Using a variety of videos and 3D environments the importance of visual cues and the differences between interpretations in real world and first person perspective 3D environments have been considered (See Chapter 3).

In order to develop realistic excavation scenarios, a functional and temporal decomposition of virtual fieldwork activities was undertaken. The resultant model allows students to focus on the management and exploratory aspects of their fieldwork, with these activities supported through synchronous and asynchronous communication tools and a variety of 2D and 3D interfaces which integrate visualisation technologies appropriate to the activity being undertaken (See Chapter 4).

To allow learning scenarios to be developed by tutors and deployed to learners, a framework has been designed that integrates real-time 3D visualisations, 2D exploration and management interfaces and a virtual learning environment (See Chapter 4). This framework organises an excavation into a simulation that contains a series of consecutive stages which encourage student engagement through the attainment of successive intermediary goals. This work is drawn from an analysis and synthesis of

both archaeological excavation processes and the methodologies used by computer games and edutainment to maintain user engagement (See Chapter 4).

In an effort to engage with learners and develop realistic learning scenarios, simulations have been designed so that they can make use of customisable game logic that is able to realistically correlate users' actions to the successful accomplishment of objectives (See Chapter 4). This work required numerous iterations involving designers, software engineers, learners and domain experts.

In order to evaluate the effectiveness of the framework, an instance of the architecture was developed which supports virtual fieldwork through the integration of 2D environments, 3D environments and management interfaces. The implementation of the framework, LAVA, was deployed in a classroom environment and evaluated by two AN3020 cohorts as well as individual students and domain experts. This deployment highlighted the operational aspects of the architecture using a real-world case-study based on detailed archaeological information obtained from domain experts (See Chapter 4) and enabled the collection of evaluation data based on real world usage scenarios (See Chapter 5).

During the development of the case study, several 3D models, 2D diagrams and first person perspective environments were constructed in different modelling packages. An evaluation of the relative merit of each model and modelling package was considered with respect to the educational goals associated with different aspects of an excavation (See Chapter 3 and Chapter 4). A comprehensive series of 2D resources was also constructed, with the creation of realistic 2D maps and resources enabling a 2D simulation of the excavation process to be developed. This work required the systematic digitalisation and authentic placement of artefacts within schematics of the site, thereby allowing learners to discover artefacts and architecture within an appropriate context (See Chapter 3 and Chapter 4).

In order to ensure flexibility, an interface has been designed which allows learning environment data to be extracted and shared with LAVA and other third party extensions to the platform in real time (See Chapter 4). In the context of this dissertation, this work is important in allowing LAVA to obtain student data from institutional data sources, with updates to LAVA related data being fed back into the institution as required. From a student perspective, it is desirable to ensure that LAVA integrates seamlessly with the existing learning environment infrastructure. To this end, a Web-based delivery system makes it possible for all required additional software and extensions to the learning environment to be delivered to client machines as required, thereby allowing seamless explorative investigation of a scenario using interfaces delivered by both the learning environment and external third party extensions (See Chapter 4).

In order to assess the validity of this work, an evaluation of the framework, via the LAVA case study, has been undertaken. Considering the impact that the framework has on user motivation and delivery of learning outcomes is an important part of this work, and figures heavily in the evaluation activities undertaken. In addition, an assessment of the generality of the work and its applicability to alternative

educational domains was reviewed. Subject areas such as architecture, geography and history, where the temporal, physical or financial costs of participation in the real world is prohibitive, were highlighted as being well placed to benefit from the use of the framework (See Chapter 2 and Chapter 6).

7.4 Thesis Statement

New technologies such as Web 2.0 and 3D MUVE environments are empowering users to create and communicate information through emerging social networks. No longer are users simply consumers of information, they are rapidly becoming significant producers of it. Throughout the lifetime of this work, this social transition has begun to extend into the educational sector, with educators increasingly showing efforts to move beyond didactic approaches which see learners as passive consumers of information, to environments which encourage and support learner's efforts to apply, analyse and evaluate their knowledge.

When considering subjects in which the application of knowledge to concrete scenarios is complex, difficult or expensive to achieve, traditional didactic approaches to teaching have traditionally fared poorly. By embracing new technologies, alternative pedagogical approaches can be developed which more readily meet the challenges that these disciplines pose.

With the advancement of computer capabilities comes an increasing availability of MUVE and Web 2.0 technologies. In future it will be common practice to use these technologies to build realistic, engaging and collaborative learning scenarios which not only support the transfer of knowledge, but which also allow learners to apply and evaluate it.

This thesis is demonstrated by the LAVA case study presented in this dissertation. Through the combination of existing learning technologies and 3D MUVE environments LAVA provides support for learners to engage in a realistic, collaborative fieldwork exercise in which they can apply their knowledge and evaluate the results.

7.4 Conclusion

This dissertation has described how 3D environments can be leveraged to enable students to engage in virtual fieldwork activities which encourage learners to become active participants rather than passive recipients of knowledge. By reducing reliance on traditional didactic approaches, LAVA expands support for alternative pedagogical approaches which allow learners to engage in higher order learning behaviours that enable learners to progress from comprehension through to application and analysis.

Appendix A – Published Work

Listed here are the publications generated by the research described by this dissertation. All publications were submitted to conferences that adopted a peer reviewing process prior to publication acceptance:

1. Getchell, K, Miller, A, Allison, C, Sweetman, R, Exploring the Second Life of a Byzantine Basilica. In Serious Games on the Move, O. Petrovic and A. Brand, Editors. 2009, SpringWien: New York, NY, USA. P. 165-180.

2. Allison, C, Oliver, I, Getchell, K, Miller, A, Active Learning with Planetary Objects. 8th Annual Conference for the Higher Education Academy Subject Network for Information and Computer Science, Southampton, UK. 2007.

3. Getchell, K, Nicoll, J, Kerbey, C, Miller, A, Allison, C, Sweetman, R, Complin, J, Michaelson, R, A Computer Games Approach to Exploratory Learning - Lava: A Case Study in System Design. 3rd International Conference on Web Information Systems and Technologies, Barcelona, Spain. 2007.

4. Purdie, S, Allison, C, Nicoll, R, Getchell, K, Bateman, M, Michaelson, R, The Continuing Evolution of an Academically Driven Framework for the Research, Deployment and Management of Learning. E-Learning and Teaching Workshop, Higher Education Academy Subject Network for Information and Computer Science, Greenwich, London, UK. 2007.

5. Getchell, K, Nicoll, J, Kerbey, C, Miller, A, Allison, C, Sweetman, R, Michaelson, R, Evaluating Exploratory Learning in LAVA. IASTED Web-based Education 2007, Chamonix, France. 2007.

6. Allison, C, Miller, A, Getchell, K, Sturgeon, T, Exploratory Learning for Computer Networking. 6th International Conference on Web-based Learning, Edinburgh, UK. 2007.

7. Summers, E, Getchell, K, Miller, A, Allison, C, Generating 3D Multiplayer Game Maps from 2D Architectural Plans. 8th International Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting, Liverpool John Moores University, Liverpool, UK. 2007.

8. Oliver, I, Getchell, K, Miller, A, Allison, C, Using Disruptive Technology for Explorative Learning. 12th ACM SIGCSE Annual Conference on Innovation and Technology in Computer Science Education, Dundee, UK. 2007.

9. Getchell, K, Miller, A, Colin, A, Kerbey, C, Hardy, R, Sweetman, R, Crook, V, Complin, J, The LAVA Project: A Service Based Approach to Supporting Exploratory Learning. IADIS International Conference WWW/Internet, Murcia, Spain. 2006.

10. Sturgeon, T, Miller, A, Getchell, K, Allison, C, Real Time Mixed Reality in Virtual Environments. 7th International Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting, Liverpool John Moores University, Liverpool, UK. 2006.

11. Getchell, K, Miller, A, Allison, C, A TCP Learning Environment. 6th Annual Conference for the Higher Education Academy Subject Network for Information and Computer Science, York, UK. 2005.

Appendix B – Interface Design Process

B.1 The 2D Environment

When considering how best to present LAVA simulations to students, two options were considered: a single user desktop application, or a shared Web-based system. Given the desire to support groupwork and to allow students to undertake excavations from a variety of locations, preference was given to a Web-based system, with the use of learning environments being considered alongside the development of a customised proprietary solution. Clearly, the development of a fully customised solution would meet all educational requirements; however the limited scope for deployment in alternative scenarios was a concern. In addition, it was clear that much of the functionality required: authentication of users and groups, management of resources, sequencing of materials etc., was available in pre-existing learning environments, and so their use was actively considered.

The use of the Web as a mechanism for delivering learning resources has been widely adopted by higher educational establishments over the past 10 years. As such, the benefits of Web-based courseware have been well documented [18, 103, 236, 302, 422, 423], with early adopters quickly realising their ability to improve student satisfaction through the introduction of Web-based learning materials into the curriculum [424]. In addition, many of the pitfalls associated with early adoption of the technology have been recognised, acknowledged and dealt with. Indeed, learning environments are now no longer highly specialised software products maintained by the academic community, but are instead commercial products, purchased off the shelf and able to be customised to address the needs of both large and small educational establishments [41].

Given the maturity and level of customisation offered by both commercial and open source learning environments, their use as a platform for LAVA's 2D interfaces was carefully considered. The standardised and uniform interface was a significant advantage, with users benefiting from familiarity with the interface gained through their use of the learning environment in other academic courses. However, in trials it was determined that the limited expansion capabilities of many commercial learning environments restricted their ability to interface with other components within LAVA. As such, the development process focussed solely on the use of open source learning environments.

After developing several courses in a variety of learning environments, MMS was chosen as the base for the 2D excavation management components of LAVA. As an institutional learning environment, MMS was able to provide a familiar interface to students, with the extensible nature of the software making it possible for extensions to be developed to support the integration of a simulation engine to manage the underlying excavation process. In addition, extensions to MMS were developed to allow data maintained within the system to be shared with external resources, including game engines and MUVEs responsible for displaying 3D representations of the excavation.

B.2 The 3D Environment

Throughout the life of this project, the pace of development associated with 3D technologies has been significant. Multi-user virtual environments like Second Life [5], Open Simulator [22] and World of Warcraft [421] have expanded rapidly as more and more users have been able to log in owing to advances in the performance of standard desktop computers [3]. Indeed, when considering the rapid growth in popularity of these types of online environment amongst industrial [425] and home users, there is a compelling case for employing these types of 3D technologies in educational settings.

In order to get a rounded appreciation of the different types of 3D environment available, a number of 3D technologies have been explored by this work, ranging from those which provide 3D visualisations of static scenes to those which provide an expansive shared 3D environment which is open for exploration and modification by the virtual users within it. All have been evaluated, and their appropriateness for different aspects of the educational process considered. Organised into five distinct groupings, the technologies can be broadly categorised as follows:

- **3D Modelling and Rendering Tools:** Market leading commercial software such as Audodesk 3D Studio Max makes it possible for high definition 3D scenes to be composed using specialist software and rendered for viewing in a variety of graphics and video formats. In general, these tools generate view only 3D scenes which cannot be modified by users directly, with any user interaction being limited to starting a pre-defined sequence of events (for example starting a motion sequence etc.).

- **3D Engines and Libraries** offer strong development opportunities, with the underlying 3D technology supporting the rendering of any type of 3D scene. However, for 3D engines and libraries to be usable they need to be coupled to physics engines, collision detection mechanisms and user interfaces. This raises the complexity associated with developing a customised solution based on a 3D engine and/or library.

- **First Person Perspective Games** combine 3D graphics capabilities with physics and audio engines and collision detection mechanisms. Many offer the ability to develop custom maps and levels. Owing to the naturally limited environment of a game level, first person perspective games provide many of the features required to restrict a user's activity to predefined areas. However, as games have pre-defined objectives, it can be difficult to introduce alternative aims and objectives due to user interface and gameplay restrictions.

- **Massively Multiplayer Online Games** have a long history of development, with more recent titles offering graphically rich, expansive environments to explore. Supporting multiple users, the objectives of massively multiplayer online games are less restrictive than those imposed by first person perspective games, with a greater emphasis on communication and interaction between users. The underlying environment of a massively multiplayer online game is shared by all users and, as such is maintained between sessions. As users progress through the game

they are able to explore the environment as they wish. However, the ability for users to make modifications to the environment is limited so that any changes are in accordance with the aims and objectives of the game itself.

- **Multi-User Virtual Environments** share many of the features of massively multiplayer online games: an environment shared with multiple users which maintains state over multiple sessions, a graphically rich, expansive environment and the ability to support communication between users. However, unlike massively multiplayer online games, multi-user virtual environment do not have any predetermined aims and objectives. As such, users are presented with an underlying environment which they are free to shape and explore. In this way, multi-user virtual environments support modification of the environment at levels not available in massively multiplayer online games or first person perspective games.

Throughout the evaluation process, the strengths and weaknesses of each type of environment have been carefully considered, with Table 19 providing a summary of the key differences between each of the five categories.

In broad terms, each of the technologies can be used to develop some type of 3D visualisation, with the main differences being in respect to the environment presented and the ability for a user to manipulate, interact with and change their perspective of it. Within the 3D visualisations in LAVA it is important for users to be able to explore and modify their surroundings from a variety of perspectives. Given this, each of the technologies under consideration have been ranked according to the suitability of the environment they provide, the level of interactivity offered and the variety of perspectives offered to users. These rankings act as a barometer to assess the suitability of the technology for use within LAVA simulations.

As shown in Table 19, 3D modelling and rendering tools score poorly in terms of the perspective, environment and interactivity offered owing to their ability to present only a pre-defined representation of a scene. In contrast, all other types of 3D environment score much better in terms of allowing users to interact with, and change their perception of the presented scene. The main difference is due to the fact that, unlike 3D modelling and rendering tools, all the other technologies employ real time rendering techniques to allow users to change their perspective and otherwise interact with the environment in real time.

Historically, the main advantage of 3D modelling and rendering tools was their ability to provide high quality visualisations of scenes, of a far greater definition than those rendered by real time engines used in first person perspective games. However, with the increasing power of desktop computers [3], this advantage has reduced in recent years, with games and online environments sporting significant improvements in visual appearance [426]. Whilst still not able to compete with the quality of 3D modelling and rendering tools, most modern games and multi-user virtual environments are able to provide visualisations which are detailed enough to convey significant amounts of visual information.

When considering the ability to interact with and modify the environment, massively multiplayer online games and multi-user virtual environments excel in particular. Not only are they able to present a changing visual environment as 3D engines and libraries, and first person perspective games can, but they also support much richer levels of environmental modification, with multi-user virtual environments in particular allowing users to not only shape the environment, but also to build and define it from the ground up.

The differentiating factors between massively multiplayer online games and multi-user virtual environments are more subtle, with both technologies offering high levels of interactivity and user led manipulation of the environment. However, unlike massively multiplayer online games which have an underlying objective or purpose which users (i.e. players) must meet, multi-user virtual environments do not impose any types of aims or objectives on users, instead the system provides an open environment which users are free to explore and adapt as they see fit (subject to any terms and conditions and/or usage restrictions imposed by the system provider: for example, rules to prevent inappropriate content or copyrighted materials being reproduced). In this way multi-user virtual environments are able to provide a more varied environment, which acts as a microcosm of the real world, if slightly skewed owing to the non-representative sample of the population who regularly make use of multi-user virtual environment technologies [427].

Technology	Examples	Environment	Interactivity	Perspectives	Objectives	Rankings
3D Modelling and Rendering Tools	Audodesk 3D Studio Max [142] VRML/Web 3D [418, 419]	None, rendering of visuals only	None, rendering of visuals only	Fixed	None, rendering of visuals only	Environment: 0/5 Interactivity: 2/5 Perspective: 1/5 **LAVA Suitability: 3/15**
3D Engines and Libraries	jPCT [143] Java 3D [144] Unreal Runtime [372]	Implementation dependent, no inherent support	Implementation dependent, no inherent support	Implementation dependent, no inherent support	Implementation dependent, no inherent support	Environment: 2/5 Interactivity: 2/5 Perspective: 2/5 **LAVA Suitability: 6/15**
First Person Perspective Games	Unreal Tournament [23] Quake I, II, III, IV [4, 141, 355, 356]	Multiuser – shared, resets on new game Single user – user specific, resets on new game	Movement within environment Communication Interaction with in game elements	First Person Perspective	Fixed, constrictive	Environment: 3/5 Interactivity: 2/5 Perspective: 2/5 **LAVA Suitability: 7/15**
Massively Multiplayer Online Games	The Realm Online [428] World of Warcraft [421] Samurai Romanesque [429]	Shared, maintained globally	Movement within environment Communication Interaction with in game elements	Multiple	Fixed, loose	Environment: 4/5 Interactivity: 4/5 Perspective: 5/5 **LAVA Suitability: 13/15**
Multi-User Virtual Environments	Second Life [5] Open Simulator [22] Active Worlds [24] There [128]	Shared, maintained globally, modified and created by users using tools within the software	Movement within environment Communication Interaction with in game elements Modification of the environment	Multiple	Managed by users, no inherent objectives	Environment: 5/5 Interactivity: 5/5 Perspective: 5/5 **LAVA Suitability: 15/15**

Table 19 – 3D Technologies, Their Capabilities and Suitability for LAVA 3D Recreations

Appendix C – Pre-session Questionnaire

Please answer the following questions as fully as possible. If you are not sure what to write, please seek assistance from the session demonstrator.

Session Information

Session ID _____ Date _____

Personal Information

Group Identifier _____ Age _____

Educational Information

Year of Study ☐ 1st ☐ 2nd ☐ 3rd ☐ 4th ☐ Other: _____

Intended Degree Subject _____

What is your highest level of education?
- ☐ Standard Grade / GCSE
- ☐ Highers / A-Levels
- ☐ Undergraduate Degree
- ☐ Postgraduate Degree
- ☐ Other: _____

Background Experience

Have you had any previous fieldwork training?	☐ Yes	☐ No
Have you been involved in any excavation work?	☐ Yes	☐ No

IT Experience

How would you rate your IT competency	☐ Advanced	☐ Intermediate	☐ Novice
Have you used MMS before? (if you don't know what MMS is, choose no)	☐ Yes		☐ No
Have you used the LAVA software before?	☐ Yes		☐ No

Study Objectives and Future Work

Are you happy to participate in this evaluation session?	☐ Yes	☐ No
Do you understand the purpose of this evaluation session?	☐ Yes	☐ No
Would you be willing to participate in further evaluation sessions? (If you are, please leave your email address so we can contact you)	☐ Yes, email: _____	☐ No
Would you be willing to participate in an interview to discuss the usability of the LAVA software that you have used in this session? (If you are, please leave your email address so we can contact you)	☐ Yes, email: _____	☐ No

Appendix D – Post-session Questionnaire

Please answer the following questions as fully as possible. If you are not sure what to write, please seek assistance from the session demonstrator.

Session Information

Session ID _____ Date _____

Personal Information

Group Identifier _____ Age _____

Section A – System Usability Scale

	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I think that I would like to use this system frequently	☐	☐	☐	☐	☐
2. I found the system unnecessarily complex	☐	☐	☐	☐	☐
3. I thought the system was easy to use	☐	☐	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☐
5. I found the various functions in this system were well integrated	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☐	☐	☐
8. I found the system very cumbersome to use	☐	☐	☐	☐	☐
9. I felt very confident using the system	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☐

Section B – Educational Considerations

	Strongly Disagree 1	2	3	4	Strongly Agree 5
1. I feel that I have learned something by using this system	☐	☐	☐	☐	☐
2. The excavation simulation reveals believable information	☐	☐	☐	☐	☐
3. I found it difficult to find out information about the archaeological site	☐	☐	☐	☐	☐
4. The quality of the material presented was consistent	☐	☐	☐	☐	☐

5. I believed that all of the artefacts I discovered could have been located within the region of the excavation	☐	☐	☐	☐	☐
6. I feel that using this system helps develop my understanding of fieldwork methods and techniques	☐	☐	☐	☐	☐
7. I found the system educationally stimulating	☐	☐	☐	☐	☐
8. I was able to easily identify material culture	☐	☐	☐	☐	☐
9. The tools provided by the system allowed me to practice the theory I have learned relating to managing an excavation project	☐	☐	☐	☐	☐
10. Working in a group helped me understand the excavation process	☐	☐	☐	☐	☐
11. I found it useful to be able to identify where finds were located within the site	☐	☐	☐	☐	☐
12. The descriptions of the artefacts I found were reasonable	☐	☐	☐	☐	☐
13. The flow of the excavation made sense to me	☐	☐	☐	☐	☐
14. I was able to find the tools and information I needed to maintain my context sheets	☐	☐	☐	☐	☐
15. I would have preferred to work individually using the system	☐	☐	☐	☐	☐

Section C – Free Form Questions	
1. Is there any aspect of the system you particularly liked?	
2. Was there anything you found difficult to do in the system?	
3. Are there any features not already present that you would like to see added?	
4. Do you have any comments about this session in general?	

Appendix E – Post-task Questionnaire

Please answer the following questions as fully as possible. If you are not sure what to write, please seek assistance from the session demonstrator.

Session Information

Session ID _____ Date _____

Personal Information

Group Identifier _____ Age _____

Task Information

1. What task have you been working on?

2. How easy was it to find out how to use the system to perform the task? ☐ Easy ☐ Neither Easy or Hard ☐ Hard

3. Did the system hinder your progress in achieving the task? ☐ Yes ☐ No

4. Did any part of the process work particularly well, or particularly badly?

5. What would make it easier for the task to be completed?

6. Were you happy with the way the system provided you with information relating to your progress through the task? ☐ Yes ☐ No

   Why?

7. Did you achieve your task successfully? ☐ Yes ☐ No

   Why? What went right / wrong?

Appendix F – Semi-structured Interview Questions

A outline structure of questions used to elicit task detail from evaluation participants who volunteered to participate in semi-structured interview sessions. The approach is adapted from [430].

Questions	Purpose
1. What do you do?	Obtains the user's goal
2. Why do you do it?	Obtains method
3. How do you do it?	Obtains subtask. Used recursively for each subtask
4. What are the preconditions for doing this?	To find out what outside influences there are
5. What are the results of doing this?	To example the product and see what the purpose is
6. What errors occur?	Error capture
7. How do you correct them?	Error correction

Appendix G – Properties of Investigative Techniques

G.1 Questionnaires

	Questionnaires
Delivery	Printed handouts, completed by subjects individually and returned to evaluation team. Alternatively, electronic forms were used to capture responses using Web pages.
Focus	Realism (educational section of post session questionnaire), usability (SUS).
Strengths	Allow subjects time to consider their answers without interference. Cheap and easy to distribute in volume (especially true with electronic questionnaires). Allow respondents to provide a uniformed set of responses using Likert scales etc. Standardised questions allow for standardised analysis of responses. Anonymous submission may lead to more honest answers.
Weaknesses	Response rate can be low. Lack of guidance can lead to confusion amongst participants. Subjects' interpretations of questions may vary.
Goals	To determine how realistic subjects felt the educational scenarios presented to them were. Honest responses, not tainted by the fact that the subjects had to explain themselves to an interviewer. To get an overall picture of how the subjects felt the system operated so that we could focus on problem areas. To determine how usable subjects found the system to be. Wanted to build a SUS score so that we could compare with other systems. Also wanted to be able to track how the usability of the LAVA system develops over time.
Limitations	Difficult to analyse if open questions are asked. When closed questions are asked it becomes difficult to solicit user opinion. As subjects interpret the questions on their own, there are no guarantees that the subjects all interpret the questions in the same way.

G.2 Interviews

	Interviews
Delivery	Individual subjects who indicated that they were interested in being involved in interviews were contacted following the group sessions. Individual subjects were then walked through a series of structured questions by an interviewer on a one-to-one basis.
Focus	Used to focus on areas of LAVA that were commented upon during group evaluation sessions. Used to collaborate the findings of the group sessions and to examine any differences between the group results and individual results.
Strengths	Non-leading and open ended questions allow subjects to lead the discussion and focus on the areas that they are most interested in. Ability to provide feedback to inform and answer the issues that the subject may raise. Depth of feedback. Unexpected issues/topic can emerge. Ability for interviewer to probe subject for further information. Topic list ensures a core list of questions are asked. As the subject controls the flow of the interview, the environment is more natural and relaxed – may encourage more frank responses.
Weaknesses	Possibility that interviewer could become judgemental and taint the interview process. Resulting feedback difficult to analyse – interviewer must perform analysis. Easy for bias to creep in.
Goals	To encourage more focused feedback on specific areas of the LAVA system. To determine areas of the system which are most problematic for subjects.
Limitations	Time consuming and intensive. Requires subjects to volunteer additional time. Findings, whilst detailed, cannot be generalised over an entire group.

G.3 Individual and Group Observation

	Individual and Group Observation
Delivery	Groups were set a series of tasks which were to be tackled during a timetabled evaluation session. During the evaluation session technical assistance was provided by a dedicated support team, whilst the teaching staff interacted with the subjects. The evaluation team performed no active role within the evaluation session; their only task was to passively watch the subjects as they engaged with the LAVA system.
Focus	Used to focus on the way in which the subjects engaged with LAVA. A group based observation allowed the subjects' collective responses to be recorded and thus provides a general overview of subject engagement during the session. By observing the entire session as the groups worked through a test list of tasks, the evaluators can identify specific activities which promoted positive engagement with the system, and activities which were less engaging for the subject's.
Strengths	Provides an overview of the engagement of all groups during the entire evaluation session. Allows a more balanced overview of engagement to be obtained and thus avoids problems with subject's personal preferences.
Weaknesses	Requires each subject group to be working a broadly the same pace, so that they approach each activity at roughly the same time. Requires a number of observers. Does not provide detailed analysis, only indicative subject responses.
Goals	To get an overview of areas where engagement was strong, for example shortly after artefacts are found etc. To get an overview of areas where engagement is low and subjects are less interested.
Limitations	In real-world evaluation scenarios each subject group are going to be working at different speeds, so it is important that the evaluation team carefully coordinate the session so as to maintain a steady progress through the tasks.

G.4 Co-participation

	Co-participation
Delivery	Groups were divided into pairs during each lab based evaluation session.
Focus	Collaboration, group communication, use of electronic resources amongst the group. Ways in which the groups separated and assigned tasks to each other. Engagement.
Strengths	Good way to obtain in use feedback from subjects. Promotes natural interaction with the LAVA system. Produces feedback which can be recorded by evaluation staff. Allows subjects to form a shared understanding of the software in use, Allows evaluators to see how subjects approach problem solving with the system.
Weaknesses	Different learning, verbal and cultural styles will affect the feedback provided. Candidates may not collaborate as effectively as desired – screening can help. Apprehension will affect feedback. Subjects may feel uncomfortable if it is not made clear what they are required to do. All feedback will be shaped by both members of the group.
Goals	To witness how subjects interact with LAVA in an environment in which they can collaborate without the use of electronic means To see how groups separate the tasks their group is required to perform and assign them to individuals. To obtain audible feedback as the groups work with the system to provide indicators as to what they understand/do not understand, find easy/difficult, enjoy/dislike.
Limitations	Groups form a shared response to the system so this needs to be recognised when reviewing feedback offered. The collaboration may taint subsequent individual feedback (questionnaires etc). Difficult to capture and evaluate all data.

References

1. *BS ISO 690-2: 1997: Information and documentation. Bibliographic references. Electronic documents or parts thereof*. 1998, British Standards Institute. p. 28.
2. Bloom, B.S., *Taxonomy of Educational Objectives: The Classification of Educational Goals - Handbook I: Cognitive Domain*. 1956, New York, NY, USA: McKay.
3. Moore, G.E., *Cramming More Components onto Integrated Circuits*. Electronics, 1965. **38**(8).
4. idSoftware, *Quake*. 1996, Activision.
5. *Second Life*. 2003, Linden Research Incorporated.
6. Mango, C., *Byzantine Architecture*. 1976, New York, NY, USA: H N Abrams.
7. Cartledge, P. and A. Spawforth, *Hellenistic and Roman Sparta: A Tale of Two Cities (Societies & Cities of Ancient Greece)*. 1989: Routledge.
8. Cartledge, P., *Sparta and Lakonia: A Regional History 1300 to 362 BC* 2nd ed. 2002, Oxford: Routledge.
9. Spielberg, S., *Raiders of the Lost Ark*. 1981, Lucasfilm.
10. *Time Team*. 2008, Channel 4 Television.
11. Cornwell, B., *Stonehenge: A Novel of 2000 BC*. 2000: HarperCollins.
12. Berners-Lee, T. and M. Fischetti, *Weaving the Web: Origins and Future of the World Wide Web*. 1999: Orion Business Publishing.
13. Wikipedia. *MUVE*. [cited December 2008]; Available from: http://en.wikipedia.org/wiki/MUVE.
14. Wikipedia. *First-Person Shooter Games*. [cited April 2007]; Available from: http://en.wikipedia.org/wiki/First-person_shooter.
15. Sweetman, R. *The Sparta Basilica Project*. [Archaeological Excavation Report] 2000-2001 [cited June 2006]; Available from: http://www.bsa.gla.ac.uk/research/index.htm?field/recent/spartabasilica/main.
16. Sweetman, R. and E. Katsara, *The Acropolis Basilica Project, Sparta: A Preliminary Report for the 2000 Season*, in *Annual of the British School at Athens (volume 97)*. 2002, British School at Athens: Athens. p. 429-468.
17. Allison, C., et al. *An Integrated Framework for Distributed Learning Environments*. in *6th ISPE International Conference on Concurrent Engineering: Advances in Concurrent Engineering*. 1999. Bath, UK: ISPE.
18. Allison, C., et al. *A Role Based Institutional Portal - Module Management System (MMS)*. in *14th International Conference on Database and Expert Systems Applications (DEXA)*. 2003. Prague, Czech Republic: IEEE Computer Society.
19. Purdie, S., et al., *The Continuing Evolution of an Academically Driven Framework for the Research, Deployment and Management of Learning*, in *e-Learning and Teaching Workshop*. 2007, Higher Education Academy Subject Network for Information and Computer Science: Greenwich, London.
20. Malone, T., *What Makes Things Fun to Learn? A Study of Intrinsically Motivating Computer Games*, in *Department of Psychology*. 1980, Stanford University: Stanford, California, USA.
21. *Java BluePrints - The Model View Controller Design Pattern*. 2002 [cited April 2005]; Available from: http://java.sun.com/blueprints/patterns/MVC-detailed.html.
22. *Open Simulator*. [cited January 2008]; Available from: http://www.opensimulator.org/.
23. *Unreal Tournament*. 1998, Epic Games.
24. *Activeworlds: Home of the 3D Chat, Virtual Worlds Building Platform*. [cited April 2008]; Available from: http://www.activeworlds.com/.
25. Apple. *QuickTime 7*. 2008 [cited May 2008]; Available from: http://www.apple.com/quicktime/.
26. Wikipedia. *Massively Multiplayer Online Games*. [cited April 2006]; Available from: http://en.wikipedia.org/wiki/Massively_multiplayer_online_game.
27. O'Reilly, T. *What is Web 2.0*. 2005 [cited April 2009]; Available from: http://www.oreillynet.com/pub/a/oreilly/tim/news/2005/09/30/what-is-web-20.html.
28. Piaget, J., *The Psychology of Intelligence*. 1950, New York: Routledge.
29. Flavell, J.H., *The Developmental Psychology of Jean Piaget*. 1963, New York, NY, USA: Van Nostrand Reinhold.
30. Furth, H.G., *Piaget and Knowledge: Theoretical Foundations*. 1st ed. 1969, New York, NY, USA: Prentice Hall. 270.

31. Gagne, R.M., *Institutional Technology: Foundations*. 1987, Hillsdale, NJ, USA: Lawrence Erlbaum Associates.
32. Jackson, R.L., *Collaboration and Learning within Tele-Immersive Virtual Environments*. 2000, University of Washington: Seattle, WA, USA.
33. Albano, G., M. Gaeta, and S. Salerno, *E-Learning: A Model and Process Proposal.* International Journal of Knowledge and Learning, 2006. **2**(1-2): p. 73-88.
34. Reynolds, B., *Learning and Traching in the Practice of Social Work*. 2nd ed. 1965, New York, NY, USA: Russell and Russell.
35. Gronlung, N.E., *Stating Behavioral Objectives for Classroom Instruction*. 1970, New York, NY, USA: Macmillan.
36. Land, S. and M.J. Hannafin, *Student-Centered Learning Environments*, in *Theoretical Foundations of Learning Environments*, D.H. Jonassen and S. Land, Editors. 2000, Routledge: Mahwah, NJ, USA.
37. Anderson, L.W., et al., *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. 2001, New York, NY, USA: Longman.
38. Dave, R.H., *Developing and Writing Behavioural Objectives*, R.J. Armstrong, Editor. 1970, Educational Innovators Press: Tucson, AZ, USA.
39. Clark, D. *Learning Domains or Bloom's Taxonomy*. [cited March 2009]; Available from: http://www.nwlink.com/~donclark/hrd/bloom.html.
40. *The Oxford English Dictionary*. 2nd ed, ed. J. Simpson and E. Weiner. 1989, Oxford, UK: Clarendon Press. 22000.
41. *WebCT*. [cited January 2008]; Available from: http://en.wikipedia.org/wiki/WebCT.
42. Kolb, D.A., *Experiential Learning - Experience as the Source of Learning and Development*. 1984, New Jersey: Prentice Hall. 288.
43. Itin, C.M., *Reasserting the Philosophy of Experiential Education as a Vehicle for Change in the 21st Century.* The Journal of Experiential Education, 1999. **22**(2): p. 91-98.
44. Merriam, S.B. and R.S. Caffarella, *Learning in Adulthood: A Comprehensive Guide*. 1998, New York, NY, USA: Jossey-Bass. 528.
45. *McMaster University - Inspiring Innovation and Discovery*. 2009 [cited January 2009]; Available from: http://www.mcmaster.ca/.
46. Merrill, M.D., *A Pebble-in-the-Pond Model for Instructional Design.* Performance Improvement, 2002. **41**(7): p. 39-44.
47. Jonassen, D. and S. Land, *Theoretical Foundations of Learning Enviornments*. 2000, Mahwah, NY, USA: Lawrence Erlbaum Associates.
48. Merrill, M.D., *A Task-Centered Instructional Strategy.* Journal of Research on Technology in Education, 2007. **40**(1): p. 33-50.
49. Hmelo-Silver, C.E. and H.S. Barrows, *Goals and Strategies of a Problem-based Learning Facilitator.* The Interdisciplinary Journal of Problem-based Learning, 2006. **1**(1): p. 21-39.
50. Piaget, J., *The Origins of Intelligence in Children*. 1952, New York, NY, USA: International Universities Press.
51. Papert, S.A., *Mindstorms: Children, Computers, and Powerful Ideas*. 1980, Jackson, TN, USA: Perseus Books. 252.
52. *LEGO.com: The Official Web Site of LEGO Products!* [cited January 2009]; Available from: http://www.lego.com/.
53. *LEGO.com: MINDSTORMS NXT Home*. [cited January 2009]; Available from: http://mindstorms.lego.com/.
54. Vygotsky, L., *Mind in Society: The Development of Higher Psychological Processes*. 1978, Cambridge, MA, USA: Harvard University Press.
55. Furness, T.A., W. Winn, and R. Yu, *The Impact of Three Dimensional Immersive Virtual Environments on Modern Pedagogy; Global Change, VR and Learning*. 1998, University of Washington: Washington, WA, USA.
56. Winn, W., M. Windschitl, and A. Thomson-Bulldis, *Learning Science in Virtual Environments: A Theoretical Framework and Research Agenda.* Educational Media International, 1999. **36**(4): p. 217-279.
57. Hay, K., et al. *Virtual Gorilla Modeling Project: Middle School Students Constructing Virtual Models for Learning*. in *Fourth International Conference of the Learning Sciences*. 2000. Ann Arbor, MI, USA.
58. Chaiklin, S., *The Zone of Proximal Development in Vygotsky's Analysis of Learning and Instruction*, in *Vygotsky's Educational Theory in Cultural Context* A. Kozulin, et al., Editors. 2003, Cambridge University Press: Cambridge, UK. p. 492.

59. Winn, W., et al., *Features of Virtual Environments that Contribute to Learners' Understanding of Earth Science*, in *Annual Meeting of the National Association for Research in Science Teaching*. 2003: New Orleans, LA, USA.
60. Moreno, R., *Pedagogical Agents in Virtual Reality Environments: Do Multimedia Principles Still Apply*, in *World Conference on Educational Multimedia, Hypermedia and Telecommunications*. 2002, ED-Media: Chesapeake, VA, USA.
61. Mayer, R., *Multimedia Learning*. 2001, Cambridge, UK: Cambridge University Press. 222.
62. Mayer, R., *Multimedia Learning*. 2nd Edition ed. 2009, Cambridge, UK: Cambridge University Press. 320.
63. Lécuyer, C., *Making Silicon Valley Innovation and the Growth of High Tech, 19301970: Innovation and the Growth of High Tech, 1930-1970* 2007, Boston, MA, USA: MIT Press.
64. *TI People | Jack Kilby | The Chip that Jack Built*. [cited January 2009]; Available from: http://www.ti.com/corp/docs/kilbyctr/jackbuilt.shtml.
65. *Excerpts from A Conversation with Gordon Moore: Moore's Law*. 2005 [cited March 2009]; Available from: http://download.intel.com/museum/Moores_law/Video-Transcripts/Excepts_A_Conversation_with_Gordon_Moore.pdf.
66. *"Moore's Law" Predicts the Future of Integrated Circuits*. 2007 [cited March 2009]; Available from: http://www.computerhistory.org/semiconductor/timeline/1965-Moore.html.
67. Walter, C., *Kryder's Law.* Scientific American, (August 2005).
68. Robinson, G. *Speeding Net Traffic with Tiny Mirrors*. EE Times 26 September 2000 [cited August 2008]; Available from: http://www.eetimes.com/story/OEG20000926S0065.
69. Nielsen, J. *Nielsen's Law of Internet Bandwidth*. 1998-2008 [cited April 2009]; Available from: http://www.useit.com/alertbox/980405.html.
70. Myhrvold, N., *Moore's Law Corollary: Pixel Power*, in *The New York Times*. 7 June 2006: New York, NY, USA.
71. *CPU Transistor Count*. 2009 [cited April 2009]; Available from: http://en.wikipedia.org/wiki/Transistor_count.
72. *Intel 90nm Pentium M 755: Dothan Investigated*. 2004 [cited April 2009]; Available from: http://www.anandtech.com/cpuchipsets/showdoc.aspx?i=2129.
73. Moore, G.E., *Progress in Digital Integrated Electronics*, in *International Electron Devices Meeting - Technical Digest*. 1975. p. 11-13.
74. Bell, C.G. and J.E. McNamara, *High-tech Ventures: A Guide for Entrepreneurial Success*. 1991, New York, NY, USA: Perseus Books.
75. Bell, C.G., *Bell's Law for the Birth and Death of Computer Classes.* Communications of the ACM, 2008. **51**(1): p. 86-94.
76. Bell, C.G., R.C. Chen, and S.L. Rege, *Effect of Technology on Near Term Computer Structures.* IEEE Computer, 1972. **5**(2): p. 29-38.
77. *W3C - World Wide Web Consortium*. [cited January 2009]; Available from: http://www.w3.org.
78. *Web Services Glossary*. 2004 [cited January 2009]; Available from: http://www.w3.org/TR/ws-gloss/.
79. *University of St Andrews - Scotland's First University*. [cited June 2008]; Available from: http://www.st-andrews.ac.uk/.
80. *Adobe Flash Platform*. 2009 [cited January 2009]; Available from: http://www.adobe.com/flashplatform/.
81. *Bebo*. [cited March 2009]; Available from: http://www.bebo.com/.
82. *MySpace*. [cited December 2008]; Available from: http://www.myspace.com/.
83. *Twitter: What are you doing?* [cited March 2009]; Available from: http://twitter.com/.
84. *YouTube*. [cited December 2008]; Available from: http://www.youtube.com/.
85. *JISC: Supporting Education and Research*. 2009 [cited April 2009; Available from: http://www.jisc.ac.uk/.
86. Britain, S. and O. Liber. *A Framework for Pedagogical Evaluation of Virtual Learning Environments*. 1999 [cited March 2009]; Available from: http://www.jisc.ac.uk/uploaded_documents/jtap-041.doc.
87. Michaelson, R., *Let's Get Real: Virtual or Managed Learning Environments?*, in *Learning and Teaching Support Network BEST Conference*. 2002.
88. *The University of British Columbia*. [cited April 2009]; Available from: http://www.ubc.ca/.
89. *Blackboard*. [cited April 2009]; Available from: http://www.blackboard.com/.
90. JISC. *MLEs for Lifelong Learning: Building MLEs across HE and FE*. 2005 [cited March 2009]; Available from: http://www.jisc.ac.uk/whatwedo/programmes/buildmlehefe.aspx.

91. JISC. *MLE Infokit - Creating a Managed Learning Environment (MLE)*. 2004 [cited March 2009; Available from: http://www.jiscinfonet.ac.uk/InfoKits/creating-an-mle.
92. JISC. *JISC Centre for Educational Technology and Interoperability Standards (CETIS)*. 2009 [cited March 2009]; Available from: http://jisc.cetis.ac.uk/.
93. *Yahoo - the world's most visited homepage*. 2009 [cited September 2009]; Available from: http://www.yahoo.com/.
94. *iGoogle - a customisable AJAX based startpage for the web*. 2009 [cited April 2009]; Available from: http://www.google.com/ig.
95. *Kelly Search - Business to Business Supplier Search*. 2009 [cited April 2009]; Available from: http://www.kellysearch.co.uk/.
96. *Yell.com - the UK's local search engine for UK business listings*. 2009 [cited April 2009]; Available from: http://www.yell.com/.
97. *jasig - the consortium sponsoring open source software projects for higher education*. 2009 [cited April 2009]; Available from: http://www.jasig.org/.
98. Michaelson, R. and C. Allison, *Portal Wars: a UK Perspective on e-Learning Adoption*, in *9th UKAIS Conference*. 2004: Newcastle, UK.
99. Pearce, L., L. Carpenter, and R. Martin, *Stakeholder Requirements for Institutional Portals*. 2003, The University of Hull: Hull, Yorkshire, UK. p. 68.
100. *uPortal - an open source enterprise portal framework*. 2009 [cited April 2009]; Available from: http://www.jasig.org/uportal.
101. Kraan, W., *Open uPortal Technology Gains Ground in the UK*. 2002, CETIS.
102. *The COSE Virtual Learning Environment*. 2009 [cited April 2009]; Available from: http://www.staffs.ac.uk/COSE/.
103. Michaelson, R. and J. Serrano. *TAGS: A Model for Managing Distributed Learning Environments*. in *Scottish Business Education Group*. 1999.
104. *Bodington - an open source Virtual Learning Environment*. 2009 [cited April 2009]; Available from: http://bodington.org/.
105. Winn, W.J.R., *Fourteen Propositions about Educational Uses of Virtual Reality.* Educational Technology, 1999. **39**(4).
106. Winn, W., et al., *Learning Science in an Immersive Virtual Enviornment*, in *Annual Meeting of the American Educational Research Association*. 2001: Seattle, WA, USA.
107. Winn, W., *Learning in Artificial Environments: Embodiment, Embeddedness and Dynamic Adaptation.* Technology, Instruction, Cognition and Learning, 2003. **1**(1): p. 87-114.
108. Wickens, C.D. and P. Baker, *Cognitive Issues in Virtual Reality*. Virtual Environments and Advanced Interface Design, ed. I.W. Barfield and T.A. Furness. 1995, New York, NY, USA: Oxford University Press.
109. Taylor, S. *Vassar's Virtual Sistine Chapel*. [cited April 2009]; Available from: http://slurl.com/secondlife/Vassar/200/85/27.
110. Bricken, M., *Virtual Worlds: No Interface to Design*. Cyberspace: First Steps, ed. M. Benedikt. 1990, Cambridge, MA, USA: MIT Press.
111. Bricken, M. and C.M. Bryne, *Summer Students in Virtual Reality: A Pilot Study on Educational Applications of Virtual Reality Technology*. Virtual Reality, Applications and Explorations, ed. Wexelblat. 1992, Cambridge, MA, USA: Academic Press Professional.
112. Winn, W., *The Impact of Three-Dimensional Immersive Virtual Environments on Modern Pedagogy*. 1997, Human Interface Technology Lab: Seattle, WA, USA.
113. Winn, W., et al., *Learning Science in an Immersive Virtual Environment*, in *Annual Meeting of the American Educational Research Association*. 2001: Seattle, WA, USA.
114. Jackson, R.L. and W. Will, *Collaboration and Learing in Immersive Virtual Environments*, in *Computer Support for Collaborative Learning (CSCL) Conference*. 1999: Palo Alto, CA, USA.
115. Dede, C., et al., *Multisensory Immersion as A Modeling Environment for Learning Complex Scientific Concepts*. Computer Modeling and Simulation in Science Education. 1999, New York, NY, USA: Springer-Verlag.
116. Zeltzer, D., *Autonomu, Interaction and Presence.* Presence: Teleoperators and Virtual Environments, 1992. **1**(1): p. 127-232.
117. *Mimic Haptic Devices*. [cited December 2008]; Available from: http://www.mimic.ws/.
118. Psokta, J., *Factors Affecting the Location of Virtual Egocenters*. From the Renaissance to Cyberspace. 1996, Alexandria, VA, USA: US Army Research Institute.
119. Witmer, B. and M. Singer, *Measuring Presence in Virtual Environments: A Presence Questionnaire.* Presence: Teleoperators and Virtual Environments, 1998. **7**(3): p. 225-240.

120. Lessiter, J., et al., *A Cross-Media Presence questionnaire: The ITC-Sense of Presence Inventory.* Presence: Teleoperators and Virtual Environments, 2001. **10**(3).
121. Slater, M., *Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire.* Presence: Teleoperators and Virtual Environments, 1999. **8**(5): p. 560-565.
122. Pausch, R., D. Proffitt, and G. Williams, *Quantifying Immersion in Virtual Reality*, in *SIGGRAPH 1997*. 1997, ACM: Los Angeles, LA, USA.
123. Darken, R.P., et al., *Quantitative Measures of Presence in Virtual Environments: The Roles of Attention and Spatial Comprehension.* Cyberpsychology and Behaviour, 1999. **2**(4): p. 337-347.
124. Osberg, K.M., *Constructivism in Practice: The Case for Meaning-Making in the Virtual World*, in *Department of Computer Science*. 1997, University of Washington: Seattle, WA, USA.
125. Salzman, M.C., et al., *Using VR's Frames of Reference in Mastering Abstract Information*, in *Third International Conference on Learning Sciences*. 1998: Charlottesville, VA, USA.
126. Cobb, S., et al., *Development and Evaluation of Virtual Environments for Education*. Handbook of Virtual Environments; Design, Implementation and Applications, ed. K.M. Stanney. 2002, Mahway, NJ, USA and London, UK: Lawrence Erlbaum Associates.
127. Dede, C. *The River City Project: Multi-User Virtual Environment Experiential Simulator*. [cited March 2009; Available from: http://muve.gse.harvard.edu/muvees2003/index.html.
128. Harvey, W. and J. Ventrella, *There*. 2003, Makena Technologies.
129. Ellis, S.R.E., *Pictorial Communication in Virtual and Real Environments*. 2nd ed. 1991, London, UK: Tailor and Francis.
130. Mayer, R.E., *Educational Psychology; A Cognitive Approach*. 1987, Boston, MA, USA: Little, Brown and Company.
131. Gardner, H., *Intelligence Reframed*. 1999, New York, NY, USA: Basic Books.
132. Chin, D.N., *KNOME: Modeling What the User Knows in UC*. User Models in Dialog Systems, ed. A. Kobsa and W. Wahlster. 1989, New York, NY, USA: Springer-Verlag.
133. Garlatti, S., S. Iksal, and P. Kervella, *Adaptive On-Line Information System by Means of a Task Model and Spatial Views*, in *2nd Workshop on Adaptive Systems and User Modelling on the WWW*. 1999: Toronto, ON, CA.
134. Rich, E., *Stereotypes and User Modeling*. User Models in Dialog Systems, ed. A.K.A.W. Wahlster. 1989, New York, NY, USA: Springer Verlag.
135. Carver, C.A., R.A. Howard, and W.D. Lane, *Enhancing Student Learning Through Hypermedia Courseware and Incorporation of Student Learning Styles.* IEEE Transactions on Education, 1999. **42**(1).
136. Larkin-Hein, T. and D.D. Budny, *Research on Learning Style: Applications in the Physics and Engineering Classrooms.* IEEE Transactions on Education, 2001. **44**(3).
137. Danielson, R.L., *Work in Progress: Learning Styles, Media Preferences and Adaptive Education*, in *Adaptive Systems and User Modeling on the World Wide Web*. 1997: Chia Laguna, Sardinia.
138. Chen, Y. and R.D. Macredie, *Cognitive Styles and Hypermedia Navigation: Development of a Learning Model.* Journal of the American Society for Information Science and Technology, 2002. **53**(1): p. 3-15.
139. *IMS Learning Design Best Practice and Implementation Guide*. 2003, IMS Global Learning Consortium.
140. Learning, A.D. *Sharable Content Object Reference Model (SCORM) 2004 Specification*. [cited March 2008]; Available from: http://www.adlnet.gov/Downloads/DownloadPage.aspx?ID=237.
141. idSoftware, *Quake 2*. 1997, Activision.
142. *Audodesk 3D Studio Max*. [cited September 2008]; Available from: http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=5659302.
143. *jPCT Java 3D API*. [cited September 2008]; Available from: http://www.jpct.net/.
144. *Java 3D Parent Project*. [cited September 2008]; Available from: https://java3d.dev.java.net/.
145. *Moodle: Open Source Course Management System*. [cited April 2007]; Available from: http://moodle.org/.
146. *LAMS: Learning Activity Management System*. [cited April 2008]; Available from: http://www.lamsinternational.com/.

147. Weber, A., K. RuferBach, and R. Platel, *Creating Your World: The Official Guide to Advanced Content Creation for Second Life*. 2007, New York, NY, USA: John Wiley and Sons.
148. Tapley, R., *Designing Your Second Life*. 2007, Indianapolis, IN, USA: New Riders.
149. Monstre, I. *Building in Second Life*. 2007 [cited March 2008]; Available from: http://www.slbuilding.com/.
150. Boehm, B.W., *A Sprial Model of Software Development and Enhancement.* IEEE Computer, 1988. **21**(5): p. 61-72.
151. Rühlmann, R., *Angband Version 3.0.6 (Windows)*. 2005.
152. Rühlmann, R. *Thangorodrim - The Angband Page*. [cited December 2008]; Available from: http://www.thangorodrim.net/.
153. *On Sparta*. 2nd ed, ed. R.J.A. Talbert. 2005, London: Penguin Classics.
154. Dawkins, R., *Laconia I. Excavations at Sparta, 1910. The season's work*, in *Annual of the British School at Athens (volume 16)*. 1910, British School at Athens: Athens.
155. Spielberg, S., *Indiana Jones and the Raiders of the Lost Ark*. 1981, Paramount Pictures: USA.
156. Spielberg, S., *Indiana Jones and the Temple of Doom*. 1984, Paramount Pictures: USA.
157. Spielberg, S., *Indiana Jones and the Last Crusade*. 1989, Paramount Pictures: USA.
158. Spielberg, S., *Indiana Jones and the Kingdom of the Crystal Skull*. 2008, Paramount Pictures: USA.
159. Robinson, T., *Time Team*. 2008, Channel 4 Television: UK.
160. Collis, J., *Towards a national training scheme for England and the United Kingdom.* Antiquity, 2000. **74**(283): p. 208-214.
161. Aitchison, K., *Supply, demand and a failure of understanding: addressing the culture clash between archaeologists' expectations for training and employment in 'academia' versus 'practice'* World Archaeology, 2004. **36**(2): p. 203-219.
162. Collis, J., ed. *Teaching archaeology in British universities: a personal polemic*. Interrogating Pedagogies: Archaeology in Higher Education, ed. P. Rainbird and Y. Hamilakis. 2001, BAR International Series 948: Oxford, UK. 15-20.
163. *The Higher Education Academy subject centre for History, Classics and Archaeology*. [cited December 2008]; Available from: http://www.heacademy.ac.uk/hca.
164. Cobb, H., *Creating Tomorrow's Archaeologists: Who Sets the Agenda?*, in *TAG 2004*. 2004, Higher Education Authority Archaeology Subject Centre: Glasgow.
165. Wilkes, J. and G. Waywell, *Excavations at Sparta: The Roman Stoa, 1988-91 Part 2*, in *Annual of the British School at Athens (volume 89)*. 1994, British School at Athens: Athens. p. 377-432.
166. Wilkes, J. and G. Waywell, *Excavations at the Ancient Theatre of Sparta 1992-94: Preliminary Report*, in *Annual of the British School at Athens (volume 90)*. 1995, British School at Athens: Athens. p. 377-432.
167. *ARCHI, the archaeological sites database*. [cited December 2008]; Available from: http://www.digital-documents.co.uk/.
168. Miyake, N., *Constructive Interaction and the Iterative Process of Understanding.* Cognitive Science, 1986. **10**(2): p. 151-177.
169. Fosnot, C.T., *Constructivism: Theory, Perspectives, and Practice*. 2nd ed. 2005, New York, NY, USA: Teachers' College Press.
170. Wadsworth, B.J., *Piaget's Theory of Cognitive and Affective Development: The Foundations of Constructivism* 5th ed. 1995, Princeton, NC, USA: Merrill.
171. Savery, J.R. and T.M. Duffy, *Problem Based Learning: An Instructional Model and its Constructivist Framework*. Constructivist Learning Environments: Case Studies in Instructional Design, ed. B. Wilson. 1995, Englewood Cliffs, New Jersey, USA: Educational Technology Publications.
172. Ainley, M., *What do we know about student motivation and engagement?*, in *Annual meeting of the Australian Association for Research in Education*. 2004: Melbourne, Australia.
173. Koeneke, R.A., *VMS Moria version 4.7*. 1987.
174. DarkGod, *ToME: Tales of Middle Earth*. 2008.
175. Harrington, M. and G. Newell, *Half-Life*. 1998, Valve Software.
176. Jones, D. and Z. Clarke, *Grand Theft Auto*. 1997, Rockstar North/Rockstar Games.
177. Wikipedia. *First-person Shooter*. [cited December 2008]; Available from: http://en.wikipedia.org/wiki/First-person_shooter.
178. *Join Statement of the UK Research Councils' Training Requirements for Research Students*, UKGrad.

179. Dix, A., et al., *Human Computer Interaction*. 2003, New York, NY, USA: Prentice Hall.
180. Bosanquet, R.C., *Laconia II. Excavations at Sparta, 1906. The season's work*, in *Annual of the British School at Athens (volume 12)*. 1906, British School at Athens: Athens. p. 277-83.
181. Adamantiou, A. 1934.
182. Vokotopoulos, P., *Church Architecture in West Central Greece and Epeiros from the End of the Seventh through the End of the Tenth Century*. 1975, Center for Byzantine Studies: Thessalonika. p. xxii, 232; 59.
183. Kourinou-Pikoula, E., *Epigraphes apo te Sparte*. 1986, Horos 4. p. 65-9.
184. *The British School at Athens*. [cited April 2008]; Available from: http://www.bsa.ac.uk/.
185. Dawkins, R., *Laconia I. Excavations at Sparta, 1907. The season's work and summary of results*, in *Annual of the British School at Athens (volume 13)*. 1907, British School at Athens: Athens.
186. Dawkins, R., *Laconia I. Excavations at Sparta, 1908. The season's work*, in *Annual of the British School at Athens (volume 14)*. 1908, British School at Athens: Athens.
187. Dawkins, R., *Laconia I. Excavations at Sparta, 1909. The season's work*, in *Annual of the British School at Athens (volume 15)*. 1909, British School at Athens: Athens.
188. Soteriou, G., 1939.
189. Koukoules, F., *Αρχιν. Μελετίου Εύαγγ. Γαλανοπούλου*. 1935. p. 464-5.
190. Malone, T. *What Makes Things Fun to Learn? Heuristics for Designing Instructional Computer Games*. in *Proceedings of the 3rd ACM SIGSMALL Symposium and the First SIGPC Symposium on Small systems* 1980. Palo Alto, California, USA: ACM Press, New York, NY, USA.
191. Barendregt, W., et al., *Identifying Usability and Fun Problems in a Computer Game During First Use and After Some Practice.* International Journal of Human-Computer Studies, 2006. **64**: p. 830-846.
192. Berlyne, D.E., *Structure and Direction in Thinking*. 1965, New York, NY, USA: John Wiley and Sons. 378.
193. *America's Army: Special Forces Overmatch*. [cited June 2008]; Available from: http://www.americasarmy.com/.
194. Wikipedia. *Machinima*. [cited December 2008]; Available from: http://en.wikipedia.org/wiki/Machinima.
195. *Machinima.com*. [cited December 2008]; Available from: http://www.machinima.com/.
196. *Vimeo*. [cited December 2008]; Available from: http://www.vimeo.com/.
197. *Facebook*. [cited December 2008]; Available from: http://www.facebook.com/.
198. *Flight Training at British Airways*. [cited June 2008]; Available from: http://www.ebaft.com/index.htm.
199. *Flight Simulator Training - Virtual Aviation*. [cited June 2008]; Available from: http://www.virtualaviation.co.uk/.
200. Brenton, H., et al., *Using Multimedia and Web3D to Enhance Anatomy Teaching.* Computers and Education, 2007. **49**(1): p. 32-53.
201. Storer, T. and I. Duncan, *3D Animation of Java Program Execution for Teaching Object Oriented Concepts*, in *Seventh Internation Conference on Visualization, Imaging and Image Processing*. 2007, IASTED: Palma de Mallorca.
202. Widdowson, H.G., *The Roles of Teacher and Learner.* ELT Journal, 1987. **41**: p. 83-88.
203. Carlson, R., *Malcolm Knowles: Apostle of Andragogy.* Vitae Scholasticae, 1981. **8**(1).
204. Moore, M. and G. Kearsley, *Distance Education: A Systems View*. 1996, Belmont, CA, USA: Wadsworth Publishing.
205. Kenyon, C. and S. Hase, *Moving from Andragogy to Heutagogy in Vocational Education*, in *Australian Vocational Education and Training Research Association (AVETRA) Conference* 2001: Adelaide, Australia.
206. *Championship Manager*, Eidos Interactive: London, UK.
207. *FIFA 2008*, Electronic Arts Canada: Burnaby, BC, CA.
208. Wang, J., M. Lewis, and J. Gennari. *A Game Engine based Simulation of the NIST Urban Search and Rescue Arenas*. in *Winter Simulation Conference 2003*. 2003. New Orleans, LA, USA: ACM.
209. *Quake blows away design problems*. [cited December 2008]; Available from: http://news.bbc.co.uk/1/hi/education/982346.stm.
210. *Torque Game Engine*, Garage Games: Eugene, OR, USA.

211. Moloney, J. and R. Amor, *String CVE: Advances In a Game Engine Based Collaborative Virtual Environment For Architectural Design*, in *International Conference on Applications of Virtual Reality*. 2003: Blacksburg, VA, USA.
212. Moloney, J. and L. Harvey, *Visualization and 'Auralization' of Architectural Design in a Game Engine Based Collaborative Virtual Environment*, in *IEEE 8th International Conference on Information Visualisation*. 2004, IEEE: London, UK.
213. Kaminka, G.A. *Gamebots - Network Control of Unreal Tournament Bots*. [cited December 2008]; Available from: http://gamebots.sourceforge.net/.
214. Agency, D.A.R.P. *DOD Standard: Transmission Control Protocol*. 1980 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc0761.txt?number=761.
215. DARPA. *RFC793 - Transmission Control Protocol - DARPA Internet Program Protocol Specification*. 1981 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc0793.txt?number=793.
216. Postel, J. *RFC768 - User Datagram Protocol*. 1980 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc0768.txt?number=768.
217. Henderson, T.N.H., *The effects of relative delay in networked games*, in *Department of Computer Science*. 2003, University College London: London.
218. Fernandes, S., et al., *Traffic Analysis Beyond This World: the Case of Second Life*, in *17th International Workshop on Network and Operating Systems Support for Digital Audio and Video*. 2007, ACM SIGMM: Urbana-Champaign, IL, USA.
219. Antonello, R., et al., *Traffic Analysis and Synthetic Models of Second Life.* ACM/Springer Multimedia Systems, 2008.
220. Kinicki, J. and M. Claypool, *Traffic Analysis of Avatars in Second Life*, in *18th ACM International Workshop on Network and Operating Systems Support for Digital Audio and Video (NOSSDAV)*. 2008, ACM: Braunschweig, DE.
221. Oliver, I.A., *Analysis of Second Life and Open Sim Network Traffic*. 2008, School of Computer Science Technical Report, University of St Andrews: St Andrews, UK.
222. *About Lag - Second Life Wiki*. 2008 [cited December 2008]; Available from: http://wiki.secondlife.com/wiki/About_Lag.
223. Berners-Lee, T., R. Fielding, and H. Frystyk. *RFC1945 - Hypertext Transfer Protocol -- HTTP/1.0*. 1996 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc1945.txt?number=1945.
224. Fielding, R., et al. *RFC2616 - Hypertext Transfer Protocol -- HTTP/1.1*. 1999 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc2616.txt?number=2616.
225. Miles, M.B. and M. Huberman, *Qualitative Data Analysis*. 1994, Thousand Oaks, CA, USA: Sage Publications Inc.
226. Denzin, N.K. and Y. Lincoln, *The SAGE Handbook of Qualitative Research*. 2005, Thousand Oaks, CA, USA: Sage Publications Inc.
227. Creswell, J.W., *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*. 2008, Thousand Oaks, CA, USA: Sage Publications Inc.
228. Taylor, S.J. and R. Bogdan, *Introduction to Qualitative Research Methods*. 1998, New York, NY, USA: John Wiley and Sons.
229. Jain, R.K., *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation and Modelling* 1991, New York, NY, USA: John Wiley and Sons.
230. Blaikie, N., *Analyzing Quantitative Data*. 2003, Thousand Oaks, CA, USA: Sage Publications Inc.
231. Murphy, E., et al., *Qualitative research methods in health technology assessment: a review of the literature.* Health Technology Assessment, 1998. **2**(16).
232. Kerlinger, F.N., *Foundations of Behavioural Research: Educational, Psychological and Sociological Enquiry*. 1986, Burlington, MA, USA: Academic Press Inc.
233. Shadish, W.R. and T.D. Cook, *Donald Campbell and Evaluation Theory.* American Journal of Evaluation, 1998. **19**(3): p. 417-422.
234. Kuhn, T.S., *The Function of Measurement in Modern Physical Science.* ISIS, 1961. **52**(168): p. 161-193.
235. Nicoll, J.R., A. ruddle, and C. Allison, *Redressing Server Limitations in Network Service Delay*, in *3rd Annual Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting (PGNet)*. 2002, John Moores University: Liverpool, UK.
236. Power, D., R. Michaelson, and C. Allison, *The Finesse Portfolio Management Facility*, in *9th CTI Accounting, Finance and Management Conference*. 1998: York, UK.

237. Allison, C., D. McKechan, and P. Lindsay, *Determining the Sources of Delay in a Distrubted Learning Environment*, in *Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting (PGNet)*. 2001, John Moores University: Liverpool, UK.
238. Likert, R., *Technique for the Measurement of Attitudes.* Archives of Psychology 1932. **140**: p. 1-55.
239. Meyers, L.S., G.C. Garnst, and A.J. Guarino, *Applied Multivariate Research: Design and Interpretation*. 2005: Sage Publications. 760.
240. Wikipedia. *System Usability Scale*. [cited June 2007]; Available from: http://en.wikipedia.org/wiki/System_Usability_Scale.
241. Brooke, J., *SUS: a "quick and dirty" usability scale*, in *Usability Evaluation in Industry*, P.W. Jordan, et al., Editors. 1996, Taylor and Francis: London.
242. Brown, G. and G. Yule, *Discourse Analysis*. 1983, Cambridge, UK: Cambridge University Press.
243. Gee, J.P., *An Introduction to Discourse Analysis: Theory and Method*. 2005, London: Routledge.
244. Heppner, P.P., B.E. Wampold, and D.M. Kivlighan, *Research Design in Counseling*. 3rd ed. 2008: Thomson.
245. Rosenthal, R., *Experimenter Effects in Behavioural Research*. Revised ed. 1976, New York, NY, USA: John Wiley and Sons.
246. Sheldrake, R., *Experimenter Effects in Scientific Research: How Widely are they Neglected?* Journal of Scientific Exploration, 1998. **12**: p. 73-78.
247. Oppenheim, A.N., *Questionnaire Design*. New ed. 2000, London, UK: Continuum International Publishing Group Ltd.
248. Wikipedia. *Structured Interviews*. [cited December 2008]; Available from: http://en.wikipedia.org/wiki/Structured_interview.
249. Ericsson, K.A. and H.A. Simon, *Verbal Reports as Data.* Psychological Review, 1980. **87**(3): p. 215-251.
250. Ericsson, K.A. and H.A. Simon, *Protocol Analysis: Verbal Reports as Data*. 2nd ed. 1993, Boston, MA, USA: MIT Press.
251. Sacks, H., *Lectures on Conversation*. 1995, Hoboken, NJ, USA: Blackwell Publishing.
252. Rosenthal, R. and L. Jacobson, *Pygmalion in the classroom*. New ed. 2003, Bancyfelin, UK: Crown House Publishing.
253. Jussim, L. and K.D. Harber, *Teacher Expectations and Self-Fulfilling Prophecies : Knowns and Unknowns, Resolved and Unresolved Controversies.* Personality and Social Psychology Review, 2005. **9**(2): p. 131-155.
254. Wilson, C., *Pros and Cons of Co-participation in Usability Studies.* Usability Interface, 1998. **4**(4).
255. Rosenthal, R., *Experimenter Effects in Behavioural Research*. New ed. 1966, New York, NY, USA: Appleton-Century-Crofts.
256. Gokhale, A.A., *Collaborative Learning Enhances Critical Thinking.* Journal of Technology Education, 1995. **7**(1).
257. Wilson, J.D., N. Hoskin, and J.T. Nosek, *The Benefits of Collaboration for Student Programmers*, in *24th SIGCSE Technical Symposium on Computer Science Education* 1993, ACM: Indianapolis, IN, US.
258. Kahler, H., *Constructive Interaction and Collaborative Work.* Interactions, May, 2000: p. 27-34.
259. Van-den-Haak, M.J., de-Jong, and P.J. Schellens, *Employing Think-Aloud Protocols and Constructive Interaction to Test the Usability of Online Library Catalogues: A Methodological Comparison.* Interacting with Computers, 2004. **16**(6): p. 1153-1170.
260. Hunter, J. and W. Crawford, *Java Servlet Programming* 2nd ed. 2003, Cambridge, MA, USA: O'Reilly Media. 780.
261. *Apache Tomcat*. [cited March 2008]; Available from: http://tomcat.apache.org/.
262. Ruddle, A., C. Allison, and J.R. Nicoll, *Analysing the Latency of WWW Applications.* Software Practice and Experience, 2003. **33**(1): p. 1301-1322.
263. Michaelson, R., et al., *Evaluating Finess: A Case-Study in Group-Based CAL.* Computers and Education, 2001. **37**(1): p. 67-80.
264. Allison, C., M. Bramley, and J. Serrano, *The World Wide Wait: Where Does the Time Go?*, in *Euromicro 1998: Engineering Systems and Software for the Next Decade*. 1998, IEEE Press: Vesteras, SE.

265. Allison, C., et al., *Quality of Service Issues in Distributed Learning Environments*, in *Euromicro 2000: Engineering Systems and Software for the Next Decade*. 2000, IEEE Press: Maastricht, NL.
266. Bouch, A., A. Kuchinsky, and N. Bhatti, *Quality is in the Eye of the Beholder: Meeting Users' Requirements for Internet Quality of Service*, in *SIGCHI Conference on Human Factors in Computing Systems*. 2000, ACM: The Hague, NL.
267. *TCPDump - Network Traffic Monitor*. [cited December 2008]; Available from: http://www.tcpdump.org/.
268. *Fife and Tayside Metropolitan Area Network (FaTMAN)*. [cited January 2008]; Available from: http://www.fatman.net.uk/.
269. *Mobile Broadband Review - Compare Mobile Broadband Providers*. 2008 [cited December 2008]; Available from: http://www.mobilebroadband123.co.uk/index.htm.
270. Stribling, J. *All Pairs Ping - Planetlab Ping Data*. 2004 [cited April 2005]; Available from: http://pdos.csail.mit.edu/~strib/pl_app/.
271. Paterson, L., et al., *A Blueprint for Introducing Disruptive Technology into the Internet*, in *ACM Workshop on Hot Topics in Networks (HotNets-I)*. 2002, ACM: Princeton, New Jersey, USA.
272. *PlanetLab - An Open Platform for Developing, Deploying and Accessing Planetary-Scale Services*. [cited December 2008]; Available from: http://www.planet-lab.org/.
273. Getchell, K., A. Miller, and C. Allison, *Experiences using PlanetLab to Evaluate Network Applications*, in *International Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting*. 2005, John Moores University: Liverpool, UK.
274. *WIDE Project - Network Communications Research*. [cited December 2008]; Available from: http://www.wide.ad.jp/.
275. *Region Performance Improvement Guide*. 2003 [cited December 2008]; Available from: http://wiki.secondlife.com/wiki/Region_Performance_Improvement_Guide.
276. Varvello, M., et al., *Is There Life in Second Life?* 2008, Thomson Technical Report CR-PRL-CR-PRL-2008-07-0002.
277. Hall, T., M. Healey, and M. Harrison, *Fieldwork and Disables Students: Discourses of Exclusion and Inclusion.* Transactions of the Institute of British Geographers, 2002. **27**(2): p. 213-231.
278. Rosenberg, M.J., *E-Learning: Strategies for Delivering Knowledge in the Digital Age* 2000: McGraw-Hill Professional. 344.
279. Mioduser, D., et al., *Web-Based Learning Environments (WBLE): Current Implementation and Evolving Trends.* Journal of Network and Computer Applications, 1999. **22**(4): p. 233-247.
280. Bersin, J., *The Blended Learning Book: Best Practices, Proven Methodologies, and Lessons Learned*. 2004: Jossey Bass. 352.
281. Sharma, P. and B. Barrett, *Blended Learning*. 2007: Macmillan Education. 160.
282. Casey, J., *Intellectual Property Rights (IPR) in Networked e-Learning*. 2006, JISC Legal Information Service.
283. Luckmann, T. and P.L. Berger, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*. 1991: Penguin Social Sciences.
284. *Moodle Usage Statistics*. [cited April 2009]; Available from: http://moodle.org/stats/.
285. *The Open University - Distance Learning and Adult Education*. [cited April 2009]; Available from: http://www.open.ac.uk/.
286. *The Open University - Open Learn*. [cited April 2009]; Available from: http://openlearn.open.ac.uk/.
287. *University of Glasgow*. [cited April 2009]; Available from: http://www.gla.ac.uk/.
288. *Moodle at the University of Glasgow*. [cited April 2009]; Available from: http://moodle.gla.ac.uk/login/index.php.
289. *Bodington - What is Bodington?* [cited April 2009]; Available from: http://bodington.org/whatisbod.php.
290. *University of Leeds*. [cited April 2009]; Available from: http://www.leeds.ac.uk/.
291. *Bodington Common at the University of Leeds*. [cited April 2009]; Available from: http://vle.leeds.ac.uk/site/.
292. *University of Oxford*. [cited April 2009]; Available from: http://www.ox.ac.uk/.
293. *WebLeans - Oxford Campus*. [cited April 2009]; Available from: http://weblearn.ox.ac.uk/site/.

294. *UHI Millennium Institute - Creating the University of the Highlands and Islands*. [cited April 2009]; Available from: http://www.uhi.ac.uk/home.
295. *The Future: WebLearn Beta - The University of Oxford VLE*. [cited April 2009]; Available from: http://www.oucs.ox.ac.uk/ltg/vle/index.xml.ID=future.
296. *Virtual Learning Environments at Leeds University*. [cited April 2009]; Available from: http://www.leeds.ac.uk/library/vle/.
297. *Learning Design Specification*. [Web Site] [cited 2006 1 June]; Available from: http://www.imsproject.org/learningdesign/index.html.
298. *JISC - IMS Content Packaging and Management Project*. [Web Site] [cited 2006 1 June]; Available from: http://www.jisc.ac.uk/index.cfm?name=project_ims_cpm.
299. *Microsoft Office SharePoint - Connecting People, Process and Information*. [cited April 2009]; Available from: http://sharepoint.microsoft.com/Pages/Default.aspx.
300. Masterman, L. and S.D. Lee, *Evaluation of the Practitioner Trial of LAMS: Final Report*. 2005, Learning Technologies Group, Oxford University Computing Services: Oxford, Oxfordshire, UK. p. 42.
301. Allison, C., et al. *The TAGS Framework for Web-based Learning Environments*. in *Web Based Learning Environments*. 2000. Porto, Portugal.
302. Michaelson, R., et al., *Group Work and the Web: FINESSE and TAGS*. Learning and Teaching for Business: case studies of successful innovation, ed. D. Hawkridge and R. Kaye. 2003: Kogan Page. 122-137.
303. *Reuters UK Markets - FTSE, FTSE100*. [cited April 2009]; Available from: http://uk.reuters.com/business/markets/uk.
304. *University of St andrews Robocode Competition*. [cited April 2009]; Available from: http://robocode.cs.st-andrews.ac.uk/.
305. *Blackboard and WebCT Announce Agreement to Merge*. [cited April 2009]; Available from: http://investor.blackboard.com/phoenix.zhtml?c=177018&p=irol-newsArticle&ID=767025.
306. *IMS Global Learning Consortium Enterprise Specification*. [cited April 2009]; Available from: http://www.imsglobal.org/enterprise/index.html.
307. Gudgin, M., et al. *SOAP Version 1.2 Part 1: Messaging Framework (Second Edition)*. 2007 [cited April 2009]; Available from: http://www.w3.org/TR/soap12-part1/#intro.
308. *ANGEL Learning - Learning Management Suite for K-12 and Higher Education*. [cited April 2009]; Available from: http://www.angellearning.com/.
309. *Indiana University OnCourse Collaboration and Learning*. [cited April 2009]; Available from: https://oncourse.iu.edu/portal.
310. *IMS Global Learning Consortium, Inc.* [cited April 2009]; Available from: http://www.imsglobal.org/.
311. *IMS Global Learning Consortium: Common Cartridge Alliance*. [cited April 2009]; Available from: http://www.imsglobal.org/cc/alliance.html.
312. *IMS Global Learning Consortium: IMS Question and Test Interoperability Specification*. [cited April 2009]; Available from: http://www.imsglobal.org/question/.
313. *IMS Global Learning Consortium: Tools Interoperability Guidelines*. [cited April 2009]; Available from: http://www.imsglobal.org/ti/index.html.
314. *IMS Global Learning Consortium: Content Packaging Specification*. [cited April 2009]; Available from: http://www.imsglobal.org/content/packaging/.
315. *Advanced Distributed Learning Sharable Content Object Reference Model (SCORM) 2004 Specification*. [cited March 2008]; Available from: http://www.adlnet.gov/Downloads/DownloadPage.aspx?ID=237.
316. *IMS Global Learning Consortium: IMS Learner Information Package Accessibility for LIP*. [cited April 2009]; Available from: http://www.imsglobal.org/accessibility/.
317. *Blackboard and Angel Learning: Learning, Together*. [cited June 2009]; Available from: https://www.blackboard.com/Company/Angel.aspx.
318. Berners-Lee, T. and D. Connolly. *Hypertext Markup Language*. 1995 [cited April 2009]; Available from: http://www.ietf.org/rfc/rfc1866.txt?number=1866.
319. *HTML 4.01 Specification*. 1999 [cited April 2009]; Available from: http://www.w3.org/TR/html401/.
320. *XHTML 1.0 The Extensible HyperText Markup Language (Second Edition)*. 2002 [cited April 2009]; Available from: http://www.w3.org/TR/xhtml1/.
321. *HTML 5*. 2009 [cited April 2009]; Available from: http://www.w3.org/TR/html5/.
322. Miller, P., *Interoperability: What is it and Why should I want it?*, in *Ariadne*. 2000.

323. Konstantas, D., et al., *Interoperability of Enterprise Software and Applications* 2005: Springer. 466.
324. *Draft Standard for Extensible Markup Language (XML) Scheme Definition Language Binding for Learning Object Metadata*. 2004, Learning Technology Standards Committee of the IEEE Computer Society: New York, NY, USA. p. 50.
325. *ISO - International Organisation for Standardisation*. [cited April 2009]; Available from: http://www.iso.org/iso/home.htm.
326. *Advanced Distributed Learning*. [cited April 2009]; Available from: http://www.adlnet.org/Pages/Default.aspx.
327. *IMS Global Learning Consortium: Background*. [cited April 2009]; Available from: http://www.imsglobal.org/background.html.
328. *Welcome to IMS Global Learning Consortium, Inc.* [cited April 2009]; Available from: http://www.imsglobal.org/.
329. Zimmermann, H., *OSI Reference Model.* IEE Transactions on Communications, 1980. **28**(4): p. 425.
330. DARPA. *RFC761 - DOD Standard: Transmission Control Protocol*. 1980 [cited December 2008]; Available from: http://www.ietf.org/rfc/rfc0761.txt?number=761.
331. Spurlock, M., *Super Size Me*. 2004.
332. Guggenheim, D., *An Inconvenient Truth*. 2006.
333. *Mythbusters*. [cited April 2009]; Available from: http://www.discoverychannel.co.uk/web/mythbusters/.
334. *Sesame Street*. [cited April 2009]; Available from: http://www.sesamestreet.org/home.
335. *BBC Radio 4 - The Archers*. [cited April 2009]; Available from: http://www.bbc.co.uk/radio4/archers/.
336. *BBC - CBeebies Home*. [cited April 2009]; Available from: http://www.bbc.co.uk/cbeebies/.
337. *Fantastic Contraption: A Fun Online Physics Puzzel*. [cited April 2009]; Available from: http://fantasticcontraption.com/.
338. *London Science Museum*. [cited April 2009]; Available from: http://www.sciencemuseum.org.uk/.
339. *London Science Museum - Visit the Museum - Launchpad*. [cited April 2009]; Available from: http://www.sciencemuseum.org.uk/visitmuseum/galleries/launchpad.aspx?keywords=launchpad.
340. *The Powerhouse Museum | Science + Design | Sydney, Australia*. [cited April 2009]; Available from: http://www.powerhousemuseum.com/.
341. Stoll, C., *High Tech Heretic: Why Computers Don't Belong in the Classroom and Other Reflections by a Computer Contrarian*. 1999: Doubleday. 240.
342. *Reader Rabbit*. 1998, The Learning Company.
343. Cole, J. and B. Degen, *The Magic School Bus*: Scholastic Inc.
344. *Maths Blaster: Master the Basics*. 2006, Knowledge Adventure
345. Okan, Z., *Edutainment: is learning at risk?* British Journal of Educational Technology, 2003. **34**(3): p. 255.
346. *Grey's Anatomy - ABC.com*. [cited April 2009]; Available from: http://abc.go.com/primetime/greysanatomy/index?pn=index.
347. *BBC - Casualty*. [cited April 2009]; Available from: http://www.bbc.co.uk/casualty/.
348. *Cost of Making Games Set to Soar*. 2005 [cited April 2009]; Available from: http://news.bbc.co.uk/1/hi/technology/4442346.stm.
349. Scacchi, W., *Free and Open Source Development Practices in the Game Community.* IEEE Software, 2004. **21**(1): p. 59-66.
350. Sotamaa, O., *"Have Fun Working with Our Product!": Critical Perspectives On Computer Game Mod Competitions*, in *Digital Games Research Association 2005 Conference*. 2005, University of Vancouver: Vancouver, BC, CA.
351. *Mod DB - Games and Mod Development for PC, XBox, Playstation and Nintendo*. [cited April 2009]; Available from: http://www.moddb.com/.
352. Sotamaa, O., *When The Game is Not Enough: Motivations and Practices among Computer Game Modding Culture* 2008, Department of Information Studies and Interactive Media, University of Tampere, Finland.
353. idSoftware, *GtkRadiant*. 2007.
354. *Unreal Editor*. 2004, Epic Games.
355. idSoftware, *Quake 3 Arena*. 1999, Activision.

356. RavenSoftware, *Quake 4*. 2005, Activision.
357. Adams, E. and A. Rollings, *Fundamentals of Game Design (Game Design and Development)*. 2006, New York, NY, USA: Prentice Hall. 600.
358. *America's Army - Training and Missions*. [cited April 2009]; Available from: http://www.americasarmy.com/aa/intel/missions.php.
359. *America's Army - Every Detail Counts - Real Heros*. [cited April 2009]; Available from: http://www.americasarmy.com/realheroes/.
360. *Grand Theft Auto 2*. 1999, DMA Design, Tarantula Studios.
361. *Grand Theft Auto III*. 2001, DMA Design, Rockstar Vienna.
362. *Grand Theft Auto IV*. 2008, Rockstar North, Rockstar Toronto.
363. Lindholm, T. and F. Yellin, *The Java Virtual Machine Specification* 2nd ed. 1999, New York, NY, USA: Prentice Hall. 496.
364. Gosling, J., et al., *The Java Language Specification, Third Edition*. 3rd ed. 2005: Addison Wesley. 688.
365. Sharp, J. and J. Jagger, *Microsoft Visual C#.NET Step by Step*. 2002: Microsoft Press. 621.
366. *Jake 2*. 2005 [cited September 2006]; Available from: http://www.bytonic.de/html/jake2.html.
367. *Visual3D.NET Game Engine for .NET/XNA*. [cited April 2009]; Available from: http://www.visual3d.net/.
368. Kernighan, B.W. and D. Ritchie, *The C Programming Language* 2nd ed. 1988: Prentice Hall. 274.
369. Stroustrup, B., *The C++ Programming Language*. 1986: Addison-Wesley. 328.
370. *Valve Software*. [cited April 2009]; Available from: http://www.valvesoftware.com/.
371. *Steam Hardware Survey*. [cited April 2009]; Available from: http://store.steampowered.com/hwsurvey/.
372. *UnrealEngine 2 Runtime*. [cited January 2009]; Available from: http://udn.epicgames.com/Two/UnrealEngine2Runtime.html.
373. *Quake Blows Away Design Problems*. 2000 [cited April 2009]; Available from: http://news.bbc.co.uk/1/hi/education/982346.stm.
374. *Welcome to the University of Auckland*. [cited April 2009]; Available from: http://www.auckland.ac.nz/uoa/.
375. Kaminka, G.A., et al., *GameBots: A Flexible Test Bed for Multiagent Team Research.* Communications of the ACM, 2002. **45**(1): p. 43-45.
376. *Sid Meier's Civilization III*. 2001, Infogrames.
377. Jacobson, J. *Gates of Horus*. 2008 [cited April 2009]; Available from: http://planetjeff.net/html/pro_gates.html.
378. Jacobson, J., *Ancient Architecture in Virtual Reality; Does Visual Immersion Really Aid Learning?*, in *School of Information Sciences*. 2008, University of Pittsburgh: Pittsburgh, PA, USA.
379. *Medieval: Total War*. 2002, Activision. p. Computer Game.
380. *Football Focus - BBC Sport*. [cited April 2009]; Available from: http://news.bbc.co.uk/sport1/hi/football/football_focus/default.stm.
381. Strachan, G., *Strachan: My Life in Football*. 2007: Sphere. 416.
382. *Coventry City Football Club*. [cited April 2009]; Available from: http://www.ccfc.co.uk/page/Welcome.
383. Frye, B. and A.M. Frager, *Civilization, Colonization, SimCity: Simulations for the Social Studies Classroom.* Learning and Leading with Technology, 1996. **24**(2): p. 21-23, 32.
384. Squire, K.D., *Replaying History*. 2004, Indiana University.
385. Squire, K.D., *Sid Meier's Civilization III.* Simulations and Gaming, 2004. **35**(1): p. 135-140.
386. *MIT Games to Teach*. [cited April 2009]; Available from: http://icampus.mit.edu/projects/GamesToTeach.shtml.
387. *MIT - Massachusetts Institute of Technology*. [cited April 2009]; Available from: http://www.mit.edu/.
388. *Microsoft Corporation*. [cited April 2009]; Available from: http://www.microsoft.com/en/gb/default.aspx.
389. *Civ World*. [cited April 2009]; Available from: http://civworld.gameslearningsociety.org/index.php.
390. *Civ World - Civistorians*. [cited April 2009]; Available from: http://civworld.gameslearningsociety.org/civistorians.php.

391. *Civ World - Curriculum Downloads*. [cited April 2009]; Available from: http://civworld.gameslearningsociety.org/curriculum.php.
392. Jacobson, J. and L. Holden, *The Virtual Egyptian Temple*, in *World Conference on Educational Media, Hypermedia and Telecommunications*. 2005, ED-Media: Montreal, QC, CA.
393. *Unreal Tournament 2004*. 2004, Epic Games.
394. Arnold, D., *Temples of the Last Pharaohs*. 1999: Oxford University Press.
395. *Medinet Habu*. 1930-1969, The Oriental Institute, The University of Chicago: Chicago, IL, USA.
396. DeLeon, V.J., *Notre-Dame Cathedral: A Globally Accessible Multi-User Real-Time Virtual Reconstruction*, in *5th International Conference on Virtual Systems and Multimedia (VSMM)*. 1999: Dundee, UK.
397. Seward, D., *A Brief History of the Hundred Years War: The English in France, 1337-1453*. 2003: Robinson Publishing. 304.
398. Mayer, H.E. and J. Gillingham, *The Crusades*. 1988, Oxford, Oxfordshire, UK: Oxford University Press. 366.
399. Heron, A. and E. James, *Su Doku For Dummies* 2005: John Wiley & Sons 336.
400. Norris, G., *For a New Concert Experience, get a Second Life*, in *The Daily Telegraph*. 15 September 2007: London.
401. *Duran Duran to give Virtual Gigs*. [cited April 2009]; Available from: http://news.bbc.co.uk/1/hi/technology/5253782.stm.
402. *Second Life Games*. [cited April 2009]; Available from: http://slgames.wordpress.com/.
403. *Vue - Virtual University of Edinburgh*. [cited April 2009]; Available from: http://vue.ed.ac.uk/.
404. *Havok Physics*. [cited April 2009]; Available from: http://www.havok.com/content/view/17/30/.
405. Kirriemuir, J., *An update of the July 2007 "snapshot" of UK Higher and Further Education Developments in Second Life*. 2007, Eduserv Foundation.
406. Kirriemuir, J., *A July 2007 "snapshot" of UK Higher and Further Education Developments in Second Life*. 2007, Eduserv Foundation.
407. Ketelhut, D.J., et al., *Inquiry Teaching for Depth and Coverage via Multi-User Virtual Environments.* 2005, Harvard University: Cambridge, MA, USA.
408. Spanfelner, D.L., *WebQuests, An Interactive Approach to the Web.* Community & Junior College Libraries, 2000. **9**(4): p. 23-28.
409. Rowntree, D., *Educational Technology in Curriculum Development*. 2nd ed. 1982: Longman Higher Education. 216.
410. Feldman, H.D., *Computer-Based Simulation Games: A Viable Educational Technique for Entrepreneurship Classes?* . Simulation and Gaming, 1995. **26**(3): p. 346-360.
411. Sturgeon, T., A. Miller, and C. Allison, *A WiFi Virtual Laboratory*, in *International Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting*. 2006, Liverpool John Moores University: Liverpool, UK.
412. Allison, C., et al., *Exploratory Learning for Computer Networking*, in *6th International Conference on Web-based Learning*. 2007: Edinbrugh, UK.
413. Sturgeon, T., C. Allison, and A. Miller, *802.11 Wireless Experiments in a Virtual World*, in *14th Annual Conference on Innovation and Technology in Computer Science Education*. 2009: Paris, France.
414. Stainfield, J., et al., *International Perspectives on Virtual Fieldwork.* Symposium on International Fieldwork, Journal of Geography in Higher Education, 2000. **24**(2): p. 255-262.
415. Kent, M., D.D. Gilbertson, and C.O. Hunt, *Fieldwork in Geography Teaching: A Critical Review of the Literature and Approaches.* Journal of Geography in Higher Education, 1997. **21**: p. 313-332.
416. Getchell, K., et al., *Exploring the Second Life of a Byzantine Basilica*, in *Serious Games on the Move*, O. Petrovic and A. Brand, Editors. 2009, SpringerWien: New York, NY, USA. p. 165-180.
417. *Casablanca Island - Visit the Country of Morocco in Second Life*. [cited April 2009]; Available from: http://casablanca.life3solutions.com/.
418. *VRML*. [cited September 2008]; Available from: http://en.wikipedia.org/wiki/VRML.
419. *Web3D Consortium - Royalty Free, Open Standards for Real-Time 3D Communication*. [cited September 2008]; Available from: http://www.web3d.org/.

420. Raggett, D., *A Review of the HTML+ Document Format*, in *First International Conference on the World-Wide Web*. 1994, CERN: Geneva, Switzerland.
421. Blizzard. *World of Warcraft*. [cited September 2008]; Available from: http://www.worldofwarcraft.com/.
422. Goldberg, M.W., S. Salari, and P. Swoboda, *World Wide Web - Course Tool: An Environment for Building WWW-Based Courses.* Computer Networks, 1996. **28**(7-11): p. 1219-1231.
423. Holliday, M.A., *Animation of Computer Networking Concepts.* ACM Journal of Educational Resources in Computing, 2003. **3**(2): p. 1-26.
424. JISC. *e-Learning Focus*. 2006 [cited June 2006]; Available from: http://www.elearning.ac.uk/.
425. IBM. *Virtual Worlds Come to Life at IBM*. 2007 [cited January 2009]; Available from: http://domino.watson.ibm.com/comm/pr.nsf/pages/news.20070416_virtualworlds.html.
426. Ward, M. *Rays Light Up Life-Like Graphics*. 2007 [cited January 2009]; Available from: http://news.bbc.co.uk/1/hi/technology/6457951.stm.
427. Yee, N., *The Demographics, Motivations, and Derived Experiences of Users of Massively Multi-User Online Graphical Environments.* MIT - Presence: Teleoperators and Virtual Environments, 2006. **15**(3): p. 309-329.
428. NorsemanGames. *The Realm Online*. 1995 [cited January 2009]; Available from: http://www.realmserver.com/.
429. Krikke, J., *Samurai Romanesque, J2ME, and the Battle for Mobile Cyberspace.* IEEE: Computer Graphics and Applications, 2003. **23**(1): p. 16-23.
430. Faulkner, X., *Usability Engineering (Grassroots)*. 2000, Basingstoke, UK: Palgrave Macmillan.